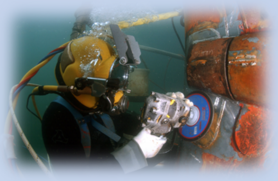
Trainee Assistant Diving Supervisor

Course Manual



PREFACE

The diving supervisor is the link between the 'Diving Contractor' and the 'Client', more importantly they are the link between the divers and the contractor.

The diving supervisor must be up to date and current with all legislation, this could be International maritime Contractors Association (IMCA) DO 14, The Health and Safety Executive Approved Code of Practice (ACOP) for Offshore Diving for UK waters, Norwegian Legislation and each country has a version of their own diving legislation, or they might just use IMCA DO 14 as best practice.

IMCA DO 14 2007

HSE Offshore ACOP

With both of these manuals, they list the roles and responsibilities of all involved in the 'Diving Project.'

If you are diving on the UK continental Shelf or if the contract originated in the UK you must follow the 'HSE Offshore Approve Code of Practice'.

With the ACOP it always starts with the 'UK statutory Regulation' in *Italic and the '*Guide in normal type below the regulation.

It clearly states in both of the above documents that the Supervisor must be appointed in writing by the contractor.

To become an IMCA Air Diving Supervisor, you must follow the guidance laid out in IMCA DO13.

AIR DIVER TO AIR DIVING SUPERVISOR

SURFACE SUPPLIED DIVER

- **Hold an IMCA recognised Surface Supplied Diving Qualification**
- **Demonstrated competence as an Offshore Air Diver**

↓

Completes and passes an approved Air Diving Supervisor Training Course

↓

TRAINEE DIVING SUPERVISOR (AIR)

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- **Completes 200 hands-on hours working as Trainee Air Diving Supervisor on at least 100 surface dives**
- **Demonstrates competence as an offshore air diver and completes 200 offshore commercial air dives**

↓

DIVING SUPERVISOR (AIR)

The 'Assistant Air Diving Supervisor' qualification is only valid for three years. You must do the IMCA Module 1 exam before this date expires!

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TABLE OF CONTENTS

Contents

Section 1
Diving Physics

INTRODUCTION 1

Whatever your role in the diving operation, weather diver or surface support, it is essential that you are familiar with the changing physical factors which affect the diver and influence the techniques and procedures used.

All diving is similarly affected by the following Laws of Physics:

-	Boyle's Law	Gas Law
-	Charles' Law	Gas Law
-	Dalton's Law	Gas Law
-	Henry's Law	Law of Solubility
-	Archimedes Principle	Buoyancy

Before we continue with the Laws of Physics we must understand the units of measurement employed, and the conversion factors linking the different systems.

Units of Measurement 1.2

There are two systems commonly used in the diving industry:

- The Metric or SI System (System International).
- The Imperial System.

Most companies conducting diving operations now use the metric system, but some American companies continue to use the imperial system. Of the two, the metric system is the easier, but diving personnel must be conversant with both systems.

	THE METRIC SYSTEM	THE IMPERIAL SYSTEM
LENGTH	Metre (m)	Foot (ft) and inch (in)
DEPTH	Metres of Sea water (msw)	Feet of sea water (fsw)
AREA	Square metres (m^2)	Square feet (ft^2)
VOLUME	Litres (l) or Cubic metres (m^3) 1000 l = 1 m^3	Cubic feet (ft^3) or gallons (gal)
WEIGHT	Kilograms (kg) or Tonnes (t) 1000 kg = 1 t	Pounds (lb) or Tons (ton) 2240 lb = 1 ton
PRESSURE	Millibar (mbar) or bars (bar) 1,000 mbar = 1 bar 10 msw = 1 bar	Pounds per Square Inch (psi) or Atmospheres (atm) 14.7 psi = 1 atm 33 fsw = 1 atm

The following abbreviations are used throughout this manual:

Name	Abbreviation
Absolute pressure	AP
Atmosphere	atm
Atmospheres absolute	ata
Bar	bar
Cubic feet	ft^3
Cubic metre	m^3
Feet of sea water	fsw
Gauge Pressure	GP
Litres	l
Metres of sea water	msw
Millibar	mbar
Partial pressure	p
Parts per million	ppml
Percentage	%

Conversion Factors 1.2.1

The following tables give an accurate means of converting between the metric and the imperial systems.

For common usage offshore, and for use in IMCA exam calculations.

The following are taken as being (approximately) equal:

1 atm ≅ 1 bar ≅ 14.7 psi ≅ 1 kg/cm^2 ≅ 760 mmHg

also

10msw ≅ 1 bar ≅ 1 atm ≅ 33 fsw

Length 1.2.2

TO CONVERT	INTO	MULTIPLY BY
Centimetres	feet	0.033
	inches	0.394
	metres	0.001
Feet	cm	30.480
Inches	cm	2.540
	metres	0.0254
Kilometres	feet	3280.84
	inches	39370.1
	miles	0.621
	nautical miles	0.540
Metres	feet	3.281
	inches	39.370

Volume 1.2.3

TO CONVERT	INTO	MULTIPLY BY
Cubic centimetres (cc)	cubic inches	0.061
Cubic feet (ft^3)	cc	28317
	cubic inches	1728
	m^3	0.028
	Litres	28.3
Cubic inches	cc	16.3
	litres	0.016
Cubic metres (m^3)	ft^3	35.3
	cubic inches	61023.7
	litres	1000
Litres	ft^3	0.035

Pressure 1.2.4

TO CONVERT	INTO	MULTIPLY BY
Atmospheres	bar	1.013
	feet of sea water (fsw)	33.000
	kg sq/cm	1.033
	metres of sea water (msw)	10.060
	millimetres of mercury (mmHg)	760
	pounds per square inch (psi)	14.696
Bar	atmospheres	0.987
	fsw	32.570
	kg/sq cm	1.020
	msw	9.928
	mmHg	750.062
	psi	14.504
Feet of sea water	atmospheres	0.0303
	bar	0.0307
	kg/sq cm	0.0313
	mmHg	23.031
	psi	0.4453
	msw	0.305
Kilograms per square centimetre	atmospheres	0.968
	bar	0.981
	fsw	31.940
	msw	9.736
	mmHg	735.560
	psi	14.223
Metre of seawater	atmospheres	0.099
	bar	0.101
	fsw	3.280
	kg sq/cm	0.103
	mmHg	75.529
	psi	1.461

***Remember for exam purpose:**

$$1 \text{ atm} \cong 1 \text{ bar} \cong 14.7 \text{ psi} \cong 1 \text{ kg/cm}^2 \cong 760 \text{ mmHg}$$

also

$$10\text{msw} \cong 1 \text{ bar} \cong 1 \text{ atm} \cong 33 \text{ fsw}$$

THE EFFECTS OF PRESSURE 1.3

On the surface of the earth we are all exposed to the pressure exerted by the weight or mass of the atmosphere above us. This is called atmospheric or barometric pressure. If we alter our position within the atmosphere the pressure will be altered accordingly, e.g. if we move upward through the atmosphere the pressure will decrease. If we ascend to a level of some 18,000 feet the pressure at that point will be equal to approximately half of the pressure at sea level. If we descended into a mineshaft, for example, the additional depth of the atmosphere will increase the barometric pressure.

Because of the relative lightness of air, the pressure differences in such moves are small. In diving, the massive weight difference between air and water means that small depth changes in water result in significant pressure differences.

Pressure is measured in a variety of units from either of two reference points;

- It can be expressed relative to a vacuum (zero pressure). This is called absolute pressure (AP).
- It can be measured relative to atmospheric pressure. This is called relative or gauge pressure (GP).

thus at sea level the gauge pressure is 0 and the absolute pressure is 1 atmosphere.

More common units for measuring pressure and approximate conversion factors are:

1 Atmosphere	=	14.7 pounds per square inch
	=	1 bar (actually 14.5 psi)
	=	1 kilogram per square centimetre
	=	760 mm of mercury (symbol Hg)

If you had an imaginary tube with a bore area equalling one square inch, extending from sea level to the edge of the atmosphere (some 60 miles), the weight of the atmosphere measured at sea level would be 14.7 lb.

Because of the weight difference between water and air, a depth increase in water of only 10msw or 33fsw will increase the pressure by 1 atmosphere. Each additional 10msw or 33fsw increase will add 1 atmosphere.

Thus at a depth of 60m in sea water, the gauge pressure will equal 6 bar but the absolute pressure will equal 7 bar.

Pressure Conversion Table 1.3.1

For exact conversion figures see the table on page 7. But for common usage offshore, and for use in IMCA exam calculations.

The following are taken as being (approximately) equal:

1 atmosphere	=	10 metres of sea water
	=	33 feet of sea water
	=	34 feet of freshwater
	=	$1kg/cm^2$
	=	14.7 psi
	=	1 bar
	=	760 mmHg
	=	760 Torr
	=	1 atm

NOTE: A pressure of 1 atm on a chamber door, will exert 14.7 psi on that door. Therefore if the door diameter equals 24” the area (πr^2) is 452 square inches. Thus the total pressure on the chamber door is 6,644 lb., i.e. 2.9 tons.

The Effects of Pressure on a Divers Body 1.3.2

Many people have difficulty in understanding why the substantial pressure increases experienced underwater do not crush the diver.

The answer can be considered in two ways. The body largely comprises liquid and solid parts in different ratios for different tissues. These liquid and solid parts are virtually incompressible so a pressure applied to them does not alter their volume. The water pressure, i.e. hydrostatic pressure, is transmitted through them. After immersion the increase in pressure relative to depth pushes against the skin, which pushes against the adjoining tissue and so on until the skin on the other side of the body is pushed against the water pressure. Thus the system remains in balance.

The effects of pressure on the gas spaces within the body are more complex. The basic fact is that the applied pressure does not constitute a problem so long as the pressure within the gas space is equal to the external pressure. Only if pressure differentials exist between the gas space and the surrounding water, will the potential for physical damage be present. If the pressure within the lung was greater than the pressure outside the body by a value equivalent to a depth of only 2 metres, then the lung would be structurally damaged.

Thus, it can be seen that pressure itself will not hurt the diver but that an imbalance of pressure between the diver and his environment can.

Before we progress onto the gas laws, we need a short explanation of some frequently occurring problems:

Transposing of Formulas, i.e. the adjustment of the formula to suit our needs

Example:

If we use the Boyle's Law formula $P_1V_1 = P_2V_2$ and require to find V_2 then:

- We must know the other 3 values, and
- We must adjust the formula to isolate V_2 on one side.

To isolate V^2 we do the following:

Take the other factor on the same side as V_2 across and underneath the two factors on the other side, i.e.

$$V_2 = \frac{P_1V_1}{P_2}$$

To confirm this or refresh yourselves if you have the right formula, simple values can be substituted for the factors:

$P_1 = 2$

$V_1 = 6$ $\quad$ $P_1V_1 = P_2V_2$

$P_2 = 3$

$V_2 = 4$ $\quad$ $2\,x\,6 = 3\,x\,4$

This is obviously true.

Now to confirm if the V_2 formula is correct.

$$V_2 = \frac{P_1V_1}{P_2}$$

$$4 = \frac{2\,x\,6}{3}$$

This confirms that the formula has been transposed correctly.

In the case of the Charles Law formula:-

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

It is preferable to get the formula into one line by cross multiplying to give:-

$$P_1T_2 = P_2T_1$$

Once again, this can be confirmed using numbers instead of letters, e.g.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \quad \Rightarrow \quad \frac{6}{3} = \frac{4}{2}$$

Then cross multiply:

$$P_1T_2 = P_2T_1$$

$$\Rightarrow \quad 6\,x\,2 = 4\,x\,3$$

Again, the transposition is confirmed.

Rounding Up of Decimals 1.3.3

Normally in equations the numbers are rounded up or down to one decimal place.

To achieve this look at the second number after the decimal point. If this second number is less than 5, then the preceding number stays as it is, e.g. 2.34 becomes 2.3.

If the second number after the decimal point is equal to, or greater than 5 then the preceding number goes to the next greater number, e.g. 2.36 becomes 2.4.

Percent (%) and Parts Per Million (ppm) 1.3.4

Both these describe proportionally the amount of, for example, a gas in a total volume.

10% oxygen in a heliox mix means that 10% of the total volume is oxygen and the remainder, i.e. 90%, is helium. This is often written as 10/90 heliox.

That indicates that 10 parts of every hundred is oxygen with the remaining 90 parts in helium.

Some gases are measured in such small quantities that parts per hundred is too coarse a measurement. In this case, parts per million (ppm) is used.

For instance Carbon Dioxide and Carbon Monoxide are most often measured in PPM. Most CO2 analysers read in ppm but some are in %.

To Convert ppm To Percentage And Vice Versa:

$$\% = \frac{ppm}{10{,}000}$$

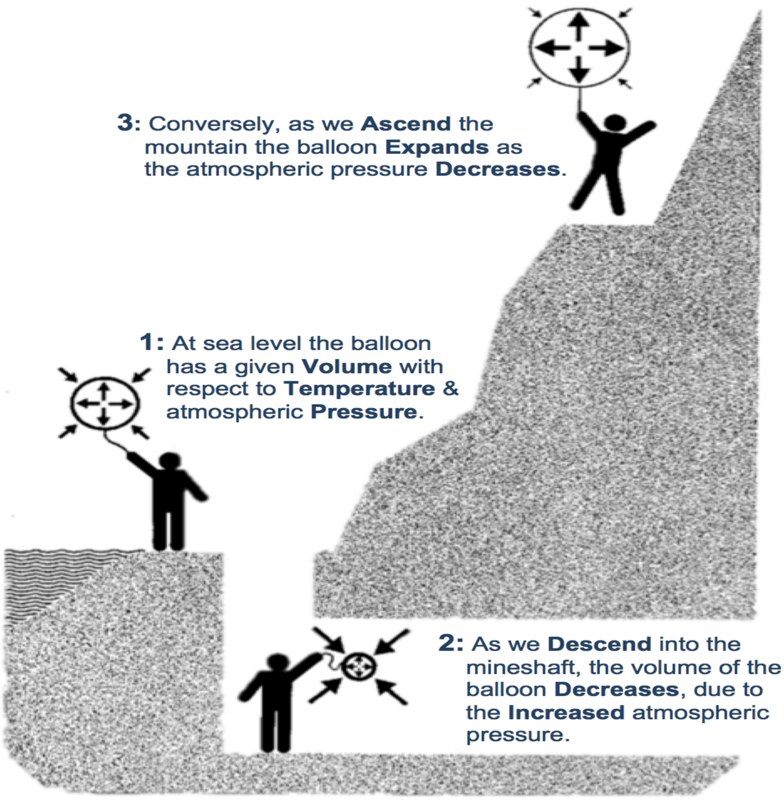
$$ppm = \%\ x\ 10{,}000$$

Therefore, 0.1% is equal to 1,000 ppm.

ATMOSPHERIC PRESSURE 1.4

Atmospheric pressure is the force per unit area exerted on a surface by the weight of air above that surface in the atmosphere of Earth. In most circumstances atmospheric pressure is closely approximated by the hydrostatic pressure caused by the weight of air above the measurement point.

On a given plane, low-pressure areas have less atmospheric mass above their location, whereas high-pressure areas have more atmospheric mass above their location. Likewise, as elevation increases, there is less overlying atmospheric mass, so that atmospheric pressure decreases with increasing elevation. On average, a column of air one square centimeter in cross-section, measured from sea level to the top of the atmosphere, has a mass of about 1.03 kg and weight of about 10.1 N.



GAS LAWS 1.5

The early gas laws were developed at the end of the 18th century, when scientists began to realize that relationships between the pressure, volume and temperature of a sample of gas could be obtained which would hold for all gases. Gases behave in a similar way over a wide variety of conditions because to a good approximation they all have molecules, which are widely spaced, and nowadays the equation of state for an ideal gas is derived from kinetic theory. The earlier gas laws are now considered as special cases of the ideal gas equation, with one or more of the variables held constant.

Boyle's Law (The Pressure / Volume Relationship) 1.5.1

Boyle's Law describes the relationship between changes in volume of a gas and the pressure applied to it (if the temperature is kept constant). It is an inversely proportional relationship (while one doubles, the other halves) at a constant temperature.

Boyle's Law
"At a constant temperature the volume of a fixed mass of gas is inversely proportional to the absolute pressure"

$$P_1V_1 = P_2V_2$$

It Can Also Be Written As:

$$PV = C$$

Where V is volume, P is absolute pressure and C is a constant.

For Example:

10 litres of gas at sea level pressure will be compressed to 5 litres at 2 ata (10m) and 1 litre at 10 ata (90m).

$P_1V_1 = P_2V_2$ 1 bar(A) x 10L = 2 bar(A) x 5L

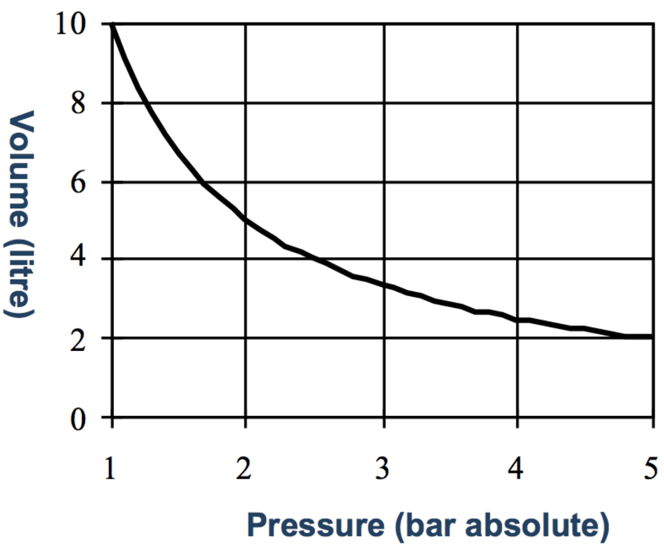
Or If Preferred:

PV = C 1 x 10 = 10 and 2 x 5 = 10

Thus during descent the increase in pressure around the body results in a volume reduction of gas in the gas spaces within the body. Unless pressure within these spaces is equalised with the external pressure then a squeeze will result. Gas (or air) must enter these cavities during periods of increasing pressure in order to maintain pressure balance. Failure to do so will result in barotrauma that may lead to tissue distortion or damage.

Conversely during ascent the gas within these spaces will expand with decreasing pressure. If there is a restriction to this expansion then barotrauma of ascent may occur.

Boyle's Law is also important in decompression. Already we have spoken about barotrauma of ascent but we must also mention the effects of Boyle's Law on bubble formation during decompression.



Ideally, bubble formation is minimised during decompression but obviously any bubbles formed are influenced by Boyle's Law whilst pressure is reduced.

The chart above shows that volume pressure changes are more pronounced at shallower depths. For example, a 10 metre or 1 bar pressure reduction at 40 metres gives a volume increase of 25%. The same pressure drop, i.e. 10 metres or 1 bar, at 10 metres means a volume increase of 100%.

This partly explains why some diving practices, e.g. upwards excursions are restricted to deeper water.

Examples Using Boyle's Law Formula:

Pressure:	1 atmosphere	=	760 mmHg	=	14.7 psi
	1 bar	=	750 mmHg	=	14.5 psi

For Calculation Purposes Only:

1 atm is said to be equal to 1 bar
1 atm = 33fsw = 14.7 psi = 1 bar = 10msw

Volume: Metric system - cubic metres are commonly used.
$1m^3$ = 1,000 L

Imperial system - cubic feet are used.
$1m^3$ = $35.32 ft^3$

Boyle's Law Formula

$$P_1V_1 = P_2V_2$$

If three of the values are known then the fourth, the unknown, can be found. To transpose the formula to find the unknown, do the following. Take the value on the same side as the unknown across and below the two values on the opposite side.

If you require to find P_2, move V_2 across and under the P_1V_1

$$P_2 = \frac{P_1V_1}{V_2}$$

Simple Example:

If a balloon has a volume of 6 litres on the surface, what will its volume be at 30 metres?

$P_1 =$ Pressure at surface = 1 bar
$V_1 =$ Volume at surface = 6 litres
$P_2 =$ Pressure at 30 metres = 4 bar (absolute)
$V_2 =$ Unknown

$$V_2 = \frac{P_1V_1}{P_2}$$

$$V_2 = \frac{1\ bar\ x\ 6\ litres}{4\ bar}$$

$$V_2 = \mathbf{1.5\ litres}$$

Some people prefer to use the formulae *PV* = *C*. Where V is volume, P is absolute pressure and C is a constant.

So 1 bar x 6L = 6 therefore 4 bar x *1.5 L* = 6

i.e. the pressure has been increased 4 times and the volume has been decreased to a ¼ of its original volume.

Simple Example (Expanded):

If the pressure is reduced the volume will increase proportionally. e.g. if the same balloon is raised to 20 metres what will be the new volume?

$$V_2 = \frac{P_1V_1}{P_2}$$

$$V_2 = \frac{4\ bar\ x\ 1.5\ litres}{3\ bar}$$

$$V_2 = \mathbf{2\ litres}$$

Again using the formulae *PV* = *C*

4 bar x 1.5L = 6 therefore 3 bar x *2L* = 6

While breathing underwater the divers respiratory volume remains about the same, as it would be doing equivalent work on the surface. Because of the increase in density of his breathing gas under the increased pressure, he must move a greater mass with each breath.

Therefore if he breathes at a rate of 35 litres per minute on the surface, then he must move an equivalent of 70 litres/minute doing similar work at a depth of 10 msw. Using Boyle's Law it is apparent that if diving at 90 msw, i.e. an absolute pressure of 10 bar, then 10 times the amount of gas must be utilised to occupy the same volume as on the surface.

Therefore for working out diver consumption (or breathing usage) the formula to use is:-

Surface consumption rate *x* Absolute Pressure = Actual consumption rate

For working out gas used in pressurising or available from cylinders it must be remembered that you start with and always will have atmospheric pressure in the cylinder,

Floodable Volume *x* Gauge Pressure = Free Gas Volume

i.e. if you blow down a 20 litre BOB (Bailout Bottle) to 200 bar, the gas used is:

FV *x* GP = 20L *x* 200 bar = 400L

For available gas use gauge or relative pressure, but for diver consumption use absolute pressure.

Calculating Gas Consumption 1.5.2

One of the most fundamental tasks of a Live Support Technician is actually calculating the divers consumption of breathing gas at the relevant depth they are working at.

Normally used consumption rates are: (at surface pressure)

For UK

Open Circuit Diving	35 l/min	or	1.25 ft^3/min
Closed Circuit Systems	5 l/min	or	0.18 ft^3/min
Bailout	40 l/min	or	1.5 ft^3/min
Built in Breathing Systems (BIBS) (Therapeutic gas)	20 l/min	or	0.70 ft^3/min

For Norway

Bailout	62.5 l/min for 10 mins
Bell on Board Gas	62.5 l/min for 20 mins

To Work Out Diver Consumption Rate

Surface Consumption Rate *x* Absolute Pressure = Actual Consumption Rate

Example:

How much gas does a diver at 32 msw use for 30 minutes?

35L *x* 30 minutes *x* 4.2 bar (A) = 4410L

To Calculate Gas Available From A Bank Or Cylinder

Depth of dive in pressure absolute must be subtracted, as must the regulator working pressure, which is normally taken as 10 bar.

Therefore if you have a 50L bottle, pressurised to 200 bar to be used for a dive to 84 metres, the volume of gas available for use is:-

GP x FV = FGV **1.5.2**

Calculating Cylinder Volume

GP *x* FV = FGV

Example:

200 bar - 10 bar (working pressure) - 9.4 bar (pressure absolute)

= 180.6 bar *x* 50 L

= 9030 L

= 9.03 m^3

How long will this gas last 2 divers on open circuit?

Consumption rate = 35L *x* 9.4 bar a *x* 2 divers = 658 L/min

Duration = $\frac{\text{Available Gas}}{\text{Consumption Rate}}$ = $\frac{\text{9030 litres}}{\text{658 litres}}$

= 13.7 minutes

To get the seconds it is 0.7 of 1 minute: 0.7 x 60 secs = 42 secs

= 13 min 42 seconds

To Work Out Duration Of Bailout Bottles

Find out the amount of gas that is available to the diver

Remembering to subtract his dive pressure and his hat working pressure from his total bailout pressure.

Example:

If a bailout with a volume of 12L is pressurised to 300bar, how much time will it give a diver at 162 msw?

Gas available = 12L *x* (300bar - 17.2bar (AP) - 10bar(HP))
= 12L *x* 272.8b
= 3273.6L of gas

Gas consumption = 40L *x* 17.2 bar (AP)
= 688 L/min

Duration = $\frac{3273.6}{688}$

= 4.76 minutes or 4 min 45 seconds

Compressor Capabilities

Compressor output = 70 m^3 per hour at 11 bar outlet pressure
Diver consumption = 35 L/min

Example:

In theory - How many divers will the compressor support at 40 msw?

Ignore the 11 bar as irrelevant (unless the outlet pressure is less than working pressure).

Gas required per diver = 35L *x* 5 bars absolute

= 175 L/min

No of divers = $\frac{\text{Compressor output (in L/min)}}{\text{Gas required}}$

= $\frac{\text{1167 L/min}}{\text{175 L/min}}$

= 6.67

Therefore, 6 divers can be supported.

Example:

In theory - How deep could the same compressor supply one diver?

Gas required for the diver = 35 L *x* 5 bars absolute

= 175 L/min

No of divers = $\frac{\text{Compressor output (in L/min)}}{\text{Gas required}}$

= $\frac{\text{1167 L/min}}{\text{175 L/min}}$

= 6.67 bar absolute
- 1 bar

= 5.67 bar gauge

$\times$ 10

= 56.7 msw

To Calculate Blowdown Gas

Because you are adding gas to a volume of gas already present, i.e. 1 ata at the surface, gauge or relative pressure is used to calculate blowdown gas. The gas used is also known as the Free Gas Volume; that is the volume the gas would take up if at 1 atmosphere.

The floodable volume is the volume of the container at 1 atmosphere, and every time one atm (or bar) is added, or taken away, this changes the volume by one floodable volume. ie an 11 m^3 is pressurised to 10 msw that means that another 11 m^3 has been added. If it is pressurised to 62 msw, that is 6.2 FV's have been added: 6.2 bar g x 11 m^3 = 68.2 m^3 has been added to the chamber

Floodable Volume (FV) *x* Gauge Pressure (GP_R) = Free Gas Volume (FGV)

Calculating Blowdown Gas

FV *x* GP_R = FGV

Example:

To pressurise an 670ft^3 chamber to 495 fsw

FV = 670 ft^3 P_R = 15 atm

Therefore 670 *x* 15 = 10050ft^3

To Find The Volume Of DDC From Gas Used In Blowdown

$$FV = \frac{\text{Gas Used}}{GP_R}$$

Example:

If gas used equals 243 m^3 to pressure a system to 42 msw then to calculate the system volume:

$$= \frac{243\ m^3}{4.2}$$

= 57.9 m^3 = system floodable volume

To Find Out Pressure Drop In A Quad After Blowdown:

$$P_R = \frac{\text{Gas Used}}{\text{FV of quad}}$$

Example:

Find the pressure drop in a quad if you pressurise a 15m^3 chamber to 80 msw from a 64 bottle quad. (Each cylinder or bottle in a quad has a given value of 50 litres)

Gas Used = 15 m^3 *x* 8 bar = 120 m^3

FV of quad = 64 *x* 50 = 3200 l = 3.2 m^3

Pressure drop from quad $\frac{120\ m^3}{3.2\ m^3}$ = 37.5 b

Example:

If you have a 15 m^3 chamber at a depth of 120 msw with a pO_2 of 0.6 bar, and a 28 m^3 chamber at a depth of 60 msw with a pO_2 of 0.4 bar, how do you find the depth at which they will equalise?

NB:- This calculation uses Bars Gauge, ie 120 msw = 12 bar

Gas Present

Chamber 1 = 15 m^3 *x* 12 bar = 180 m^3

Chamber 2 = 28 m^3 *x* 6 bar = 168 m^3

Total Gas = 348 m^3

Total Volume of System = 15 m^3 + 28 m^3 = 43 m^3

Depth of Equalisation = $\frac{348}{43}$

= 8.09 bar(G)

= 8.09 x 10 = msw

= 80.9 msw

Eventually, given time, the partial pressures (see Dalton's law) in the chamber equalisation in would find equilibrium.

To find out what partial pressure of Oxygen (pO_2) they will equalise at we need to first find out how much O_2 volume is present in the chambers; the formula for this is

Floodable Volume (FV) *x* Partial Pressure (GP) = Gas Volume

Volume of Oxygen in Chamber 1 is 15 m^3 x 0.6 bar = 9 m^3
Volume of Oxygen in Chamber 2 is 28 m^3 x 0.4 bar = 11.2 m^3

Total Volume of Oxygen in the system = 20.2 m^3
Total Volume of System = 43 m^3

$$pO_2 = \frac{\text{Oxygen Volume}}{\text{Floodable Volume}}$$

$$\frac{20.2\ m^3}{43\ m^3} = 0.47\ \text{bar}$$

This scenario would not be done as it would in manned chambers, but in theory if the chambers were

Metabolic Oxygen Consumption

The Oxygen volume formula is useful for working out how long Oxygen will last in metabolic usage. Metabolic usage is how much O_2 the body burns to maintain the chemical reactions to sustain life. **It is a constant figure and is not variable with depth changes.**

Metabolic oxygen consumption is **0.5 litres a minute per diver** (30 l/hour = 0.72 m^3/24 hours)

Example:

How long will it take 6 divers in a 24 m chamber to breathe the pO_2 from 400 millibar to 160 millibar?

Floodable Volume (FV) *x* Partial Pressure (GP) = Gas Volume

The pO_2 is being breathed from 400mb to 160mb, so 240mb is being consumed, therefore the volume of O_2 consumed is:

24 m^3 x 240 millibar = 5760 litres (note the answer is in litres if mbars are used, but in cubic metres if bars are used)

Oxygen consumption rate:

6 divers x 30 litres/hour = 180L/hr

$$\frac{5760\ \text{litres}}{\mathbf{180\ litres}} = 32\ \text{hrs}$$

Calculating Gas Volume
FV *x* Partial Pressure (GP)
= Gas Volume

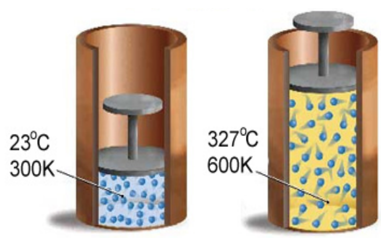
Charle's Law (Temperature Effect on the Pressure / Volume) 1.5.3

Temperature changes in a gas alter the pressure or volume in a uniform way. This is described in Charles Law, which states:

"If pressure is constant, the volume of a fixed mass of gas is proportional to its absolute temperature"

It can equally be stated:

"If the volume is constant, the pressure of a fixed mass of gas is proportional to its absolute temperature"



Absolute Temperature

The temperature of a body is a measure of the intensity of its heat, and is produced by the average kinetic energy or speed of its molecules.

Zero degrees absolute is the theoretical temperature at which there is a complete absence of molecular activity (i.e. everything stops) thus no heat energy is evolved.

The temperature at which the kinetic energy is absent is given as -273°C in the Celsius scale and -460°F in the Fahrenheit scale.

- 273°C = 0 K (Kelvin)

$-460^{O}F = \quad 0^{O}R$ (Rankine)

Therefore if we look at the three states of matter, in this example of water, and convert to absolute temperature:

Unit	Absolute zero	SOLID ice	→	LIQUID water	→	GAS steam
ºC	-273		0		100	
K	0		273		373	
ºF	-460		32		212	
ºR	0		492		672	

Therefore when using absolute temperature in the Celsius scale 273 is added to the Celsius Value:

$17^{O}C$ becomes 290 K

Similarly, when using the Fahrenheit scale the addition of 460 to the Fahrenheit reading will convert to absolute scale:.

$52^{O}F$ becomes $512^{O}R$

Charles Law can be written:

At Constant Volume

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$
$$(\textbf{OR}\ P_1 \, x \, T_2 = P_2 \, x \, T_1)$$

Charles's Law Formula
Constant Volume
$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

P_1 is the pressure of a mass of gas at temperature T_1 absolute
P_2 is its pressure after the temperature has changed to T_2 absolute.

Or at Constant Pressure

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$
$$(\textbf{OR}\ V_1 \, x \, T_2 = V_2 \, x \, T_1)$$

Charles's Law Formula
Constant Pressure
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

V_1 is the volume of a mass of gas at temperature T_1 absolute
V_2 is its volume after the temperature has changed to T_2 absolute.

Combined Gas Equation **1.5.3**

Boyle's and Charles Law may be combined to give the combined gas equation.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Combined Gas Equation
$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Charles's law has much less relevance to diving physiology than Boyle's Law, however, it should be remembered when considering gas volumes and how they are affected by temperature.

Its relevance is in realising the effects of temperature fluctuation on gas pressures in quads, chambers, etc. Therefore when using the formula you will find that the volume isn't changing in the rigid metal of a chamber or cylinder, it is the depth & pressure that changes with absolute temperature.
It is for this reason that the formula most used in Charles law is:

$$P_1 \, T_2 = P_2 \, T_1$$

USING CHARLES LAW FORMULAE

Remember – you must always use Absolute Temperature.

To convert ºC to absolute: $^{O}C + 273 =$ Kelvin
To convert ºF to absolute: $^{O}F + 460 =$ ^{O}Rankine

Example:

If the temperature drops following the pressurisation or blowdown of a fixed volume vessel, then the pressure will drop:

A 10 litre cylinder is charged to 200 bar. The temperature rose to 38°C before dropping back to 18°C. Find the (new) pressure. (Cylinder volume is irrelevant.)

$T_1 =$ 38°C + 273 = 311K

$T_2 =$ 18°C + 273 = 291K

$P_1 =$ 200 bar

$P_2 =$?

$$P_2 = \frac{P_1 T_2}{T_1}$$

NB :-
When working with H.P. bottles You can work in gauge

$$P_2 = \frac{200\ x\ 291}{311}$$

$$P_2 = \mathbf{187\ bar}$$

Example:

To find a new chamber depth after cooling the depth in metres or feet of seawater should be converted to absolute pressure.

A bell was rapidly blown down to a depth of 70m. On arrival at that depth the temperature was 36.5°C. Theoretically what would the bell depth be if the temperature dropped to 21°C?

$T_1 =$ 36.5°C + 273 = 309.5K

$T_2 =$ 21 °C + 273 = 294K

$P_1 =$ 70 m = 8 bar absolute

$P_2 =$?

NB :-
When working with Chambers You must work in Absolute Pressure

$$P_2 = \frac{P_1 T_2}{T_1}$$

$$P_2 = \frac{8\ x\ 294}{309.5}$$

$$P_2 = \mathbf{7.6\ bar\ a = 66\ msw}$$

Therefore if the bell depth were not adjusted after cooling the pressure decrease would result in the water level rising in the trunking until the temperature had stabilised.

Example:

If a quad arrived onboard at a pressure of 190bar and a temperature of 16°C, what would happen if it was positioned below a flare stack and the temperature rose to 34°C?

$T_1 =$ 16°C + 273 = 289K

$T_2 =$ 34°C + 273 = 307K

$P_1 =$ 190 bar

$P_2 =$?

$$P_2 = \frac{P_1 T_2}{T_1}$$

$$P_2 = \frac{190 \ x \ 307}{289}$$

$$P_2 = 202 \ \boldsymbol{bar}$$

Therefore, the pressure has risen by 12 bar.

Temperature Conversion

To convert ^{O}Celsius to ^{O}Fahrenheit:

(^{O}C x 1.8) + 32 = ^{O}F

To convert ^{O}Fahrenheit to ^{O}Celsius:

(^{O}F – 32) ÷ 1.8 = ^{O}C

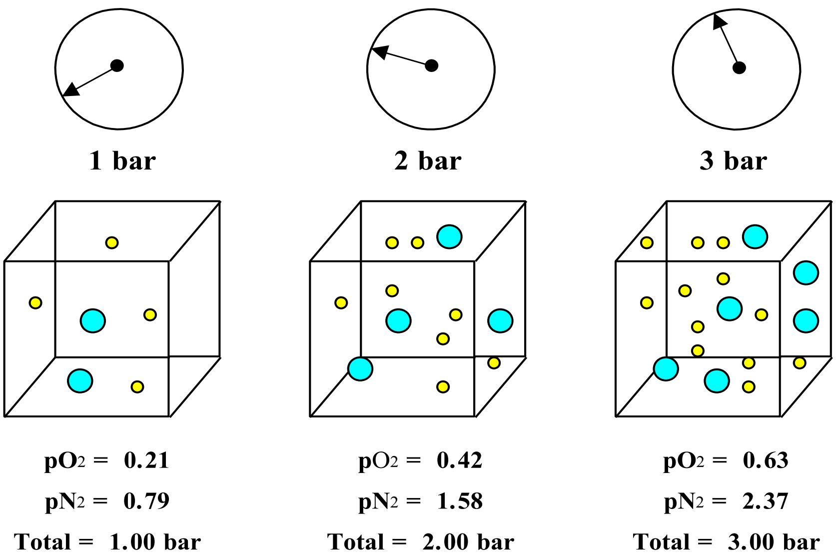
If you can remember that the conversion has the figures of 1.8 and 32 in the calculation, try to remember that 16 ^{O}C = 61 ^{O}F. This may help you to remember and work out the calculation.

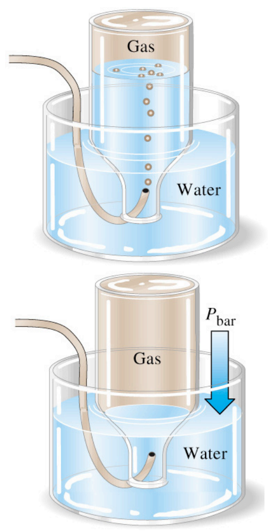
Dalton's Law (Partial Pressure) 1.5.4

The term Partial Pressure is used commonly in the diving industry. Partial pressure is simply that part of the total pressure contributed by each individual gas in a mixture. If air at an absolute pressure of 3 bar had an O_2 concentration of 21% then the partial pressure of O_2 is 21% of 3 bar.

It States:-

"The total pressure exerted by a mixture of gases is equal to the sum of the partial pressures that would be exerted by each of the constituent gases if it alone occupied the total volume."





The initial formula is:

Partial pressure (bar) x 100 = percentage x absolute pressure

i.e p x 100 = % x AP

By transposition the formula can be adjusted to find any of the values.

To find partial pressure $$p = \frac{\% \ x \ AP}{100}$$

To find percentage $\% = \frac{p \, x \, 100}{AP}$

To find absolute pressure $AP = \frac{p \, x \, 100}{\%}$

The above formulae all use absolute pressure. If adding gas to a quantity of gas already there and you wish to find partial pressures of gases added, then gauge pressure is used. If you then require to find the partial pressure at the new depth then you must add the partial pressure added to the initial partial pressure and use the absolute pressure formula to find percentage.

It is important to remember that, in most cases, absolute pressure is used and that if you are looking for a depth where a known percentage will give a known partial pressure then the answer is in absolute pressure which must be converted to a depth.

The partial pressure of breathing mixes can be manipulated to the divers advantage. For example, the composition of the gas breathed by a diver may be modified, perhaps to reduce the chance of decompression sickness by reducing the amount of inert gas, or perhaps by adjusting oxygen levels to avoid oxygen toxicity. The effects of increased partial pressures or carbon dioxide or carbon monoxide on the surface can become toxic as the pressure increases.

In air at 1 Atmosphere, the pressure contributed by oxygen = 21% of 1 atm = 0.21 atm.

In air at 1 Atmosphere, the pressure contributed by nitrogen = 79% of 1 atm = 0.79 atm.

i.e.	ppO_2	=	21% of 1 atm	=	0.21 ata
	ppN_2	=	79% of 1 atm	=	0.79 ata
	TOTAL	=	1.0 ata		

To transpose Daltons Formula:

Whichever value you require, take the other value on the same side across and below the values on the other side.

$$p = \frac{\% \, x \, ap}{100}$$

$$\% = \frac{p \, x \, 100}{ap}$$

$$ap = \frac{p \, x \, 100}{\%}$$

Dalton's Law Formula

(PARTIAL PRESSURE) ***p x 100 = % x AP***

Example:

What is the pO_2 when a diver breathes an 8/92 mix at 68 msw?

$$p = \frac{\% \, x \, ap}{100}$$

$$p = \frac{8 \, x \, 7.8}{100}$$

$$pO2 = \mathbf{0.62 \, bar \, OR \, 624 \, mbar}$$

Example:

What gas will give a pO_2 of 0.6 at a depth of 123 msw?

$$\% = \frac{pO2 \, x \, 100}{ap}$$

$$\% = \frac{0.6 \, x \, 100}{13.3}$$

$$= \mathbf{4.5\%}$$

Therefore, gas used is 4.5% O_2 and 95.5% He.

Example:

If the maximum pO_2 for a bounce dive is 1.5bar, what is the maximum depth for using an 8% mix?

$$ap = \frac{pO2 \; x \; 100}{\%}$$

$$= \frac{1.5 \; x \; 100}{8}$$

= 18.75 *bar absolute* = 17.75 *bar gauge*

= *177.5 msw*

If pressuring a system from the surface or increasing a living depth, you must take into account the partial pressures of the gases already present.

e.g. If you pressurise a system to 40 msw using 5% oxygen, then:

pO_2 initial	+	pO_2 added	=	pO_2 total
ppO_2 initial	=	21% of 1 bar	=	0.21bar or 210 mbar
ppO_2 added	=	5% of 4 bar	=	0.2bar or 200 mbar

Therefore pO_2 total = 0.41 bar or 410 mbar

Example:

To find the percentage of the gas at 40msw use absolute pressure.

$$\% = \frac{pO2 \; x \; 100}{ap}$$

$$\% = \frac{0.41 \, x \, 100}{5}$$

$$= \mathbf{8.2\%}$$

Example expansion:

Now if we increase the living depth to 110 msw using 2/98.

Then the pO_2 total = pO_2 initial + pO_2 added.

pO_2 added = $\frac{2\% \; x \; 7 \; bar \; g}{100}$ = 0.14 bar = 140 mbar

The pO_2 already there = 410 mbar

Therefore pO_2 at 110 msw = 410 + 140 = 550 mbar

The new oxygen percentage is: (First convert 550 mbars to bar)

$$= \frac{550}{1000} = 0.55 \text{ bar}$$

$$= \frac{0.55 \text{ bar } x\ 100}{12 \text{ bar a}} = 4.6\%$$

If we increase the living depth using pure helium, then the pO_2 will not change as no more oxygen has been added. The percentage though, will decrease as it now constitutes a smaller proportion of the total.

In most offshore work sites pure helium has been replaced by a 2% oxygen in helium mix. However where saturation depths are in excess of 200msw, pressurisation may result in an undesirable high partial pressure of oxygen, therefore a lower O_2 may be required i.e. 1%. Similarly when saturation depths are shallow, for example, 50msw, a higher % may be required.

The reason for using 2% instead of pure Helium is to allow a diver, who has been given this gas accidentally, to survive. When blowing down a system using 2% and another gas, the formula to calculate the initial blowdown on the high gas is:-

$$\textit{Depth in msw using high mix} = \frac{(\textit{Final } pO_2 - 210) - (\textit{Msw x } O_2 \textit{ low mix})}{(\textit{O2 high mix} - \textit{O2 low mix})}$$

Example:

Pressure a system to 97 msw using 2% and 6% to give a O_2 of 0.6 bar.

$$\frac{(600 - 210) - (97 \times 2)}{(6 - 2)}$$

$$= \frac{390 - 194}{4}$$

$$= \frac{196}{4}$$

$$= 49 \text{ msw gauge}$$

> **NB :-**
> **210 is the 210 mbars in the atmosphere at the surface when the door is closed.**
> **This is ALWAYS applied.**

Thus initial blow down will be to 49 msw using 6% then onto 97 msw using 2%.

To confirm the results, add up the partial pressures.

e.g.	pO_2 initial	=	0.21 bar
	pO_2 added using 6% to 49 msw	=	0.294 bar
	pO_2 added using 2% to 97 msw	=	0.096 ba
	Total	=	0.6 bar

Conversely, if we vent gas from a chamber or bell, the ratio of each gas in the mixture will remain unchanged, i.e. if you vent from a bell containing 5% O_2 from 90 msw, the mixture of gases will be the same all the way to the surface. The very important difference is that the partial pressures of the gases will drop significantly.

At 90 msw	pO2 = 5% of 10 bar	=	0.5 bar
On the surface	pO2 = 5% of 1 bar	=	0.05 bar (or 50mbar)

Thus you can see that the 5% oxygen at 90 msw was more than enough to support life whereas the same 5% at the surface will not.

This is important to remember, not only when surfacing a bell or chamber, but also when operating a split level saturation, the oxygen level must be checked when moving the bell or transfer chamber from one depth to the other.

Dalton's Law and Carbon Dioxide

Dalton's law and CO_2 can cause some confusion for some people. This is because we can end up dealing with very small numbers with lots of zero's and there are other systems used by some dive companies that require a different approach. There is also the "complication" of readings taken at depth and on surface.

The main unit used in measuring CO_2 is parts per million (ppm), but occasionally you will find percentage (%) readings. As with any gas the proportion of it within the container is not as important as the actual amount which with CO_2 is calculated best in millibar (mbar or mb). Companies have differing maximum levels of CO_2 allowed, but most companies allow up to 5 mbar in their living chambers. Let's use Dalton's law to work out what proportion this would be at a two different depths:

To use Dalton's law we need the pCO_2 in bar 5mb ÷ 1000 = 0.005 bar

On surface: $\frac{0.005 \times 100}{1} = 0.5\ \% \quad \times 10000 = 5000$ ppm

At 90 msw: $\frac{0.005 \times 100}{10} = 0.05\ \% \quad \times 10000 = 500$ ppm

You can see that a short cut to finding the maximum ppm for a given depth is to divide the maximum 1 atmosphere reading 5000 ppm by the absolute depth

ie at 120 msw: $\frac{5000}{13} = 384$ ppm

That covers readings taken on the surface but what about at depth? Readings at depth are normally taken by draeger tubes and the reading is a direct reading of partial pressure, although not in bar or millibar.

The units are in ppm or %, and to convert to bar or millibar then it is the reading:

ppm (at depth) ÷ 1000 = partial pressure in mbar

or

If draeger tube reads in % then % (at depth) x 10 = partial pressure in mbar

As stated some people use surface equivalent percentage or values (SEP or SEV) and a reading at depth is the SEV ie if the draeger tube reads 0.5 % or 5000 ppm these are SEV readings and some company's make these amounts their maximum level. Some companies have 20 mbar (2% or 20000 ppm SEV) as a maximum level in the bell.

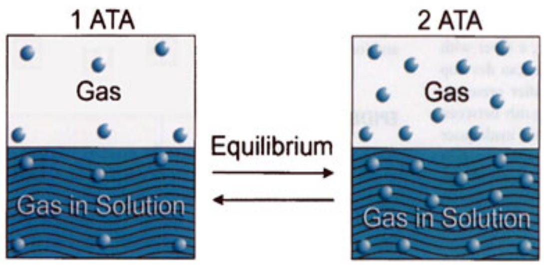
Henry's Law (Solubility of Gas) 1.5.5

Henry's Law States

"At a constant temperature the amount of gas that will dissolve in a liquid is proportional to the partial pressure of that gas in contact with the liquid."

This law implies an equilibrium in which equal amounts of each gas are passing into and out of any solution in contact with it.

At sea level (1 atm), a man's body tissues contain about 1 litre of nitrogen in solution. If he dived to 33 fsw and breathed air at 2 ata, he would eventually reach a new equilibrium and have twice as much nitrogen in solution in his tissues. If he increased depth to 132 fsw he would eventually have 5 litres of nitrogen and so on. The time taken to reach a new equilibrium depends on the solubility of the gas in the tissue and the rate at which the gas is supplied to each tissue.



The two inert gases commonly encountered in diving are nitrogen and helium. When combined with suitable oxygen content they comprise most breathing mediums, i.e. either air/nitrox or heliox.

Nitrogen and helium differ in both diffusion rate and solubility. Helium is less soluble in the tissue than nitrogen is, but it will diffuse into the tissues much faster.

There are differences in the rate of diffusion and solubility of gases in different tissues. Fatty tissues will hold significantly more Nitrogen than watery tissues (5 times more) thus will take longer to absorb or eliminate excess inert gas.

The carrier of increased gas pressures to the tissue is the blood system, therefore tissues that are highly vascularised, i.e. those that have a good blood supply, will exchange gases more quickly than tissues with a poor blood supply. Similarly, the rate of gas elimination is affected by perfusion in the tissues.

Gas movement is not instantaneous. Equilibrium can take hours. Gas molecules dissolve in the tissue and move from one area to another until the partial pressure of the gas is the same at each point.

NB: Gas pressures tend to equilibrate, not the number of gas molecules. If a gas is twice as soluble in one tissue compared to another, then there will be twice as many of its molecules in the first tissue to produce the same partial pressure. This information can be calculated from the solubility coefficients of the gas in the components of the tissue.

Thus at sea level a body is saturated with nitrogen. If we increase the pressure a corresponding amount of nitrogen will then dissolve into the body until it reaches a new saturation level. If we then decrease the pressure the tissues will have to off load the excess inert gas to the level accepted at the new depth. This is a major principle of diving and will be discussed in decompression.

Archimedes' Principle (Buoyancy) 1.5.6

The Principle States:

"An object immersed in liquid, either partially or wholly is buoyed up by a force equal to the weight of the liquid displaced"

A diver underwater is subject to Archimedes principle. If he weighs less than the weight of water he displaces, then he will tend to float to the surface, i.e. positive buoyancy. If he weighs more than the weight of the water displaced, he will sink, i.e. negative buoyancy. If his weight is equal to the weight of water displaced then he is said to be neutrally buoyant.

The formula is:

Up-thrust = Volume of liquid displaced x Density of liquid Displaced

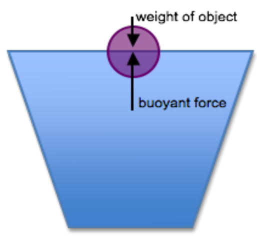
Density of Sea water = 1.03 te/m^3
64.38 lb/ft^3

Density of Freshwater = 1.0 te/m^3
62.5 lb/ft^3

Therefore, a diver can adjust his buoyancy to suit a particular work site, e.g. mid water or bottom, by the addition or removal of weight.

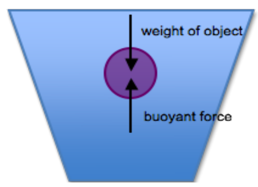
Buoyancy adjustment is used commonly for the lifting, movement or support of subsea equipment. In other words, if you know the weight and volume of a submerged object, you can adjust its state of buoyancy with the use of lifting bags. Lifting bags also use the principles of buoyancy to achieve lifts, e.g. a lifting bag will lift or achieve an up-thrust of 1.03 metric tonnes if it displaces 1m^3 of sea-water.

The Three Stages Of Buoyancy:



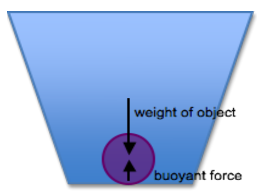
Positive Buoyancy

The weight of the object is less than the up-thrust and the object floats / rises.



Neutral Buoyancy

The weight of the object is equal to the up-thrust and the object remains in its existing position.



Negative Buoyancy

The weight of the object is greater than the up-thrust and the object sinks.

To Find The Volume Of An Object Use The Following Formulae:

Volume of a square or rectangle: Length x Width x Height

e.g. A box 1.5 m long by 1.2 m wide by 1.6 m high has a volume of:

1.5 x 1.2 x 1.6 = 2.88 m^3

If the object was fully immersed in seawater they would receive an up-thrust of:

2.88 x 1.03 = 2.97 te

Volume of a Solid Cylinder:

Area of End x Length

e.g. A sealed pipe with a diameter of 60 cm and 12 metres long has a volume of: (Area of end = πr^2 (π = 3.142))

(3.142 x 0.3 x 0.3) x 12 = 3.39 m^3

If the object was fully immersed in seawater they would receive an up-thrust of:

3.39 x 1.03 = 3.49 te

Volume of a Sphere:

$^4/_3\ \pi r^3$

e.g. A sphere with a diameter of 1.2 metres has a volume of: $^4/_3$ x 3.142 x 0.6 x 0.6 x 0.6 = 0.9m^3 If the object was fully immersed in seawater they would receive an up-thrust of:

0.9 x 1.03 = 0.927 te or 927 kg

EXAMPLES USING ARCHIMEDES PRINCIPLE FORMULA

An object 2m deep, 1m wide and 4m long, weighing 9 tons, lies on the sea-bed.

How much water must be displaced from a lifting bag to initiate a lift?

Volume of object = 2 x 1 x 4 = 8 m^3

Upthrust achieved by being immersed = 8 x 1.03 = 8.24 te

Difference between weight of object and upthrust = 9 tonnes - 8.24 = 0.76 te

Therefore, the object is 0.76 te negative.

Volume of additional displacement to achieve additional 0.76 te up-thrust;

$$= \frac{0.76}{1.03} = 0.74\ m^3 = 740 \text{ litres}$$

Thus if you displace 740 litres of water from a lifting bag, the up-thrust will equal the down-thrust, and it will become Neutrally buoyant, any further displacement in the lift bag will cause the object to become Positively buoyant, and the object will begin to rise.

GASSES ENCOUTED IN DIVING 1.6

A diver is totally dependent on a supply of breathing gas whilst underwater. This gas is supplied either via a surface umbilical or from a self-contained supply carried by the diver.

Air & Nitrox (Enriched Air) 1.6.1

Air is a mixture of gases (and vapours) containing oxygen (20.946%), nitrogen (78.084%), carbon dioxide (0.033%), argon (0.934%) and 0.003% other rare gases. Air is the most commonly used breathing gas used in diving.

If ordered in cylinders from a dive gas supplier then the supplier will actually mix Air from O_2 and N_2. This is how they also mix Nitrox which is a mixture of O_2/ N_2 in proportions to suite the partial pressure requirements of the dive mix, ie 40/60 means that there is 40% O_2 and 60% N_2

Colour Code

Air that is pumped from the atmosphere by compressors must meet the guidelines in BS EN 12021.

Colour code - diving quality Black cylinder with white collar/shoulder.

Oxygen 1.6.2

Molecular Formula	O_2
Molecular Weight	32.00
Boiling Point	-183ºC
Melting Point	-218.4oC
Specific Gravity (Air = 1)	1.053
Density	1.331 gm/l

Oxygen is a colourless, odourless, tasteless gas which is slightly soluble in water. It is slightly more dense than air at equal temperatures.

One volume of liquid oxygen gives 860 volumes of gas at ambient temperatures.

Solubility in water at 10oC and 1 atm = 0.055 (wt/%.)

Oxygen is the only life supporting gas used by the body. The other gases breathed from the atmosphere or by the diver in his breathing mix, serve only as a vehicle and dilutent for the oxygen. The body consumes O_2 at a rate given as 0.5 litres per minute (independent of ambient pressure).

If breathed at high partial pressures it can cause toxicity.

It is an oxidant and although not flammable it supports and is consumed in both respiration and combustion. It is highly reactive and great care is required in it's handling to guard against explosion/fire, indeed any gas mixture containing more than 25% O_2 must be treated as if pure Oxygen.

Colour Code

Oxygen is produced industrially by the fractional distillation of liquid air

Colour code - diving quality Black cylinder with white collar/shoulder

Nitrogen 1.6.3

Molecular Formula	N_2
Molecular Weight	28.016
Boiling Point	-195.8oC
Melting Point	-209.9oC
Specific Gravity (Air = 1)	0.967
Density	1.16 gm/l

Nitrogen is a colourless, odourless, tasteless gas. It is chemically inert and is incapable of supporting life. Its main function is as a dilutent or carrier of oxygen in a breathing mixture, but when used in a diving gas mixture it has several disadvantages.

When nitrogen is breathed at partial pressure in excess of 3.2 bar, i.e. air beyond 30 metres, it has a distinct anaesthetic effect on the body producing "nitrogen narcosis", a condition characterised by loss of judgement and disorientation.

Because of the high density of the gas compared to helium, more energy is used in the work of breathing during deeper diving.

Nitrogen is produced industrially by the fractional distillation of liquid air

Solubility in water at 10oC and 1 atm = 0.0024 (wt %).

Solubility in fat is much greater - around five times the quantity.

Colour Code

Nitrogen can cause hypoxic problems if the O_2 level is flushed to below critical level. Therefore, care must be taken when discarding or emptying N_2 cylinders.

Colour code - Grey cylinder with black collar/shoulder

Helium (& Heliox) 1.6.4

Chemical Symbol	He
Atomic Weight	4.003
Boiling Point	-268.96oC
Melting Point	-271.24oC
Specific Gravity (Air = 1)	0.138
Density	0.166 gm/l

Helium is colourless, odourless and tasteless. It is the second lightest gas known (hydrogen being the lightest) with a density of one seventh of air at equal temperature and pressure.

It has the lowest boiling point of any known substance. Helium is not flammable, is chemically inert and non-toxic. It is normally present in the dry atmosphere in trace quantities - 5 ppm by volume. It is normally extracted as a byproduct of natural gas, the major producers being the USA and Algeria. Helium does not support life and is used in deep diving as a carrier of oxygen. It is then known as Heliox, and the O_2/He mixes vary according to use, such as 2/98 for most pressurisation uses deeper than 40 msw, and 50/50 for DCI treatments between 18 to 40 msw. Care must be taken when using pure helium that oxygen levels are not reduced to dangerous levels, causing Anoxia or Hypoxia. Current IMCA guidelines recommend the base gas should contain 2% Oxygen in Helium, and not pure Helium for this reason.

Breathing heliox causes speech distortion, which hinders communication especially in very deep diving.

Helium also has a high thermal conductivity, 6 times greater than Air, which can result in rapid loss of body heat.

Apart from these two disadvantages, it still has greater advantages over nitrogen, namely because of its lower density and lack of toxic effect.

Solubility in water at 10oC and 1 atm = 0.000161 (wt/%).

Colour Code - Brown Bottle (Heliox Brown, white collar/shoulder).

Colour Code

Heliox

Helium

Argon 1.6.5

Chemical Symbol	Ar
Atomic Weight	39.95
Boiling Point	-185.9oC
Melting Point	-189.2oC
Density	1.664 g/l
Specific Gravity	1.38

Argon (a “noble” gas as is helium) is colourless, odourless and tasteless and is heavier than air at equal temperatures. It is chemically inert and is found in air in small quantities, i.e. 0.93%. It has been tried as dilutent gas in diving but is not used. It is similar to nitrogen, but is twice as narcotic and suffers the same problems with depth restrictions. It is denser than nitrogen and therefore increases the work of breathing effort.

Argon is produced industrially by the fractional distillation of liquid air

Solubility in water at 10oC and 1 atm= 0.00025 (wt/%).

It is sometimes found as a shield gas during welding but otherwise is unlikely to be found offshore.

Colour Code

Colour code - Blue cylinder

Hydrogen 1.6.6

Molecular Formula	H_2
Molecular Weight	2.016
Boiling Point	-252.8oC
Melting Point	-259.2oC
Gas Density	0.0838 g/l
Specific Gravity of Gas	0.0695

Hydrogen is colourless, odourless and tasteless. It is the lightest gas known with a density one fourteenth that of air at equal temperature and pressure.

Hydrogen is highly flammable with a wide range of flammability in both air and oxygen.

Hydrogen has been tested with a view to its being the dilutent in very deep diving. Hydrox: O_2/H_2 and Hydreliox: $O_2/H_2/He$ have been trialled, most thoroughly by Comex, but the inherent dangers of Hydrogen explosion (O_2 content must be less than 1% and external chambers are in inert environment) and also a degree of H narcosis have deterred further use .

Solubility in water at 10oC and 1 atm = 0.00017 (wt/%).

Colour Code

It is unlikely to be used generally offshore because of its highly unstable and dangerous characteristics.

Colour Code - Orange Bottle

Carbon Dioxide 1.6.7

Molecular Formula	CO_2
Molecular Weight	44.01
Triple Point at 4.17 bar (g)	-56.6oC
Specific Gravity	1.52
Density (20oC 1 ata)	1.84 gm/l

Carbon dioxide is a colourless gas that has a slightly pungent odour at high concentrations.

It is about 1½ times heavier than air at equal temperatures and pressure.

The gas is a product of several naturally occurring processes such as cellular metabolism, combustion and fermentation.

Although carbon dioxide is not generally considered poisonous, in excessive amounts it is harmful to the diver; this is called Hypercapnia. While some CO_2 is necessary to stimulate external respiration, increased partial pressures give rise to a succession of symptoms which can lead to unconsciousness and death. It must be remembered that acceptable levels in a gas at 1ata may exceed tolerable limits at increased pressures.

Colour Code

CO2 is extremely soluble in water = 0.23 (wt/%).

Colour code - Black cylinder with grey collar/shoulder

Carbon Monoxide 1.6.8

Molecular Formula	CO
Molecular Weight	28.01
Specific Gravity of Gas (Air = 1)	0.968
Density of Gas (20°C 1 ata)	1.161 gm/l

Carbon monoxide is a poisonous gas. It is colourless, odourless and tasteless, is slightly lighter than air and is difficult to detect. It is produced in small quantities by the body, especially in smokers, but the main source is from the incomplete combustion of hydrocarbons.

Typical problem areas are compressor intakes sited by engine exhausts or possible overheating in a compressor which breaks down the lubricant, producing toxic contamination of the gas.

CO is readily picked up by the oxygen carrier within the blood (i.e. haemoglobin) at the expense of the oxygen itself. Thus the body tissues become hypoxic. Low concentrations are extremely toxic so great care must be taken.

For additional information on the above mentioned contaminant gases, see the Section on Gas Toxicity.

Section 2

Anatomy & Physiology

CELLS AND TISSUE 2.1

The human body has billions of individual cells. Each one of these microscopic, but complex structures contains all the genetic information necessary to build all the body tissues and organs.

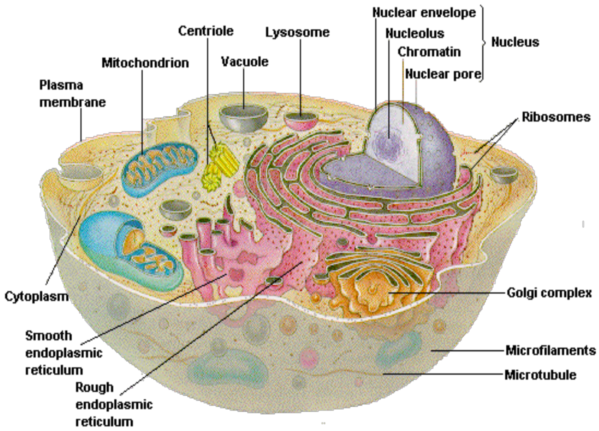
Each cell is a separate living organism and must be supplied with oxygen and nutrients by the bloodstream in **capillaries**. The bloodstream also removes the waste products from the cell. The most important of these waste products, from the diver's point of view, is carbon dioxide. The body consumes, or metabolises oxygen at the rate of 0.5 lts/minute, the ratio it produces carbon dioxide is one to one, ie the body also produces carbon dioxide at the rate of 0.5 lts/minute.

To make the oxygen pass from the blood into the cell there must be a suitable pressure gradient. In other words, the partial pressure, or tension, of oxygen in the blood must be higher than that in the cell.

To remove the carbon dioxide from the cell, the pressure gradient must slope the other way. There must be a higher carbon dioxide tension in the cell than in the blood.

The exchange of oxygen and carbon dioxide between the bloodstream and the cells is known as **internal respiration or perfusion.** This is to distinguish it from the exchange of oxygen and carbon dioxide between the capillaries and the alveoli in the lungs, which is known as **external respiration or diffusion.**

The Cell



Each cell has a limited life and cells are constantly dying and being created in the body. In the average human lifetime every cell will be replaced several times over.

If a cell is deprived of oxygen it will die very quickly. In the less important organs, this may not cause any immediate difficulty, but in the brain for example, irreparable damage can occur in only a few minutes.

When cells are deprived of oxygen the condition is known as **hypoxia**. In extreme cases where there is a complete lack of oxygen, it is known as **anoxia.**

Similar cells are grouped together to form **tissues,** each carrying out a specific function. Related tissues join to form **organs**, adapted to perform specific tasks. Groups of organs responsible for a series of interrelated functions form the **body systems.**

Body systems of particular interest in diving physiology include:

- The Respiratory System
- The Cardiovascular System
- The Nervous System
- The Special Sensory Organs
- The Skeletal System
- The Muscular System

No system operates independently. The Respiratory System, for example, is controlled by signals from the Nervous System, which in turn are initiated or triggered by carbonic acid levels in the Circulatory System.

RESPIRATORY SYSTEM 2.2

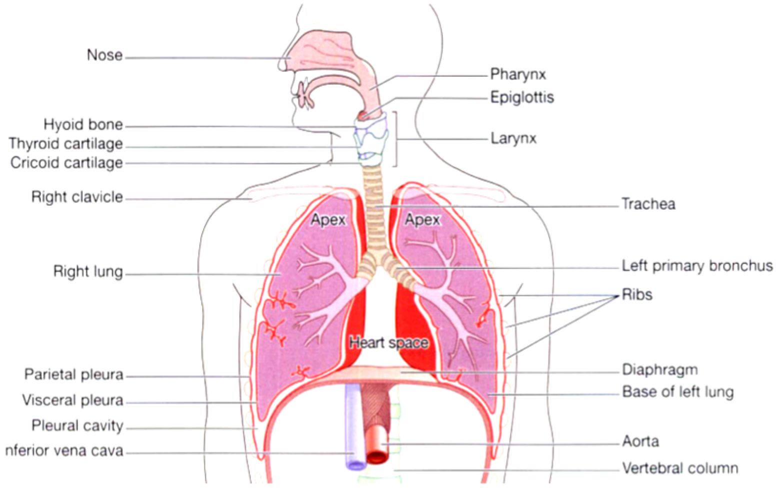
The cells of the body need energy for their chemical activity that maintains homeostasis. Most of this energy is derived from chemical reactions, which can only take place in the presence of oxygen (O_2). The main waste product of these reactions is carbon dioxide (CO_2). The respiratory system provides the route by which the supply of oxygen present in the atmospheric air gains entry to the body and it provides the route of excretion of carbon dioxide.

As the air breathed in moves through the air passages to reach the lungs, it is warmed or cooled to body temperature, moistened to become saturated with water vapour and 'cleaned' as particles of dust stick to the mucus which coats the lining membrane. Blood provides the transport system for these gases between the lungs and the cells of the body.

Exchange of gases between the blood and the lungs is called *external respiration* and that between the blood and the cells *internal respiration.*

The Organs Of The Respiratory System Are:

- Nose
- Pharynx
- Larynx
- Trachea
- Two bronchi (one bronchus to each lung)
- Bronchioles and smaller air passages
- Two lungs and their coverings, the pleura
- Muscles of respiration, the inter-costal muscles and the diaphragm



The Airway 2.2.1

The Nose

Respiratory Function of the Nose

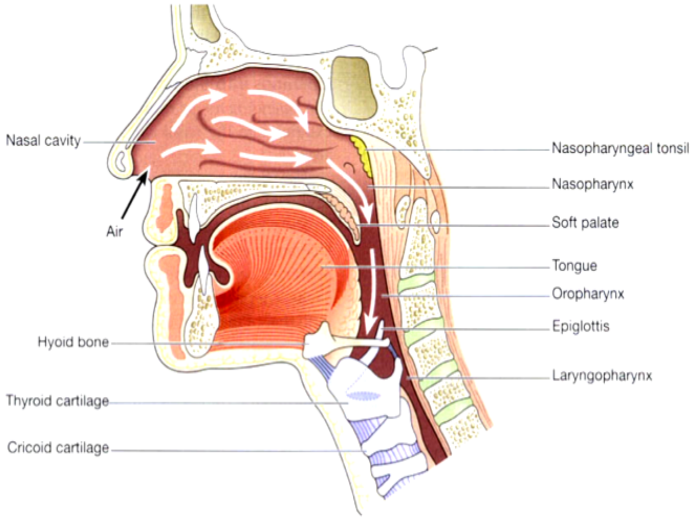
The nose is the first of the respiratory passages through which the inspired air passes. The function of the nose is to begin the process by which the air is *warmed, moistened and 'filtered'.*
The projecting *conchae* increase the surface area and cause turbulence, spreading inspired air over the whole nasal surface. The large surface area.

Filtering and Cleaning of Air.

This occurs as hairs at the anterior nares trap larger particles. Smaller particles such as dust and microbes settle and adhere to the mucus. Mucus protects the underlying epithelium from irritation and prevents drying. Synchronous beating of the cilia wafts the mucus towards the throat where it is swallowed or expectorated.

Humidification

This occurs as air travels over the moist mucosa and becomes saturated with water vapour. Irritation of the nasal mucosa results in *sneezing,* a reflex action that forcibly expels an irritant. maximises warming, humidification and filtering.



The Pharynx

The pharynx is a tube 12 to 14 cm long that extends from the base of the skull to the level of the 6th cervical vertebra. It lies behind the nose, mouth and larynx and is wider at its upper end.

For descriptive purposes the pharynx is divided into three parts: *nasopharynx, oropharynx* and *laryngopharynx.*

The Nasopharynx

The nasal part of the pharynx lies behind the nose above the level of the soft palate. On its lateral walls are the two openings of the ***eustacian tubes***, one leading to each middle ear. On the posterior wall there are the *pharyngeal tonsils* (adenoids).

The Oropharynx

The oral part of the pharynx lies behind the mouth, extending from below the level of the soft palate to the level of the upper part of the body of the 3rd cervical vertebra. The lateral walls of the pharynx blend with the soft palate to form two folds on each side.

During swallowing, the nasal and oral parts are separated by the soft palate and the *uvula.*

The Laryngopharynx

The laryngeal part of the pharynx extends from the oropharynx above and continues as the oesophagus below, i.e. from the level of the 3rd to the 6th cervical vertebrae.

Functions of the Pharynx

Passageway for Air and Food

The pharynx is an organ involved in both the respiratory and the digestive systems: air passes through the nasal and oral parts, and food through the oral and laryngeal parts.

Warming and Humidifying

By the same methods as in the nose, the air is further warmed and moistened as it passes through the pharynx.

Taste

There are olfactory nerve endings of the sense of taste in the epithelium of the oral and pharyngeal parts.

Hearing

The auditory tube, extending from the nasal part to each middle ear, allows air to enter the middle ear. Satisfactory hearing depends on the presence of air at atmospheric pressure on each side of the *tympanic membrane* (ear drum).

Protection

The lymphatic tissue of the pharyngeal and laryngeal tonsils produces antibodies in response to anti- gens, e.g. microbes. The tonsils are larger in children and tend to atrophy in adults.

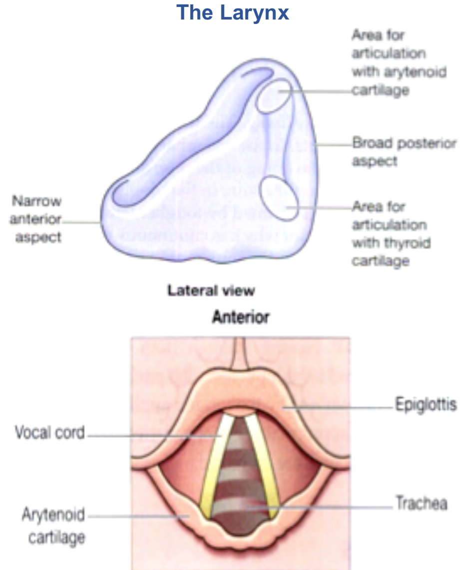
Speech

The pharynx functions in speech; by acting as a resonating chamber for the sound ascending from the larynx, it helps (together with the sinuses) to give the voice its individual characteristics.

The Larynx

The larynx is composed of several irregularly shaped cartilages attached to each other by ligaments and membranes.

The Larynx



The Main Cartilages Are:

- 1 Thyroid cartilage
- 1 Cricoid cartilage
- 1 Hyaline cartilage
- 2 Arytenoid cartilages
- 1 Epiglottis

The Thyroid Cartilage

This is the most prominent and consists of two flat pieces of hyaline cartilage, or *laminae,* fused anteriorly, forming the *laryngeal prominence* (Adam's apple). Immediately above the laryngeal prominence the laminae are separated, forming a V-shaped notch known as the *thyroid notch.*

The Cricoid Cartilage

This lies below the thyroid cartilage and is also composed of hyaline cartilage. It is shaped like a signet ring, completely encircling the larynx with the narrow part anteriorly and the broad part posteriorly.

The Epiglottis

This is a leaf-shaped fibroelastic cartilage attached to the inner surface of the anterior wall of the thyroid cartilage immediately below the thyroid notch. It rises obliquely upwards behind the tongue and the body of the hyoid bone. If the larynx is likened to a box then the epiglottis acts as the lid; it closes off the larynx during swallowing, protecting the lungs from accidental inhalation of foreign objects.

Interior of the Larynx

The *vocal cords* are two pale folds of mucous membrane with cord-like free edges, which extend from the inner wall of the thyroid prominence anteriorly to the arytenoid cartilages posteriorly.

When the muscles controlling the vocal cords are relaxed, the vocal cords open and the passageway for air coming up through the larynx is clear; the vocal cords are said to be *abducted*. The pitch of the sound produced by vibrating the vocal cords in this position is low. When the muscles controlling the vocal cords contract, the vocal cords are stretched out tightly across the larynx —they are said to be *adducted.* When the vocal cords are stretched to this extent, and are vibrated by air passing through from the lungs, the sound produced is high pitched. The pitch of the voice is therefore determined by the tension applied to the vocal cords by the appropriate sets of muscles.

Functions of the Larynx

Production of Sound

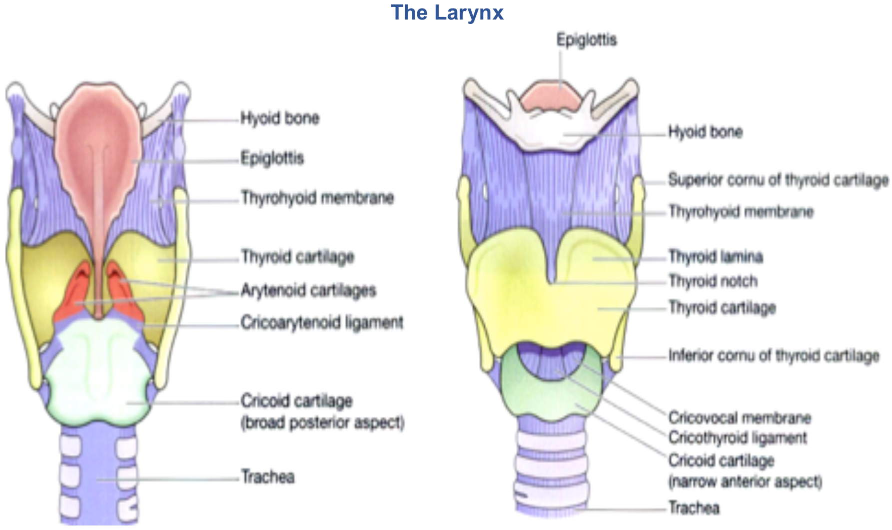
Sound Has The Properties Of *Pitch, Volume* And *Resonance:*

- Pitch of the voice depends upon the *length* and *tightness* of the cords. At puberty, the male vocal cords begin to grow longer, hence the lower pitch of the adult male voice.
- Volume of the voice depends upon *the force* with which the cords vibrate. The greater the force of expired air the more the cords vibrate and the louder the sound emitted.
- Resonance, or tone, is dependent upon the shape of the mouth, the position of the tongue and the lips, the facial muscles and the air in the para-nasal sinuses.

Speech

This occurs during expiration when the sounds produced by the vocal cords are manipulated by the tongue, cheeks and lips.

The Larynx



Protection Of The Lower Respiratory Tract

During swallowing (deglutition) the larynx moves upwards, occluding the opening into it from the pharynx and the hinged epiglottis closes over the larynx. This ensures that food passes into the oesophagus and not into the lower respiratory passages.

Passageway for Air

This is between the pharynx and trachea.

Humidifying, Filtering and Warming

These continue as inspired air travels through the larynx.

The Trachea

The trachea is composed of from 16 to 20 incomplete (C-shaped) rings of hyaline cartilages lying one above the other. The cartilages are incomplete posteriorly. Connective tissue and involuntary muscle join the cartilages and form the posterior wall where they are incomplete. The soft tissue posterior wall is in contact with the oesophagus.

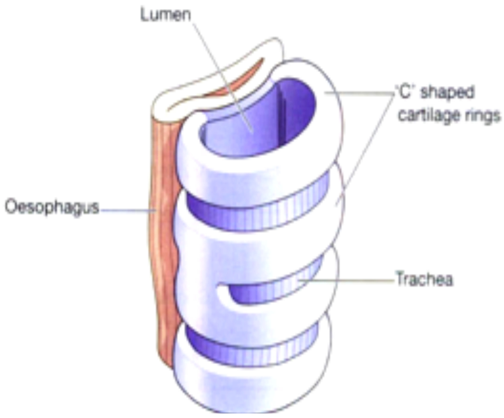
There are three layers of tissue, which 'clothe' the cartilages of the trachea.

The outer layer. This consists of fibrous and elastic tissue and encloses the cartilages.

The middle layer. This consists of cartilages and bands of smooth muscle that wind round the trachea in a helical arrangement. There is some areolar tissue, containing blood and lymph vessels and autonomic nerves.

The inner lining. This consists of ciliated columnar epithelium, containing mucus-secreting goblet cells.

The Trachea



Functions of the Trachea

Support and Patency

The arrangement of cartilage and elastic tissue prevents kinking and obstruction of the airway as the head and neck move. The absence of cartilage posteriorly allows the trachea to dilate and constrict in response to nerve stimulation, and for indentation as the oesophagus distends during swallowing.
The cartilages prevent collapse of the tube when the internal pressure is less than intrathoracic pressure,

i.e. at the end of forced expiration.

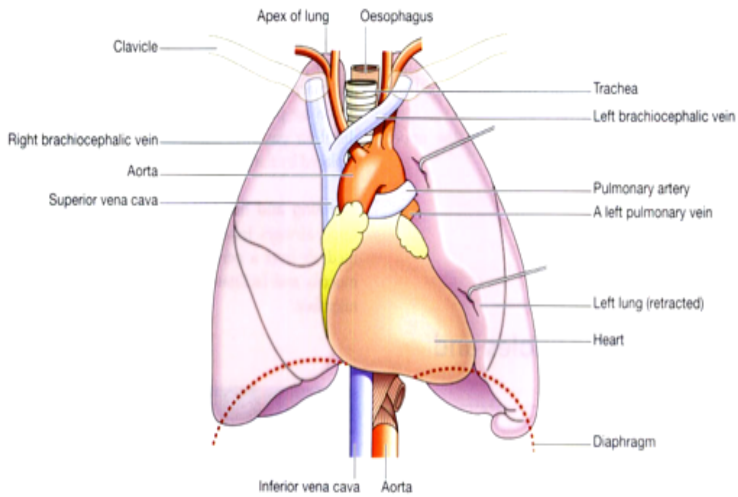
Mucociliary Escalator
This is the synchronous and regular beating of the cilia of the mucous membrane lining that wafts mucus with adherent particles upwards towards the larynx where it is swallowed or expectorated.

Cough Reflex
Nerve endings in the larynx, trachea and bronchi are sensitive to irritation that generates nerve impulses, which are conducted by the vagus nerves to the respiratory centre in the brain stem. The reflex motor response is deep inspiration followed by closure of the glottis. The abdominal and respiratory muscles then contract and suddenly the air is released under pressure expelling mucus and/or foreign material from the mouth.

The Lungs 2.2.2

Bronchus
The two primary bronchi are formed when the trachea divides, i.e. about the level of the 5th thoracic vertebra.
The right bronchus. This is wider, shorter and more vertical than the left bronchus and is therefore the more likely of the two to become obstructed by an inhaled foreign body. It is approximately 2.5cm long. After entering the right lung at the hilum it divides into three branches, one to each lobe. Each branch then subdivides into numerous smaller branches.
The left bronchus. This is about 5 cm long and is narrower than the right. After entering the lung at the hilum it divides into two branches, one to each lobe. Each branch then subdivides into progressively smaller tubes within the lung substance.

The Lungs



Bronchi and Bronchioles Structure
The bronchi are composed of the same tissues as the trachea. They are lined with ciliated columnar epithelium. The bronchi progressively subdivide into *bronchioles*, *terminal bronchioles, respiratory bronchioles, alveolar ducts* and finally, *alveoli.* Towards the distal end of the bronchi the cartilages become irregular in shape and are absent at bronchiolar level. In the absence of cartilage the smooth muscle in the walls of the bronchioles becomes thicker and is responsive to autonomic nerve stimulation and irritation. Ciliated columnar mucous membrane changes gradually to non-ciliated cuboidal shaped cells in the distal bronchioles.

Respiratory Bronchioles And Alveoli
Lobules are the blind ends of the respiratory tract distal to the terminal bronchioles, consisting of: *respiratory bronchioles, alveolar ducts* and *alveoli* (tiny air sacs). It is in these structures that the process of gas exchange occurs. The walls gradually become thinner until muscle and connective tissue fade out leaving a single layer of simple squamous epithelial cells in the alveolar ducts and alveoli. These distal respiratory passages are supported by a loose network of elastic connective tissue in which macrophages, fibroblasts, nerves and blood and lymph vessels are embedded. The alveoli are surrounded by a network of capillaries. The exchange of gases during respiration takes place across two membranes, the alveolar and capillary membranes.

Functions Of Respiratory Bronchioles And Alveoli

Defence Against Microbes
At this level, ciliated epithelium, goblet cells and mucus are no longer present.
Defence relies on protective cells present within the lung tissue. These include lymphocytes and plasma cells, which produce antibodies in the presence of antigens, and macrophages and polymorphonuclear lymphocytes, which are phagocytic. These cells are most active in the distal air passages where ciliated epithelium has been replaced by flattened cells.

Lungs

There are two lungs, one lying on each side of the midline in the thoracic cavity. They are cone-shaped and are described as having an *apex,* a *base, costal surface* and *medial surface.*

The Apex

This is rounded and rises into the root of the neck, about 25 mm (1 inch) above the level of the middle third of the clavicle. The structures associated with it are the first rib and the blood vessels and nerves in the root of the neck.

The Base

This is concave and semilunar in shape and is closely associated with the thoracic surface of the diaphragm.

The Costal Surface

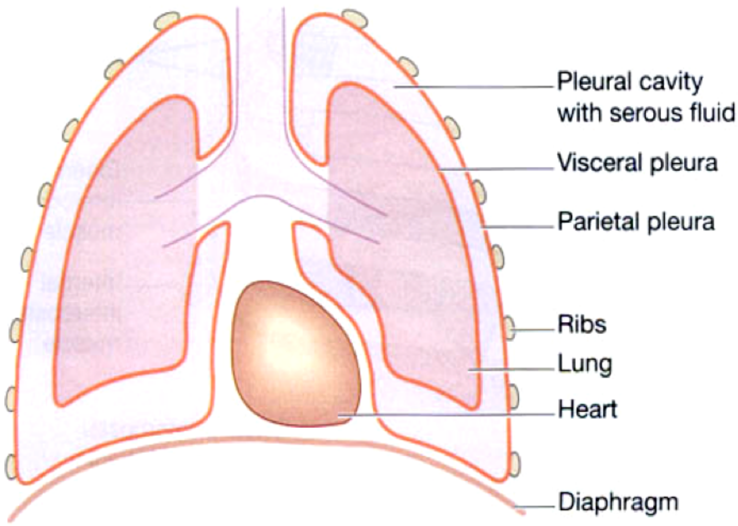
This surface is convex and is closely associated with the costal cartilages, the ribs and the intercostal muscles.

The Medial Surface

This surface is concave and has a roughly triangular-shaped area, called the *hilum,*at the level of the 5th, 6th and 7th thoracic vertebrae. Structures, which form the *root of the lung* enter and leave at the hilum. These include the primary bronchus, the pulmonary artery supplying the lung and the two pulmonary veins draining it, the bronchial artery and veins, and the lymphatic and nerve supply.
The area between the lungs is the *mediastinum.* The heart, great vessels, trachea, right and left bronchi, oesophagus, lymph nodes, lymph vessels and nerves occupy it.

Organisation of the Lungs

The *right lung* is divided into three distinct lobes: superior, middle and inferior.
The *left lung* is smaller as the heart is situated left of the midline. It is divided into only two lobes: superior and inferior.



Pleura and Pleural Cavity

The pleura consists of a closed sac of serous membrane (one for each lung) which contains a small amount of serous fluid. The lung is invaginated into this sac so that it forms two layers: one adheres to the lung and the other to the wall of the thoracic cavity.

The Visceral Pleura

This is adherent to the lung, covering each lobe and passing into the fissures which separate them.

The Parietal Pleura

This is adherent to the inside of the chest wall and the thoracic surface of the diaphragm. It remains detached from the adjacent structures in the mediastinum and is continuous with the visceral pleura round the edges of the hilum.

The Pleural Cavity

This is only a potential space. In health, the two layers of pleura are separated by only a thin film of serous fluid, which allows them to glide over each other, preventing friction between them during breathing.

The two layers of pleura, with serous fluid between them, behave in the same way as two pieces of glass separated by a thin film of water. They glide over each other easily but can be pulled apart only with difficulty, because of the surface tension between the membranes and the fluid. If either layer of pleura is punctured, the underlying lung collapses due to its inherent property of elastic recoil.

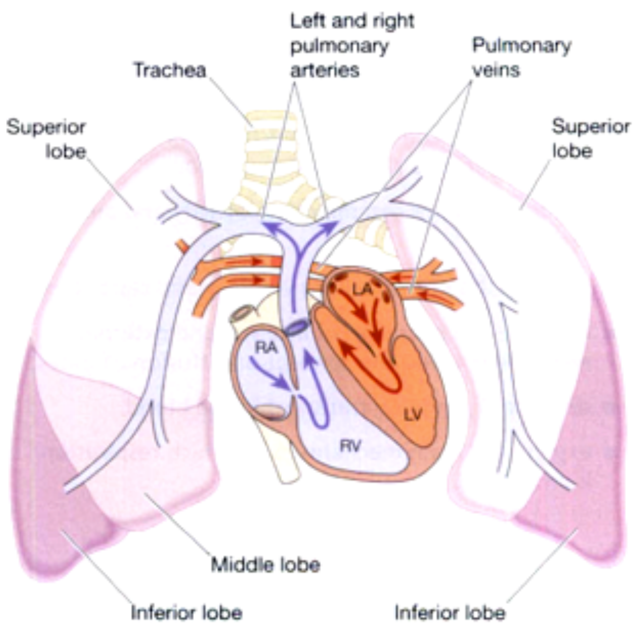
Interior of the Lungs

The lungs are composed of the bronchi and smaller air passages, alveoli, connective tissue, blood vessels, lymph vessels and nerves. The left lung is divided into two lobes and the right, into three. Each lobe is made up of a large number of lobules.

Pulmonary Blood Supply

The *pulmonary artery* divides into two, one branch conveying *deoxygenated blood* to each lung. Within the lungs each pulmonary artery divides into many branches, which eventually end in a dense capillary network around the walls of the alveoli. The walls of the alveoli and those of the capillaries each consist of only one layer of flattened epithelial cells. The exchange of gases between air in the alveoli and blood in the capillaries takes place across these two very fine membranes. The pulmonary capillaries join up, eventually becoming *two pulmonary veins* in each lung. They leave the lungs at the hilum and convey *oxygenated blood* to the left atrium of the heart. The innumerable blood capillaries and blood vessels in the lungs are supported by connective tissue.

The Lungs



Muscles of Respiration

The expansion of the chest during inspiration occurs as a result of muscular activity, partly voluntary and partly involuntary. The main muscles of respiration in normal quiet breathing are the *inter-costal muscles* and the *diaphragm.* During difficult or deep breathing they are assisted by the muscles of the neck, shoulders and abdomen.

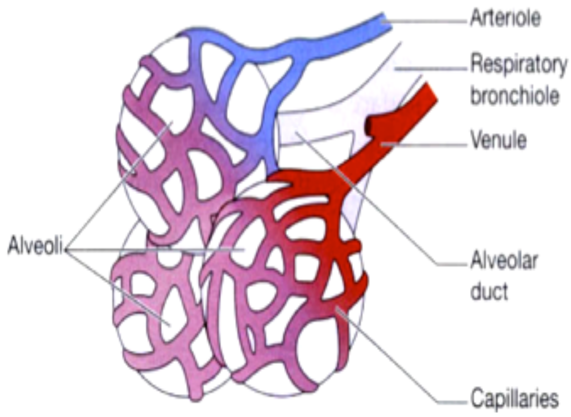
Intercostal Muscles

There are 11 pairs of intercostal muscles that occupy the spaces between the 12 pairs of ribs. They are arranged in two layers, the external and internal inter-costal muscles.

The External Inter-Costal Muscle Fibres.

These extend in a downwards and forwards direction from the lower border of the rib above to the upper border of the rib below.

The Alveolar

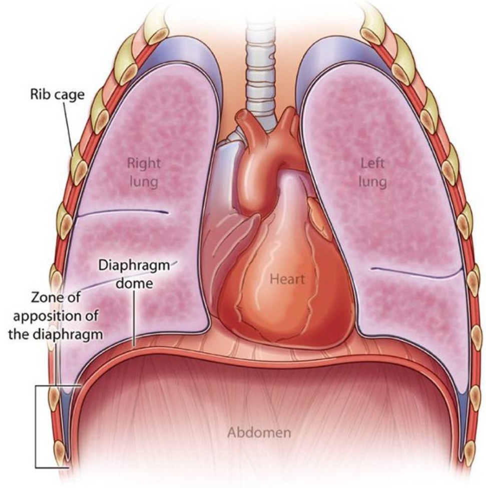


The Internal Inter-Costal Muscle Fibres

These extend in a downwards and backwards direction from the lower border of the rib above to the upper border of the rib below, crossing the external inter-costal muscle fibres at right angles.

The first rib is fixed. Therefore, when the inter-costal muscles contract they pull all the other ribs towards the first rib. Because of the shape of the ribs they move outwards when pulled upwards. In this way the thoracic cavity is enlarged anteroposteriorly and laterally. The inter-costal muscles are stimulated to contract by the *inter-costal nerves.*

The Diaphragm



Diaphragm

The diaphragm is a dome-shaped structure separating the thoracic and abdominal cavities. It forms the floor of the thoracic cavity and the roof of the abdominal cavity and consists of a central tendon from which muscle fibres radiate to be attached to the lower ribs and sternum and to the vertebral column by two crura. When the muscle of the diaphragm is relaxed, the central tendon is at the level of the 8th thoracic vertebra. When it contracts, its muscle fibres shorten and the central tendon is pulled downwards to the level of the 9th thoracic vertebra, enlarging the thoracic cavity in length. This decreases pressure in the thoracic cavity and increases it in the abdominal and pelvic cavities.

Respiration 2.2.3

Cycle of Respiration

This Occurs 12 To 16 Times Per Minute And Consists Of Three Phases:

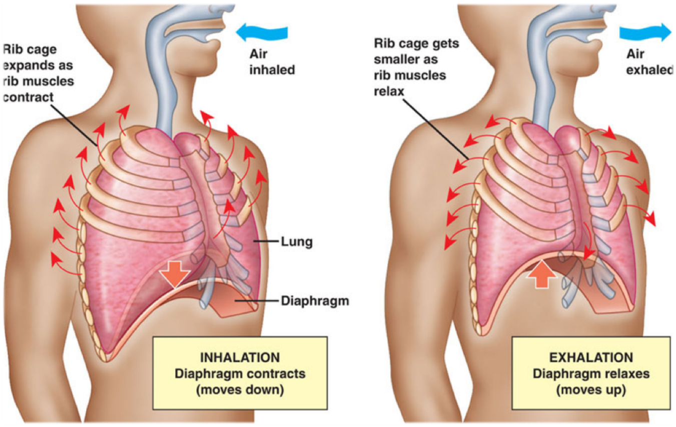
- Inspiration
- Expiration
- Pause.

Inspiration

When the capacity of the thoracic cavity is increased by simultaneous contraction of the inter-costal muscles and the diaphragm, the parietal pleura moves with the walls of the thorax and the diaphragm. This reduces the pressure in the pleural cavity to a level considerably lower than atmospheric pressure. The visceral pleura follows the parietal pleura pulling the lung with it. This stretches the lungs and the pressure within the alveoli and in the air passages falls, drawing air into the lungs in an attempt to equalise the atmospheric and alveolar air pressures.

The process of inspiration is *active,* as it requires expenditure of energy for muscle contraction. The negative pressure created in the thoracic cavity aids venous return to the heart and is known as the *respiratory pump.*

Respiration



Expiration

Relaxation of the inter-costal muscles and the diaphragm results in downward and inward movement of the rib cage and elastic recoil of the lungs. As this occurs, pressure inside the lungs exceeds that in the atmosphere and therefore air is expelled from the respiratory tract. The lungs still contain some air and are prevented from complete collapse by the intact pleura. This process is *passive* as it does not require the expenditure of energy. After expiration, there is a *pause* before the next cycle begins.

Physiological Variables Affecting Respiration

Elasticity

Elasticity is the term used to describe the ability of the lung to return to its normal shape after each breath. Loss of elasticity of the connective tissue in the lungs necessitates forced expiration and increased effort on inspiration.

Compliance

This is a measure of the distensibility of the lungs, i.e. the effort required to inflate the alveoli. When compliance is low the effort needed to inflate the lungs is greater than normal, e.g. in some diseases where elasticity is reduced or when insufficient surfactant is present. It should be noted that compliance and elasticity are opposing forces.

Airflow Resistance

When this is increased, e.g. in broncho-constriction, more respiratory effort is required to inflate the lungs. Lung volumes and capacities In normal quiet breathing there are about 15 complete respiratory cycles per minute. The lungs and the air passages are never empty and, as the exchange of gases takes place only across the walls of the alveolar ducts and alveoli, the remaining capacity of the respiratory passages is called the *anatomical dead space* (about 150 ml).

Tidal Volume (TV)

This is the amount of air, which passes into and out of the lungs during each cycle of quiet breathing (about 500ml).

Inspiratory Reserve Volume (IRV)

This is the extra volume of air that can be inhaled into the lungs during maximal inspiration.

Inspiratory Capacity (IC)

This is the amount of air that can be inspired with maximum effort. It consists of the tidal volume (500ml) plus the inspiratory reserve volume.

Functional Residual Capacity (FRC)
This is the amount of air remaining in the air passages and alveoli at the end of quiet expiration.

Expiratory Reserve Volume (ERV)
This is the largest volume of air, which can be expelled from the lungs during maximal expiration.

Residual Volume (RV)
This cannot be directly measured but is the volume of air remaining in the lungs after forced expiration.

Vital Capacity (VC)
This is the maximum volume of air, which can be moved into and out of the lungs:

VC = Tidal volume + IRV + ERV

Alveolar Ventilation
This is the volume of air that moves into and out of the alveoli per minute. It is equal to the tidal volume minus the anatomical dead space, multiplied by the respiratory rate:

Alveolar Ventilation =
= (TV - anatomical dead space) x respiratory rate
= (500-150) ml x 15 per minute
= 5.25 litres per minute

Composition of Air
Atmospheric pressure at sea level is 101.3 kilopascals (kPa) or 760mmHg. With the increase in height above sea level, atmospheric pressure is progressively reduced and at 5500 m, about two-thirds the height of Mount Everest (8850 m), it is about half that at sea level. Under water, pressure increases by approximately 1 atmosphere per 10 m below sea level.

Air is a mixture of gases: nitrogen, oxygen, carbon dioxide, water vapour and small quantities of inert gases. Each gas in the mixture exerts a part of the total pressure proportional to its concentration, i.e . the *partial pressure*. This is denoted as, e.g. PO_2, PCO_2.

The Composition Of Inspired And Expired Air		
	Inspired Air %	Expired Air %
Oxygen	21	16
Carbon Dioxide	0.04	4
Nitrogen And Rare Gases	78	78
Water Vapour	Variable	Saturated

Alveolar Air
The composition of alveolar air remains fairly constant and is different from atmospheric air. It is saturated with water vapour and contains more carbon dioxide, and less oxygen. Saturation with water vapour provides 6.3kPa (47 mmHg) thus reducing the partial pressure of all the other gases present. Gaseous exchange between the alveoli and the bloodstream *(external respiration)* is a continuous process, as the alveoli are never empty, so it is independent of the respiratory cycle. During each inspiration only some of the alveolar gases are exchanged.

Expired Air
This is a mixture of alveolar air and atmospheric air in the dead space.

Diffusion of Gases
Exchange of gases occurs when a difference in partial pressure exists across semi-permeable membranes. Gases move by diffusion from the higher concentration to the lower until equilibrium is established. Atmospheric nitrogen is not used by the body so its partial pressure remains unchanged and is the same in inspired and expired air, alveolar air and in the blood.

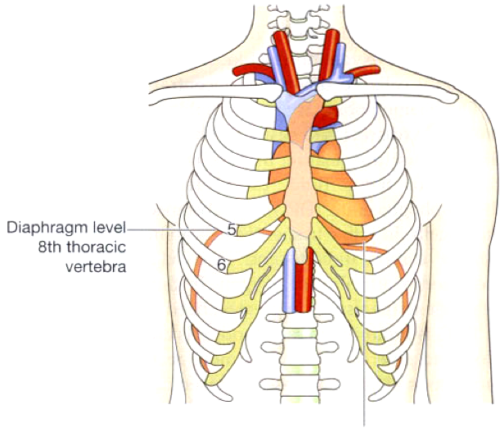
External Respiration
This is exchange of gases by diffusion between the alveoli and the blood. Each alveolar wall is one cell thick and is surrounded by a network of tiny capillaries (the walls of which are also only one cell thick). The total area for gas exchange in the lungs is 70 to 80 square metres. Venous blood arriving at the lungs has travelled from all the active tissues of the body, and contains high levels of CO_2 and low levels of O_2.

Carbon dioxide diffuses from venous blood down its concentration gradient into the alveoli until equilibrium with alveolar air is reached. By the same process, oxygen diffuses from the alveoli into the blood. The slow flow of blood through the capillaries increases the time available for diffusion to occur. When blood leaves the alveolar capillaries, the oxygen and carbon dioxide concentrations are in equilibrium with those of alveolar air.

CARDIO-VASCULAR SYSTEM 2.3

The Heart 2.3.1

The heart is a roughly cone-shaped hollow muscular organ. It is about 10 cm long and is about the size of the owner's fist. It weighs about 225g in women 310g and men in.
The heart lies in the thoracic cavity in the mediastinum between the lungs. It lies obliquely, a little more to the left than the right, and presents a *base* above, and an *apex* below. The apex is about 9 cm to the left of the midline at the level of the 5th inter-costal space, i.e. a little below the nipple and slightly nearer the midline. The base extends to the level of the 2nd rib.



Structure

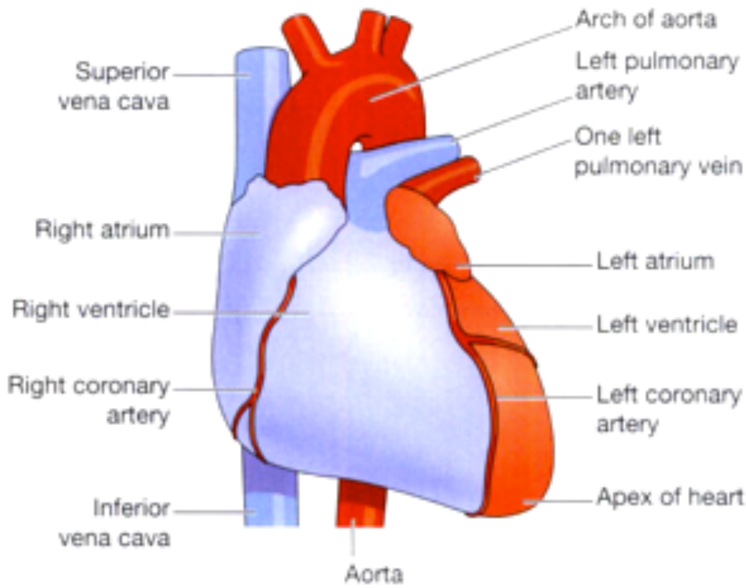
The heart is composed of three layers of tissue: pericardium, myocardium and endocardium.

Pericardium

The pericardium is made up of two sacs. The outer sac consists of fibrous tissue and the inner of a continuous double layer of serous membrane.
The outer fibrous sac is continuous with the tunica adventitia of the great blood vessels above and is adherent to the diaphragm below. Its inelastic, fibrous nature prevents overdistension of the heart.

Myocardium

The Heart



The myocardium is composed of specialised cardiac muscle found only in the heart.

It is not under voluntary control but, like skeletal muscle, cross-stripes are seen on microscopic examination. Each fibre (cell) has a nucleus and one or more branches. The ends of the cells and their branches are in very close contact with the ends and branches of adjacent cells.

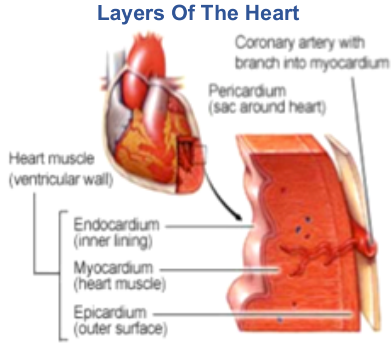
This arrangement gives cardiac muscle the appearance of being a sheet of muscle rather than a very large number of individual cells.

Because of the end-to-end continuity of the fibres, each one does not need to have a separate nerve supply. When an impulse is initiated it spreads from cell to cell via the branches and intercalated discs over the whole 'sheet' of muscle, causing contraction. The 'sheet' arrangement of the myocardium enables the atria and ventricles to contract in a coordinated and efficient manner.

The myocardium is thickest at the apex and thins out towards the base. This reflects the amount of work each chamber contributes to the pumping of blood. It is thickest in the left ventricle.

A ring of fibrous tissue that does not conduct electrical impulses separates the atria and the ventricles. Consequently, when a wave of electrical activity passes over the atrial muscle, it can only spread to the ventricles through the conducting system, which bridges the fibrous ring from atria to ventricles.

Layers Of The Heart



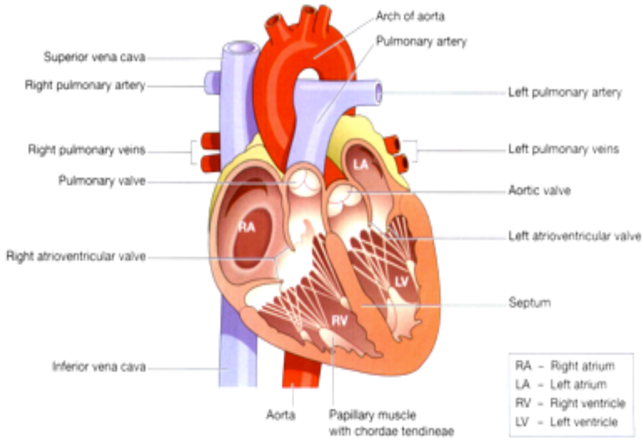
Endocardium

This forms the lining of the myocardium and the heart valves. It is a thin, smooth, glistening membrane, which permits smooth flow of blood inside the heart. It consists of flattened epithelial cells, continuous with the endothelium that lines the blood vessels.

Interior of the Heart

The heart is divided into a right and left side by the *septum*, a partition consisting of myocardium covered by endocardium.

The Heart (Internal)



After birth, blood cannot cross the septum from one side to the other. An atrioventricular valve into an upper chamber, the atrium, and a lower chamber, the ventricle divides each side.

Double folds of endocardium strengthened by a little fibrous tissue form the atrioventricular valves. The *right atrioventricular valve* (tricuspid valve) has three flaps or *cusps* and the *left atrioventricular valve* (mitral valve) has two cusps.

The valves between the atria and ventricles open and close passively, according to changes in pressure in the chambers. They open when the pressure in the atria is greater than that in the ventricles.

During *ventricular systole* (contraction) the pressure in the ventricles rises above that in the atria and the valves snap shut preventing backward flow of blood.

The valves are prevented from opening upwards into the atria by tendinous cords, called *chordae tendineae.*

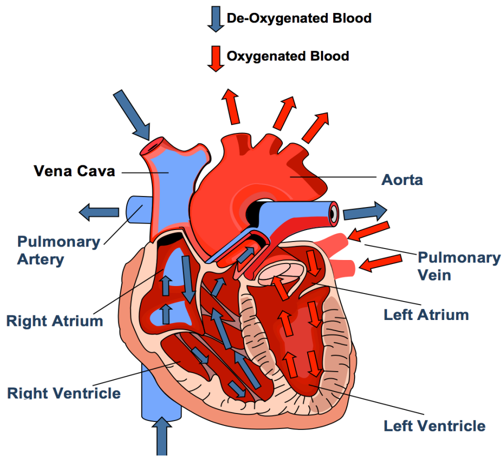
Flow Of Blood Through The Heart

The two largest veins of the body, the *superior* and *inferior venae cavae,* empty their contents into the right atrium.

This blood passes via the right atrio-ventricular valve into the right ventricle, and from there it is pumped into the *pulmonary artery* or *trunk* (the only artery in the body which carries deoxygenated blood).

The pulmonary valve, formed by three semilunar cusps, guards the opening of the pulmonary artery.

The Heart (Blood-Flow)

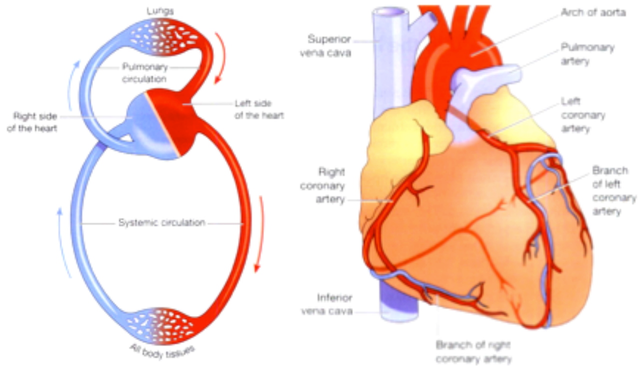


This valve prevents the back flow of blood into the right ventricle when the ventricular muscle relaxes. After leaving the heart the pulmonary artery divides into *left* and *right pulmonary arteries,* which carry the venous blood to the lungs where exchange of gases takes place: carbon dioxide is excreted and oxygen is absorbed.

Two *pulmonary veins* from each lung carry *oxygenated blood* back to the *left atrium.* Blood then passes through the left atrio-ventricular valve into the left ventricle, and from there it is pumped into the aorta, the first artery of the general circulation. The aortic valve, formed by three semilunar cusps, guards the opening of the aorta.

From this sequence of events it can be seen that the blood passes from the right to the left side of the heart via the lungs, or pulmonary circulation. However, it should be noted that both atria contract at the same time and this is followed by the simultaneous contraction of both ventricles.

The Heart (Blood-Flow)



The muscle layer of the walls of the atria is very thin in comparison with that of the ventricles. This is consistent with the amount of work it does. The atria, usually assisted by gravity, only propel the blood through the atrio-ventricular valves into the ventricles, whereas the ventricles actively pump the blood to the lungs and round the whole body. The muscle layer is thickest in the wall of the left ventricle.

The pulmonary trunk leaves the heart from the upper part of the right ventricle, and the aorta leaves from the upper part of the left ventricle.

Blood Supply To The Heart

Arterial supply

The heart is supplied with arterial blood by the *right and left coronary arteries,* which branch from the aorta immediately distal to the aortic valve.

The coronary arteries receive about 5% of the blood pumped from the heart. The coronary arteries traverse the heart, eventually forming a vast network of capillaries.

Venous Drainage

Most of the venous blood is collected into several small veins that join to form the *coronary sinus,* which opens into the right atrium.
The remainder passes directly into the heart chambers through little venous channels.

Electrical Conducting System Of The Heart

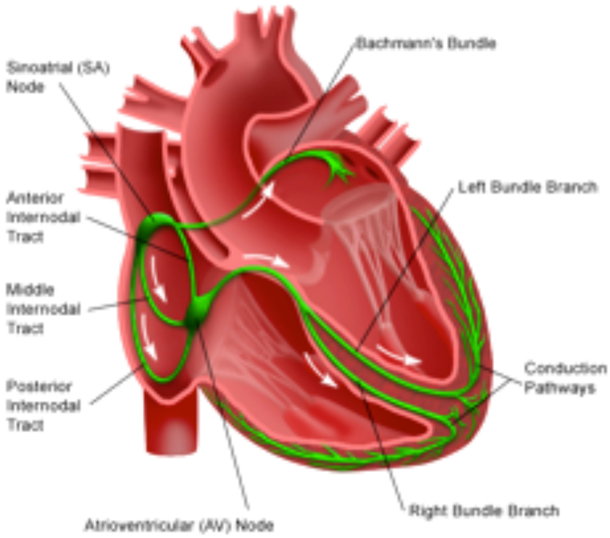
The heart has an intrinsic system whereby the cardiac muscle is automatically stimulated to contract without the need for a nerve supply from the brain. However, the intrinsic system can be stimulated or depressed by nerve impulses initiated in the brain and by circulating chemicals including hormones.

There are small groups of specialised neuromuscular cells in the myocardium, which initiate and conduct impulses causing coordinated and synchronised contraction of the heart muscle.

Sinoatrial Node (SA node)

This small mass of specialised cells is in the wall of the right atrium near the opening of the superior vena cava. The SA node is the *'pace-maker'* of the heart because it normally initiates impulses more rapidly than other groups of neuromuscular cells.

The Heart (Electrical Pathway)



Atrioventricular Node (AV node)

This small mass of neuromuscular tissue is situated in the wall of the atrial septum near the atrio-ventricular valves. Normally the AV node is stimulated by impulses that sweep over the atrial myocardium.

Atrioventricular Bundle (AV bundle or bundle of His)

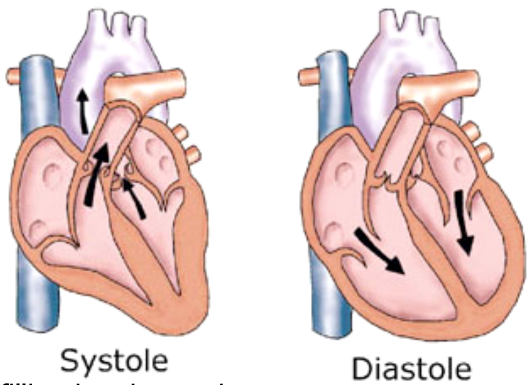
This is a mass of specialised fibres that originate from the AV node. The A V bundle crosses the fibrous ring that separates atria and ventricles then, at the upper end of the ventricular septum, it divides into *right and left bundle branches.* Within the ventricular myocardium the branches break up into fine fibres, called the *Purkinje fibres.*

The AV bundle, bundle branches and Purkinje fibres convey electrical impulses from the AV node to the apex of the myocardium where the wave of ventricular contraction begins, then sweeps upwards and outwards, pumping blood into the pulmonary artery and the aorta.

The Cardiac Cycle

The function of the heart is to maintain a constant circulation of blood throughout the body. The heart acts as a pump and its action consists of a series of events known as the *cardiac cycle*.

During each heartbeat, or cardiac cycle, the heart contracts and then relaxes. The period of contraction is called *systole* and that of relaxation, *diastole.*



Stages of the Cardiac Cycle

The normal number of cardiac cycles per minute ranges from 60 to 80. Taking 74 as an example each cycle lasts about *0.8 of a second* and consists of:

- Atrial systole (contraction of the atria).
- Ventricular systole (contraction of the ventricles).
- Cardiac diastole (relaxation of the atria and ventricles).

It does not matter at which stage of the cardiac cycle a description starts. For convenience the period when the atria are filling has been chosen.

The superior vena cava and the inferior vena cava transport deoxygenated blood into the right atrium *at the same time* as the four pulmonary veins convey oxygenated blood into the left atrium.

The atrio-ventricular valves are open and blood flows through to the ventricles. The SA node triggers a wave of contraction that spreads over the myocardium of both atria, emptying the atria and completing ventricular filling (atrial systole 0.1s). When the wave of contraction reaches the AV node it is stimulated to emit an impulse, which quickly spreads to the ventricular muscle via the AV bundle, the bundle branches and Purkinje fibres. This results in a wave of contraction, which sweeps upwards from the apex of the heart and across the walls of both ventricles pumping the blood into the pulmonary artery and the aorta (ventricular systole 0.3s). The high pressure generated during ventricular contraction is greater than that in the aorta and forces the atrioventricularvalves to close, preventing backflow of blood into the atria.

After contraction of the ventricles there is *complete cardiac diastole,* a period of *0.4 seconds,* when atria and ventricles are relaxed. During this time the myocardium recovers until it is able to contract again, and the atria refill in preparation for the next cycle.

The valves of the heart and of the great vessels open and close according to the pressure within the chambers of the heart. The AV valves are open while the ventricular muscle is relaxed during atrial filling and systole. When the ventricles contract there is a gradual increase in the pressure in these chambers, and when it rises above atrial pressure the atrio-ventricular valves close.

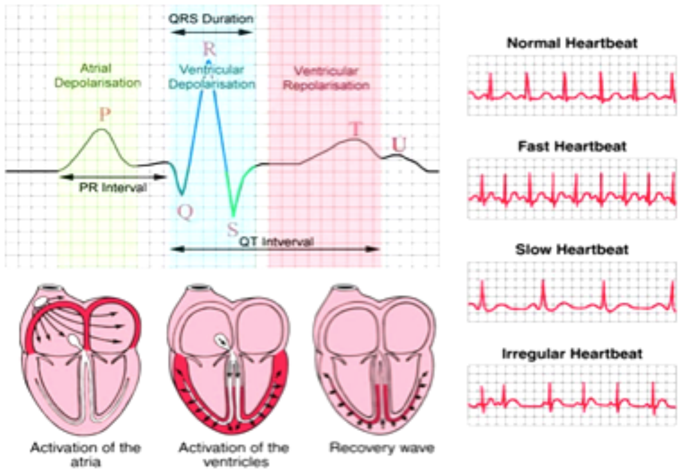
When the ventricular pressure rises above that in the pulmonary artery and in the aorta, the pulmonary and aortic valves open and blood flows into these vessels. When the ventricles relax and the pressure within them falls, the reverse process occurs. First the pulmonary and aortic valves close, then the atrio-ventricular valves open and the cycle begins again. This sequence of opening and closing valves ensures that the blood flows in only one direction. This figure also shows how the walls of the aorta and other elastic arteries stretch and recoil in response to blood pumped into them.

Electrical Changes in the Heart

As the body fluids and tissues are good conductors of electricity, the electrical activity within the heart can be detected by attaching electrodes to the surface of the body. The apparatus used is an *electrocardiograph* and the tracing is an *electrocardiogram* (ECG).

The normal ECG tracing shows five waves which, by convention, have been named P,Q, R, S and T. The P wave arises when the impulse from the SA node sweeps over the atria. The QRS complex represents the very rapid spread of the impulse from the A V node through the A V bundle and the Purkinje fibres and the electrical activity of the ventricular muscle. The T wave represents the relaxation of the ventricular muscle.

The Heart (Electrical Pathway)



The ECG described above originates from the SA node and is known as *sinus rhythm.* The rate of sinus rhythm is 60 to 100 beats per minute. A faster heart rate is called *tachycardia* and a slower heart rate, *bradycardia.*

By examining the pattern of waves and the time interval between cycles and parts of cycles, information about the state of the myocardium and the cardiac conduction system is obtained.

Cardiac Output

The cardiac output is the amount of blood ejected from the heart. The amount expelled by each contraction of the ventricles is the *stroke volume.* Cardiac output is expressed in litres per minute (1/min) and is calculated by multiplying the stroke volume by the heart rate (measured in beats per minute):

Cardiac output = Stroke volume x Heart rate

In a healthy adult at rest, the stroke volume is approximately 70ml and if the heart rate is 72 per minute, the cardiac output is 5L/minute. This can be greatly increased to meet the demands of exercise to around 25L/minute, and in athletes up to 35L/minute. This increase during exercise is called the *cardiac reserve.*

Stroke Volume

The volume of blood in the ventricles determines the stroke volume immediately before they contract, i.e. the ventricular end-diastolic volume (VEDV), sometimes called *preload.* This depends on the amount of blood returning to the heart through the superior and inferior venae cavae (the *venous return).*

Increased VEDV leads to stronger myocardial contraction, and more blood is expelled. In turn the stroke volume and cardiac output rise. This capacity to increase the stroke volume with increasing VEDV is finite, and when the limit is reached.

Other Factors That Increase Myocardial Contraction Include:

- Increased stimulation of the sympathetic nerves innervating the heart
- Hormones, e.g. adrenaline, noradrenaline, thyroxine.

Arterial Blood Pressure

This affects the stroke volume as it creates resistance to blood being pumped from the ventricles into the great arteries. This resistance (sometimes called *afterload)* is determined by the distensibility, or *elasticity,* of the large arteries and the *peripheral resistance* of arterioles.

Blood Volume

This is normally kept constant by the kidneys and if deficient the stroke volume, cardiac output and venous return decrease.

Venous Return

Venous return is the major determinant of cardiac output and, normally, the heart pumps out all blood returned to it. The force of contraction of the left ventricle ejecting blood into the aorta is not sufficient to return the blood through the veins and back to the heart. Other factors are involved.

The position of the body. Gravity assists the venous return from the head and neck when standing or sitting and offers less resistance to venous return from the lower parts of the body when an individual is lying flat.

Muscular Contraction

Valves, especially when standing, prevent this causes back flow of blood in veins of the limbs. The contraction of skeletal muscles surrounding the deep veins puts pressure on them, pushing blood towards the heart. In the lower limbs, this is called the *skeletal muscle pump.*

The Respiratory Pump

During inspiration the expansion of the chest creates a negative pressure within the thorax, assisting flow of blood towards the heart. In addition, when the diaphragm descends during inspiration, the increased intra-abdominal pressure pushes blood towards the heart.

Blood Pressure

Blood pressure is the force or pressure, which the blood exerts on the walls of the blood vessels.
The systemic arterial blood pressure, usually called simply arterial blood pressure, is the result of the discharge of blood from the left ventricle into the already full aorta.

When the left ventricle contracts and pushes blood into the aorta the pressure produced within the arterial system is called the *systolic blood pressure.* In adults it is about 120 mmHg (millimeters of mercury).

When *complete cardiac diastole* occurs and the heart is resting following the ejection of blood, the pressure within the arteries is called *diastolic blood pressure.* In an adult this is about 80mmHg. The difference between systolic and diastolic blood pressures is the *pulse pressure.*

These figures vary according to the time of day, the posture, gender and age of the individual. During bed rest at night the blood pressure tends to be lower. It increases with age and is usually higher in women than in men.
Arterial blood pressure is measured with a *sphyg-momanometer.*

It Is Usually Expressed In The Following Manner:

$$\textbf{BP} = {}^{120}/_{70}\ \textbf{mmHg}$$

Pulse

The pulse is a wave of distension and elongation felt in an artery wall due to the contraction of the left ventricle forcing about 60 to 80 millilitres of blood through the already full aorta and into the arterial system.

When the aorta is distended, a wave passes along the walls of the arteries and can be felt at any point where a superficial artery can be pressed gently against a bone. The number of pulse beats per minute normally represents the heart rate and varies considerably in different people and in the same person at different times. An average of 60 to 80 is common at rest.

Information That May Be Obtained From The Pulse Includes:

- The rate at which the heart is beating.
- The regularity with which the heartbeats occur (i.e. the length of time between beats should be the same).
- The volume or strength of the beat (it should be possible to compress the artery with moderate pressure, stopping the flow of blood; the compressibility of the blood vessel gives some indication of the blood pressure and the state of the blood vessel wall).

- The tension (the artery wall should feel soft and pliant under the fingers).

Circulation Of Blood 2.3.2

Blood Vessels

The right side of the heart pumps blood to the lungs (the pulmonary circulation) where gas exchange occurs; i.e. CO_2 leaves the blood and enters the lungs, and O_2 leaves the lungs and enters the blood. The left side of the heart pumps blood into the systemic circulation, which supplies the rest of the body.

Here, tissue wastes are passed into the blood for excretion, and body cells extract nutrients and O_2.

Arteries and Arterioles

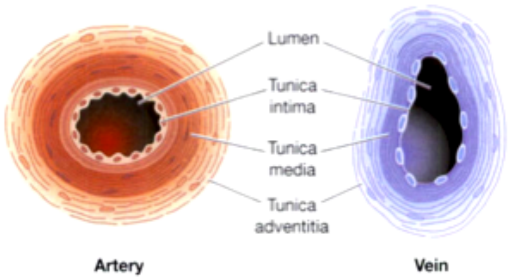
These are the blood vessels that transport blood away from the heart.

They Vary Considerably In Size And Their Walls Consist Of Three Layers Of Tissue:

- *Tunica adventitia* or outer layer of fibrous tissue.
- *Tunica media* or middle layer of smooth muscle and elastic tissue.
- *Tunica intima* or inner lining of squamous epithelium called *endothelium.*

The amount of muscular and elastic tissue varies in the arteries depending upon their size. In the large arteries, sometimes called elastic arteries, the tunica media consists of more elastic tissue and less smooth muscle. These proportions gradually change as the arteries branch many times and become smaller until in the *arterioles* (the smallest arteries) the tunica media consists almost entirely of smooth muscle. Arteries have thicker walls than veins and this enables them to withstand the high pressure of arterial blood.

Blood Vessels

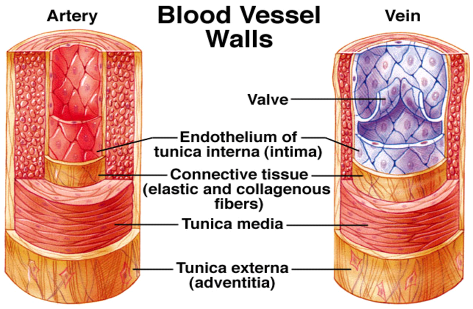


Veins and Venules

The veins are the blood vessels that return blood at low pressure to the heart. The walls of the veins are thinner than those of arteries but have the same three layers of tissue. They are thinner because there is less muscle and elastic tissue in the tunica media. When cut, the veins collapse while the thicker-walled arteries remain open.

When an artery is cut blood spurts at high pressure while a slower, steady flow of blood escapes from a vein.

Some veins possess *valves,* which prevent backflow of blood, ensuring that it flows towards the heart. Valves are abundant in the veins of the limbs, especially the lower limbs where blood must travel a considerable distance against gravity when the individual is standing.



Valves are absent in very small and very large veins in the thorax and abdomen.

They are formed by a fold of tunica intima strengthened by connective tissue. The cusps are *semilunar* in shape with the concavity towards the heart.

The smallest veins are called *venules.*

Systemic or General Circulation

The blood pumped out from the left ventricle is carried by the *branches of the aorta* around the body and is returned to the right atrium of the heart by the *superior* and *inferior venae cavae.*

Pulmonary Circulation

This consists of the circulation of blood from the right ventricle of the heart to the lungs and back to the left atrium. In the lungs, CO_2 is excreted and O_2 absorbed.

The pulmonary artery or trunk, carrying *deoxygenated blood,* leaves the upper part of the right ventricle of the heart. It passes upwards and divides into left and right pulmonary arteries at the level of the 5th thoracic vertebra.

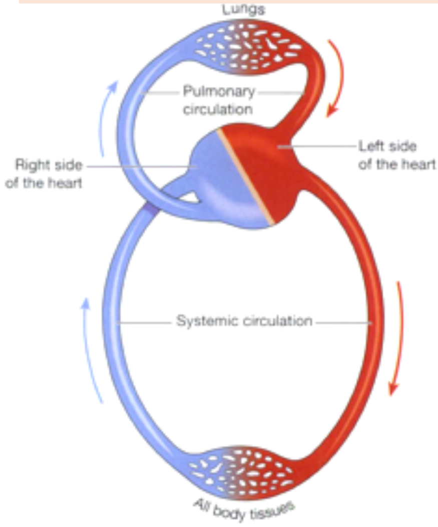
The left pulmonary artery runs to the root of the left lung where it divides into two branches, one passing into each lobe.

The right pulmonary artery passes to the root of the right lung and divides into two branches. The larger branch carries blood to the middle and lower lobes, and the smaller branch to the upper lobe.

Within the lung these arteries divide and subdivide into smaller arteries, arterioles and capillaries. The inter- change of gases takes place between capillary blood and air in the alveoli of the lungs. In each lung the capillaries containing oxygenated blood join up and eventually form two veins.

Two pulmonary veins leave each lung, returning oxygenated blood to the left atrium of the heart. During atrial systole this blood passes into the left ventricle, and during ventricular systole it is forced into the aorta, the first artery of the general circulation.

Anatomy & Physiology 2.3.2



Venous Circulation Of Blood To The Upper Limb

The veins of the upper limb are divided into two groups: deep and superficial veins.

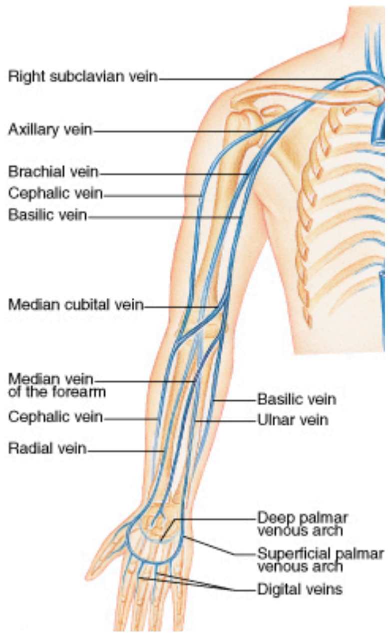
The *Deep Veins* Follow The Course Of The Arteries And Have The Same Names:

- Palmar metacarpal veins
- Deep palmar venous arch
- Ulnar and radial veins
- Brachial vein
- Axillary vein
- Subclavian vein.

The *Superficial Veins* Begin In The Hand And Consist Of The Following:

- Cephalic vein
- Basilic vein
- Median vein
- Median cubital vein.

Veins Of The Arm



The *cephalic vein* begins at the back of the hand where it collects blood from a complex of superficial veins, many of which can be easily seen. It then winds round the radial side to the anterior aspect of the forearm. In front of the elbow it gives off a large branch, the *median cubital vein,* which slants upwards and medially to join the *basilic vein.* After crossing the elbow joint the cephalic vein passes up the lateral aspect of the arm and in front of the shoulder joint to end in the axillary vein. Through its length it receives blood from the superficial tissues on the lateral aspects of the hand, forearm and arm.

The *basilic vein* begins at the back of the hand on the ulnar aspect. It ascends on the medial side of the forearm and upper arm then joins the axillary vein. It receives blood from the medial aspect of the hand, forearm and arm. There are many small veins, which link the cephalic and basilic veins.

The *median vein* is a small vein that is not always present. It begins at the palmar surface of the hand, ascends on the front of the forearm and ends in the basilic vein or the median cubital vein.

The *brachiocephalic vein* is formed when the subclavian and internal jugular veins unite. There is one on each side.

The *superior vena cava* is formed when the two brachio-cephalic veins unite. It drains all the venous blood from the head, neck and upper limbs and terminates in the right atrium. It is about 7 cm long and passes downwards along the right border of the sternum.

Blood Composition 2.3.3

The total body water in adults of average build is about 60% of body weight. This proportion is higher in young people and in adults below average weight. It is lower in the elderly and in obesity in all age groups. About 22% of body weight is extracellular water and about 38% is intracellular water.

Extracellular Fluid

The extracellular fluid (ECF) consists of blood, plasma, lymph, cerebrospinal fluid and fluid in the interstitial spaces of the body. Interstitial or intercellular fluid (tissue fluid) bathes all the cells of the body except the outer layers of skin. It is the medium through which substances pass from blood to the body cells, and from the cells to blood. Every body cell in contact with the ECF is directly dependent upon the composition of that fluid for its wellbeing.

Intracellular Fluid

The composition of intracellular fluid (ICF) is largely controlled by the Anatomy & Physiology 2.3.3 ive uptake and discharge mechanisms present in the cell membrane. The composition of ICF can therefore be very different from ECF. Thus, sodium levels are nearly ten times higher in the ECF than in the ICF. Conversely, many substances are found inside the cell in significantly higher amounts than outside, e.g. ATP, protein and potassium.

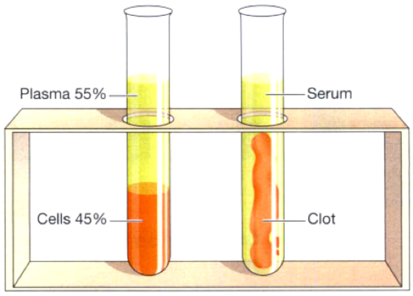
Blood is a connective tissue. It provides one of the means of communication between the cells of different parts of the body and the external environment.

Fluid Distribution

Total Body Water 40 Litres	**Extracellular Fluid (ECF)** 12 Litres (Plasma 2.5 Litres / Interstitial Fluid 9.5 Litres)
	Intracellular Fluid 28 Litres

Blood Transports:

- Oxygen from the lungs to the tissues and carbon dioxide from the tissues to the lungs for excretion
- Nutrients from the gut to the tissues and cell wastes to the excretory organs, principally the kidneys.
- Hormones secreted by endocrine glands to their target glands and tissues heat produced in active tissues to other less active tissues.
- Protective substances, e.g. antibodies, to areas of infection.
- Clotting factors that coagulate blood, minimising its loss from ruptured blood vessels.



Blood makes up about 7% of body weight (about 5.6 litres in a 70 kg man). This proportion is less in women and considerably greater in children, gradually decreasing until the adult level is reached.

Blood in the blood vessels is always in motion. The continual flow maintains a fairly constant environment for the body cells.

Blood volume and the concentration of its many constituents are kept within narrow limits by homeostatic mechanisms.

Blood Composition

Blood is composed of a straw-coloured transparent fluid, *plasma,* in which different types of cells are suspended. Plasma constitutes about 55% and cells about 45% of blood volume.

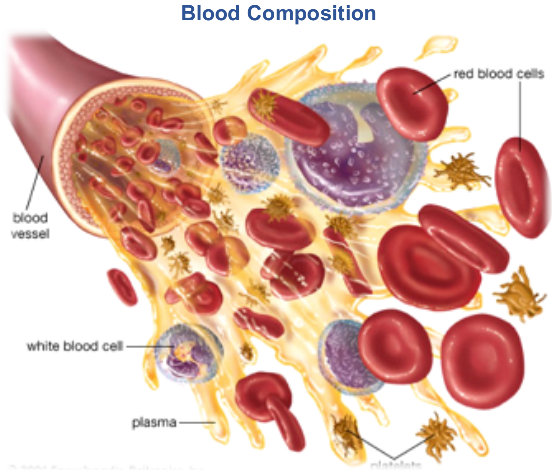
Plasma

The constituents of plasma are water (90 to 92%) and dissolved substances.

These Include:

- Plasma proteins: albumins, globulins (including *antibodies),* fibrinogen, clotting factors.
- Inorganic salts (mineral salts): sodium chloride, sodium bicarbonate, potassium, magnesium, phosphate, iron, calcium, copper, iodine & cobalt.
- Nutrients, principally from digested foods, e.g. monosaccharides (mainly glucose), amino acids, fatty acids, glycerol and vitamins.
- Organic waste materials, e.g. urea, uric acid, creatinine.
- Hormones enzymes, e.g. certain clotting factors.
- Gases, e.g. oxygen, carbon dioxide, nitrogen.

Blood Composition



Plasma Proteins

Plasma proteins, which make up about 7% of plasma, are normally retained within the blood, because they are too big to escape through the capillary pores into the tissues.

They are largely responsible for creating the osmotic pressure of blood, which keeps plasma fluid within the circulation.

If plasma protein levels fall, because of either reduced production or loss from the blood vessels, osmotic pressure is also reduced, and fluid moves into the tissues (oedema) and body cavities.

Albumins

These are formed in the liver. They are the most abundant plasma proteins and their main function is to maintain a normal plasma osmotic pressure. Albumins also act as carrier molecules for lipids and steroid hormones.

Globulins

Most are formed in the liver and the remainder in lymphoid tissue.

Their Main Functions Are:

- As antibodies (immunoglobulins), which are complex proteins produced by lymphocytes that play an important part in immunity. They bind to, and neutralise, foreign materials (antigens) such as micro-organisms.
- Transportation of some hormones and mineral salts; e.g. thyroglobulin carries the hormone thyroxine and transferrin carries the mineral iron.
- Inhibition of some proteolytic enzymes.

Clotting Factors

These are substances essential for coagulation of blood. *Serum* is plasma from which clotting factors have been removed.

Fibrinogen

This is synthesised in the liver and is essential for blood coagulation.
Plasma viscosity (thickness) is due to plasma proteins, mainly albumin and fibrinogen. Viscosity is used as a measure of the body's response to some diseases.

Inorganic salts (mineral salts or Electrolytes)

The amounts of intracellular and extracellular fluids contained in a person's body are extremely important to his healthy physiology. Losses of body fluids by vomiting, diorrhea, or excessive perspiration can produce illness or even death. Whenever body fluids are lost, the substances dissolved in the fluids are also lost. Certain inorganic substances are found in the body's fluids. These are called "electrolytes." Examples of electrolytes are potassium and chloride. These electrolytes exist in their "ion" state in the body fluids.

This means that each ion can combine with one or more ions to form needed body compounds or can produce electro-chemical equilibrium (or balance). One example of this is the osmotic pressure that causes water to flow across a cell membrane. The relationship between the concentrations of sodium and potassium electrolytes in the cells and the extracellular fluid causes the water to flow into and out from the cells. There is usually a low level of sodium in the cells and a high concentration of potassium. Alkalinity and acidity are expressed in terms of pH, which is a measure of hydrogen ion concentration, or $[H^+]$.

The pH of blood is maintained between 7.35 and 7.45 by an ongoing complicated series of chemical activities, involving buffering systems.

The movement of electrolytes is governed by their electrical charge. Some are positively charged and are called "cations." Others are negatively charged and called "anions." Below are the major electrolytes, their chemical abbreviations, and the amount of each contained in a litre of extracellular fluid.

Sodium (Na^+) 135 – 145 mmol/L

The most abundant positive electrolyte (or cation) in the extracellular fluid and is also present in intracellular fluid. The main function of sodium is in maintaining normal osmotic pressure.

Chloride (Cl^-) 95 -110 mmol/L

The most abundant negative electrolyte (or anion) in extracellular fluid and is present in intracellular fluid as well. Chloride is essential to maintain normal osmotic pressure and is found in the stomach fluid.

Potassium (K^+) 3.5-5.0 mmol/L

Potassium is the most abundant electrolyte in the intracellular fluid. Potassium is also required for osmotic pressure but has other vital functions. Potassium is required to convert dextrose (a sugar) into body energy and is vital in transmitting electrical impulses within the heart.

Bicarbonate (HCO_3^-) 19 – 25 mmol/L

Bicarbonate helps to maintain the acid-base balance within the body.

Phosphate (PO_4) 0.5 – 1.6 mmol/L

Phosphate is required for the formation of bones, teeth, and body enzymes.

Magnesium (Mg^{++}) 0.6 – 1.0 mmol/L

Magnesium is essential for the formation of enzymes within the body.

Calcium (Ca^{++}) 2.1 – 2.8 mmol/L

Calcium is essential for the formation of bones and teeth. Calcium is needed to help in blood clotting and in maintaining the rhythm of the heartbeat.

Acid Base Balance

For proper body functions to continue normally, this internal environment must be kept constant (homeostasis) and within a very narrow limit.

The acid-base balance of the blood is maintained by the chemical balance between the cations and the anions, which must be there in a very delicate balance. The cations are sodium (Na^+), potassium (K^+), calcium (Ca^+) and magnesium (Mg^+). The anions are chloride (Cl^-), bicarbonate (HCO_3^-) and phosphate (PO_4). The acid-base balance is normally expressed as the "pH." The normal range of the blood pH is 7.35 to 7.45.

The body is always slightly alkaline. The body's acid-base balance is effectively maintained under normal circumstances by the various buffer processes, which neutralize strong acids or strong bases (alkalines) using the body's various buffer systems (chemical, organic, and so forth) to help excrete excess body system products.

Nutrients

Food is digested in the alimentary tract and the resultant nutrients are absorbed, e.g. monosaccharides, amino acids, fatty acids, glycerol and vitamins. Together with mineral salts they are required by all body cells to provide energy, heat, materials for repair and replacement, and for the synthesis of other blood components and body secretions.

Organic Waste Products

Urea, creatinine and uric acid are the waste products of protein metabolism. They are formed in the liver and conveyed in blood to the kidneys for excretion. Carbon dioxide, released by all cells, is conveyed to the lungs for excretion.

Hormones

These are chemical compounds synthesised by endocrine glands. Hormones pass directly from the cells of the glands into the blood, which transports them to their target tissues and organs elsewhere in the body, where they influence cellular activity.

Gases

Oxygen (approximately 15% of the circulating volume), carbon dioxide and nitrogen are transported round the body in solution in plasma. Oxygen and carbon dioxide are also transported in combination with haemoglobin in red blood cells. Most oxygen is carried in combination with haemoglobin and most carbon dioxide as bicarbonate ions dissolved in plasma. Atmospheric nitrogen enters the body in the same way as other gases and is present in plasma but it has no physiological function.

Cellular Content of Blood

There Are Three Types Of Blood Cells:

- Erythrocytes or red cells
- Thrombocytes or platelets
- Leukocytes or white cells

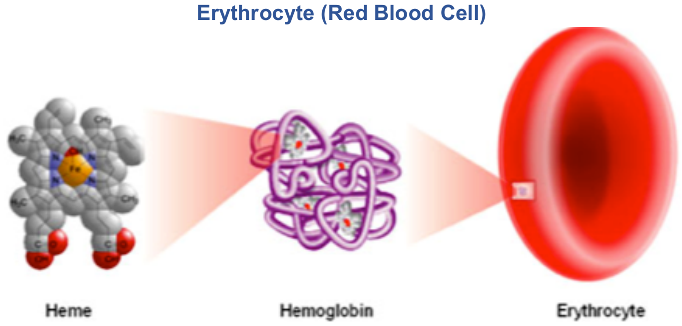
All blood cells originate from *pluripotent stem cells* and go through several developmental stages before entering the blood. Different types of blood cells follow separate lines of development. The process of blood cell formation is called *haemopoiesis* and takes place within red bone marrow.

Erythrocytes (red blood cells / R.B.C.)

Red blood cells (also referred to as erythrocytes) are the most common type of blood cell and the principal means of delivering oxygen (O_2) to the body tissues via the blood flow through the circulatory system.

These cells are rich in hemoglobin, an iron-containing bio-molecule that can bind oxygen and is responsible for the blood's red color.

Erythrocyte (Red Blood Cell)



Mature red blood cells are flexible biconcave disks that lack a cell nucleus and most organelles. 2.4 million new erythrocytes are produced *per* second. The cells develop in the bone marrow and circulate for about 100–120 days in the body before their components are recycled by macrophages. Each circulation takes about 20 seconds. Approximately a quarter of the cells in the human body are red blood cells.

Packed red blood cells, which are made from whole blood with the plasma removed, are used in transfusion medicine.

Erythrocyte count (**Male:** 4.5 x 10^{12}/l to 6.5 x 10^{12}/l (4.5 to 6.5 million/mm^3). **Female:** 4.5 x 1

This is the number of erythrocytes per litre or per cubic millimetre (mm^3) of blood.

Packed Cell Volume (PCV) or haematocrit (0.4 to 0.5 l/l (40 to 50/mm3))

This is the volume of red cells in 1 litre or 1 mm3 of whole blood.

Mean Cell Volume (MCV) 80 to 96 fl

This is the average volume of cells, measured in femtolitres (fl =10L-15L).

Haemoglobin **Male:** (13 to 18g/100ml **Female:** 11.5 to16.5 g/100 ml)

This is the weight of haemoglobin in whole blood, measured in grams per 100ml.

Leukocytes (white blood cells)

These cells have an important function in defending the body against microbes and other foreign materials. Leukocytes are the largest blood cells and they account for about 1% of the blood volume. They contain nuclei and some have granules in their cytoplasm. There are two main types:

- Granulocytes (polymorphonuclear leukocytes) — neutrophils, eosinophils and basophils
- Agranulocytes — monocytes and lymphocytes.

Granulocytes (polymorphonuclear leukocytes)

During their formation, *granulopoiesis,* they follow a common line of development through *myeloblast* to *myelocyte* before differentiating into the three types.

- Neutrophils
- Eosinophils
- Basophils

All granulocytes have multilobed nuclei in their cytoplasm. Their names represent the dyes they take up when stained in the laboratory. Eosinophils take up the red acid dye, eosin; basophils take up alkaline methylene blue; and neutrophils are purple because they take up both dyes.

Neutrophils 2.5 to 7.5 x 10^9/l

Their main function is to protect against any foreign material that gains entry to the body mainly microbes, and to remove waste materials, e.g. cell debris. They are attracted in large numbers to any area of infection by chemical substances, released by damaged cells, called *chemotaxins.* Neutrophils pass through the capillary walls in the affected area by *amoeboid movement*. Thereafter they engulf and kill the microbes by *phagocytosis.* Their granules are *lysosomes* that contain enzymes that digest the engulfed material. The pus that may form in the affected area consists of dead tissue cells, dead and live microbes, and phagocytes killed by microbes.

Neutrophil (white blood cell)

There is a physiological increase in circulating neutrophils following strenuous exercise and in the later stages of normal pregnancy.

Numbers Are Also Increased In:

- Microbial infection.
- Tissue damage, e.g. inflammation, myocardial infarction, burns, crush injuries.
- Metabolic disorders, e.g.diabetic ketoacidosis, acute gout.
- Leukaemia.
- Heavy smoking.
- Use of oral contraceptives.

Eosinophil (white blood cell)

Eosinophils 0.04 to 0.44 x 10^9/l

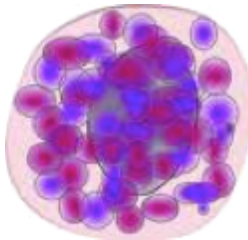
Eosinophils, although capable of phagocytosis, are less active in this than neutrophils; their specialised role appears to be in the elimination of parasites, such as worms, which are too big to be phagocytosed. They are equipped with certain toxic chemicals, stored in their granules, which they release when the eosinophil binds an infecting organism.

Eosinophils are often found at sites of allergic inflammation, such as the asthmatic airway and skin allergies. There, they promote tissue inflammation by releasing their array of toxic chemicals, but they may also dampen down the inflammatory process through the release of other chemicals, such as an enzyme that breaks down histamine.

Basophils 0.015 to 0.1 –x 10^9/l

Basophils, which are closely associated with allergic reactions, contain cytoplasmic granules packed with *heparin* (an anticoagulant), *histamine* (an inflammatory agent) and other substances that promote inflammation.

Basophil (white blood cell)



Usually the stimulus that causes basophils to release the contents of their granules is an *allergen* (an antigen that causes allergy) of some type. This binds to antibody-type receptors on the basophil membrane. A cell type very similar to basophils, except that it is found in the tissues, not in the circulation, is the *mast cell.* Mast cells release their granule contents within seconds of binding an allergen, which accounts for the rapid onset of allergic symptoms following exposure to, for example, pollen in hay fever.

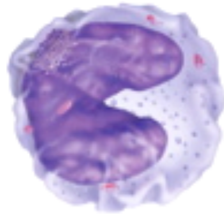
Agranulocytes

The types of leukocyte with a large nucleus and no granules in their cytoplasm are *monocytes* and *lymphocytes* and they make up 25% to 50% of all leukocytes.

Monocytes

These are large mononuclear cells that originate in red bone marrow. Some circulate in the blood and are actively motile and phagocytic while others migrate into the tissues where they develop into *macrophages.* Both types of cell produce *interleukin 1* which:

Monocyte (white blood cell)



- Acts on the hypothalamus, causing the rise in body temperature associated with microbial infections
- Stimulates the production of some globulins by the liver
- Enhances the production of activated T-lymphocytes.

Macrophages have important functions in inflammation and immunity.
Macrophages function in close association with monocytes in the blood and with lymphocytes, which influence their activity. They are actively phagocytic and if they encounter large amounts of foreign or waste material, they tend to multiply at the site and wall off the area, isolating the material, e.g. in the lungs when foreign material has been inhaled. Their numbers are increased in microbial infections, collagen diseases and some non-infective bowel conditions.

Lymphocytes

Lymphocytes are smaller than monocytes and have large nuclei. They circulate in the blood and are present in great numbers in lymphatic tissue such as lymph nodes and the spleen. Lymphocytes develop from pluripotent stem cells in red bone marrow, then travel in the blood to lymphoid tissue elsewhere in the body where they are *activated,* i.e. they become immuno-competent which means they are able to respond to *antigens* (foreign material).

Examples Of Antigens Include:

- Cells regarded by lymphocytes as abnormal, e.g. those that have been invaded by viruses, cancer cells, tissue transplant cells.
- Pollen from flowers and plants.
- Fungi.
- Bacteria.
- Some large molecule drugs, e.g. penicillin, aspirin.

Although all lymphocytes originate from one type of stem cell, when they are activated in lymphatic tissue, two distinct types of lymphocyte are produced— *T-lymphocytes* and *B-lymphocytes.*

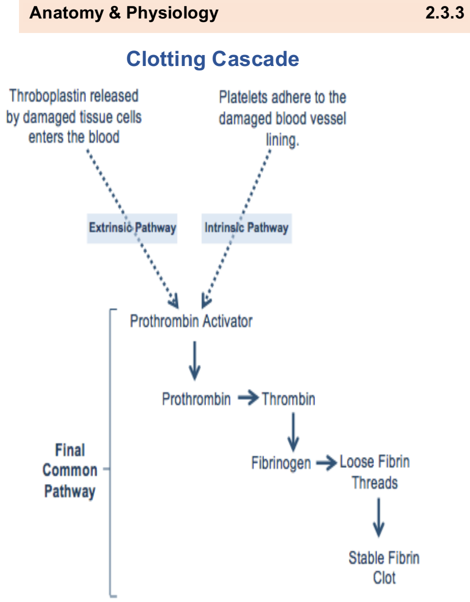
Platlets

Thrombocytes (Platelets) 200 - 350 x 10^9/l

These are very small non-nucleated discs, 2 to 4 um in diameter, derived from the cytoplasm of megakaryocytes in red bone marrow. They contain a variety of substances that promote blood clotting, which causes *haemostasis* (cessation of bleeding).

The normal blood platelet count is between 200 000 to 350 000/mm^3. The control of platelet production is not yet entirely clear but it is believed that one stimulus is a fall in platelet count and that a substance called *thrombopoietin* is involved. The life span of platelets is between 8 and 11 days and those not used in haemostasis are destroyed by macrophages, mainly in the spleen.

Haemostasis (Blood Clotting) 2.3.4



When a blood vessel is damaged, loss of blood is stopped and healing occurs in a series of overlapping processes, in which platelets play a vital part.

Vasoconstriction

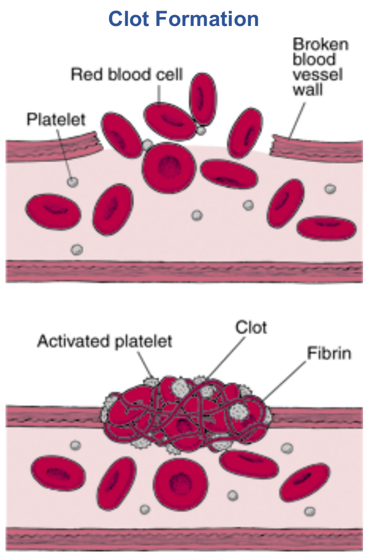
When platelets come in contact with a damaged blood vessel, their surface becomes sticky and they adhere to the damaged wall. They then release *serotonin* (5-hydroxytryptamine), which constricts (narrows) the vessel, reducing blood flow through it. The damaged vessel itself releases other chemicals that cause vasoconstriction, e.g. thromboxanes.

Platelet Plug Formation

The adherent platelets clump to each other and release other substances, including *adenosine diphosphate* (ADP), which attract more platelets to the site. Passing platelets stick to those already at the damaged vessel and they too release their chemicals. This is a positive feedback system by which many platelets rapidly arrive at the site of vascular damage and quickly form a temporary seal the *platelet plug.*

Coagulation (blood clotting)

This is a complex process that also involves a positive feedback system and only a few stages are included here. Their numbers represent the order in which they were discovered and not the order of participation in the clotting process.



Blood clotting results in formation of an insoluble thread-like mesh of *fibrin,* which traps blood cells and is much stronger than the rapidly formed platelet plug. In the final stages of this process *prothrombin activator* acts on the plasma protein *prothrombin* converting it to thrombin.

Thrombin then acts on another plasma protein *fibrinogen* and converts it to fibrin.

Two processes, which often occur together, can form prothrombin activator: the extrinsic and intrinsic pathways. The *extrinsic pathway* occurs rapidly (within seconds) when there is tissue damage outside the circulation.

Damaged tissue releases a complex of chemicals called *thromboplastin* or tissue factor, which initiates coagulation. The *intrinsic pathway* is slower (3-6 minutes) and is confined to the circulation. It is triggered by damage to a blood vessel lining (endothelium) and the effects of platelets adhering to it.

After a time the clot shrinks, squeezing out *serum,* a clear sticky fluid that consists of plasma from which clotting factors have been removed.

Fibrinolysis

After the clot has formed the process of removing it and healing the damaged blood vessel begins. The breakdown of the clot, or fibrinolysis, is the first stage. An inactive substance called *plasminogen* is present in the clot and is converted to the enzyme *plasmin* by activators released from the damaged endothelial cells.

Plasmin initiates the breakdown of fibrin to soluble products that are treated as waste material and removed by phagocytosis.

As the clot is removed, the healing process restores the integrity of the blood vessel wall.

Control of Coagulation

The process of blood clotting relies heavily on several processes thatare self-perpetuating that is, once started, a positive feedback mechanism promotes their continuation. For example, thrombin is a powerful stimulator of its own production. The body therefore possesses several mechanisms to control and limit the coagulation cascade; otherwise once started the clotting process would spread throughout the circulatory system, far beyond requirements.

The Main Controls Are:

- The perfect smoothness of normal blood vessel lining; platelets do not adhere to this surface
- The binding of thrombin to a special thrombin receptor on the cells lining blood vessels; once bound,

- The presence of natural anticoagulants, e.g. heparin, in the blood, which inactivate clotting factors.

CENTRAL NERVOUS SYSTEM 2.4

The nervous system detects and responds to changes inside and outside the body. Together with the endocrine system it controls important aspects of body function and maintains homeostasis. Nervous system stimulation provides an immediate response while endocrine activity is, in the main, slower and more prolonged.

The nervous system consists of the brain, the spinal cord and peripheral nerves. Organisation of nervous tissue within the body enables rapid communication between different parts of the body.

Response to changes in the internal environment maintains homeostasis and regulates involuntary functions, e.g. blood pressure and digestive activity. Response to changes in the external environment maintains posture and other voluntary activities.

For Descriptive Purposes The Parts Of The Nervous System Are Grouped As Follows:

- *The central nervous system* (CNS), consisting of the brain and the spinal cord
- *The peripheral nervous system* (PNS) consisting of all the nerves outside the brain and spinal cord.

The PNS comprises paired cranial and sacral nerves, some of these are sensory (afferent), some are motor (efferent) and some mixed.

It Is Useful To Consider Two Functional Parts Within The PNS:

- The sensory division
- The motor division

Nerves 2.4.1

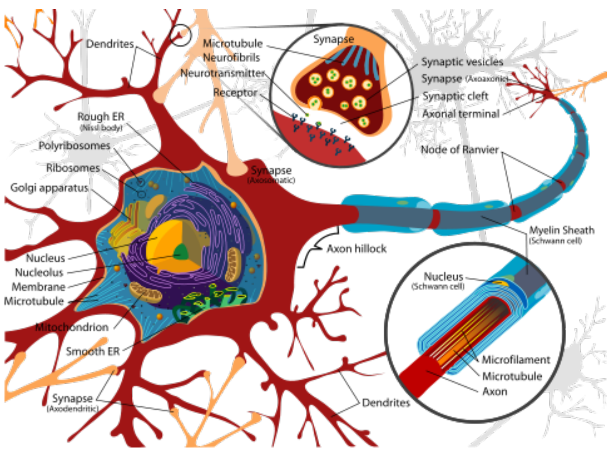
Neurones

The nervous system consists of a vast number of cells called *neurones*, supported by a special type of connective tissue, *neuroglia.* Each neurone consists of a *cell body* and its processes, one *axon* and many *dendrites.* Neurones are commonly referred to simply as nerve cells. Bundles of axons bound together are called *nerves.* Neurones cannot divide and for survival they need a continuous supply of oxygen and glucose. Unlike many other cells, neurones can synthesise chemical energy (ATP) only from glucose.

The physiological 'units' of the nervous system are *nerve impulses,* or *action potentials,* which are akin to tiny electrical charges. However, unlike ordinary electrical wires, the neurones are actively involved in conducting nerve impulses. In effect the strength of the impulse is maintained throughout the length of the neurone.

Some neurones initiate nerve impulses while others act as 'relay stations' where impulses are passed on and sometimes redirected.

Neurone



Properties of Neurones

Neurones have the characteristics of *irritability* and *conductivity.*

Irritability is the ability to initiate nerve impulses in response to stimuli from:

- Outside the body (e.g. touch, light waves).
- Inside the body (e.g. a change in the concentration of CO_2 controls respiration; a thought may result in voluntary movement).

In the body this stimulation may be described as partly electrical and partly chemical-electrical in that motor neurones and sensory nerve endings initiate nerve impulses, and chemical in the transmission of impulses between one neurone and the next or between a neurone and an effector organ.

Conductivity means the ability to transmit an impulse.

Cell Bodies

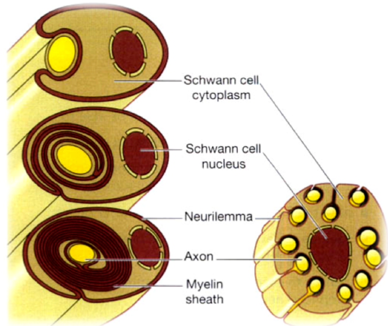
Nerve cells vary in size and shape but they are all too small to be seen by the naked eye.

Cell bodies form the *grey matter* of the nervous system and are found at the periphery of the brain and in the centre of the spinal cord. Groups of cell bodies are called *nuclei* in th

ganglia in the peripheral nervous system.

Axons and Dendrites

Axons and dendrites are extensions of cell bodies and form the *white matter* of the nervous system. Axons are found deep in the brain and in groups, called *tracts,* at the periphery of the spinal cord. They are referred to as *nerves* or *nerve fibres* outside the brain and spinal cord.



Axons

Each nerve cell has only one axon, carrying nerve impulses away from the cell body. They are usually longer than the dendrites, sometimes as long as 100cm.

Structure of an Axon

The membrane of the axon is called *axolemma* and it encloses the cytoplasmic extension of the cell body.

Large axons and those of peripheral nerves are surrounded by a *myelin sheath*. This consists of a series of *Schwann cells* arranged along the length of the axon. Each one is wrapped around the axon so that it is covered by a number of concentric layers of Schwann cell plasma membrane.

Between the layers of plasma membrane there is a small amount of fatty substance called *myelin.* The outermost layer of Schwann cell plasma membrane is sometimes called *neurilemma.* There are tiny areas of exposed axolemma between adjacent Schwann cells, called *nodes of Ranvier,* which assist the rapid transmission of nerve impulses.

Postganglionic fibres and some small fibres in the central nervous system are *non-myelinated.* In this type a number of axons are embedded in Schwann cell plasma membranes. The adjacent Schwann cells are in close association and there is no exposed axolemma. The speed of transmission of nerve impulses is significantly slower in non-myelinated fibres.

Dendrites

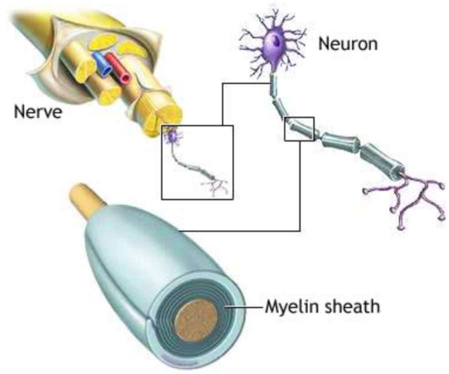
The dendrites are the many short processes that receive and carry incoming impulses towards cell bodies.

They have the same structure as axons but they are usually shorter and branching. In motor neurones they form part of synapses and in sensory neurones they form the sensory receptors that respond to stimuli.

The Nerve Impulse (action potential)

An impulse is initiated by stimulation of sensory nerve endings or by the passage of an impulse from another nerve. Transmission of the impulse, or action potential, is due to movement of ions across the nerve cell membrane. In the resting state the nerve cell membrane is *polarised* due to differences in the concentrations of ions across the plasma membrane.

Nerve Structure



This means that there is a different electrical charge on each side of the membrane that is called the *resting membrane potential.* At rest the charge on the outside is positive and inside it is negative.

The Principal Ions Involved Are:

- Sodium (Na^+) the main extracellular cation
- Potassium (K^+) the main intracellular cation.

In the *resting state* there is a continual tendency for these ions to diffuse along their concentration gradients, i.e. K^+ outwards and Na^+ into cells. When stimulated, the permeability of the nerve cell membrane to these ions changes. Initially Na^+ floods into the neurone from the ECF causing *depolarisation,* creating a *nerve impulse* or *action potential.* Depolarisation is very rapid, enabling the conduction of a nerve impulse along the entire length of a neurone in a few milliseconds (ms). It passes from the point of stimulation in one direction only, i.e. away from the point of stimulation towards the area of resting potential.

During this process K^+ floods out of the neurone and the movement of these ions returns the membrane potential to its resting state. This is called the *refractory period* during which restimulation is not possible. As the neurone returns to its original resting state, the action of the *sodium pump* expels Na^+ from the cell in exchange for K^+.

In myelinated neurones, the insulating properties of the myelin sheath prevent the movement of ions. Therefore electrical changes across the membrane can only occur at the gaps in the myelin sheath, i.e. at the nodes of Ranvier. When an impulse occurs at one node, depolarisation passes along the myelin sheath to the next node so that the flow of current appears to 'leap' from one node to the next. This is called *saltatory conduction*.

The speed of conduction depends on the diameter of the neurone: the larger the diameter, the faster the conduction. Myelinated fibres conduct impulses faster than unmyelinated fibres because saltatory conduction is faster than the complete conduction, or *simple propagation*.

The fastest fibres can conduct impulses to, e.g., skeletal muscles at a rate of 130 metres per second while the slowest impulses travel at 0.5 metres per second.

Types of Nerves

Sensory or Afferent Nerves

When action potentials are generated by sensory receptors on the dendrites of these neurones, they are trans- mitted to the spinal cord by the sensory nerve fibres. The impulses may then pass to the brain or to connector neurones of reflex arcs in the spinal cord.

Sensory Receptors

Specialised endings of sensory neurones respond to different stimuli (changes) inside and outside the body.
Somatic, cutaneous or *common senses.*
These originate in the skin. They are: pain, touch, heat and cold. Sensory nerve endings in the skin are fine branching filaments without myelin sheaths.

When stimulated, an impulse is generated and transmitted by the sensory nerves to the brain where the sensation is perceived.

Proprioceptor Senses

These originate in muscles and joints and contribute to the maintenance of balance and posture.
Special senses. These are sight, hearing, smell, touch and taste.

Autonomic Afferent Nerves

These originate in internal organs, glands and tissues, e.g. baroreceptors, chemoreceptors, and are associated with reflex regulation of involuntary activity and visceral pain.

Motor or Efferent Nerves

Motor nerves originate in the brain, spinal cord and autonomic ganglia. They transmit impulses to the effector organs: muscles and glands.

There Are Two Types:

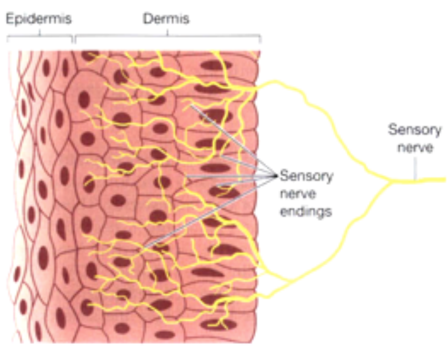
- *Somatic nerves* - Voluntary and reflex skeletal muscle contraction.
- *Autonomic nerves* (sympathetic and parasympathetic) - involved in cardiac and smooth muscle contraction and glandular secretion.

Mixed Nerves

In the spinal cord, sensory and motor nerves are arranged in separate groups, or *tracts.*

Outside the spinal cord, when sensory and motor nerves are within the same sheath of connective tissue they are called *mixed nerves.*

Sensory Nerve



The Synapse And Neurotransmitters

There is always more than one neurone involved in the transmission of a nerve impulse from its origin to its destination, whether it is sensory or motor. There is no physical contact between these neurones. The point at which the nerve impulse passes from one to another is the *synapse.* At its free end the axon of the *presynaptic neurone* breaks up into minute branches, which terminate in small swellings called *synaptic knobs,* or terminal boutons. These are in close proximity to the dendrites and the cell body of the *postsynaptic neurone.*

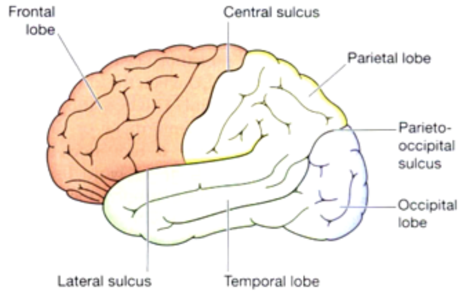
The space between them is the *synaptic cleft.* In the ends of synaptic knobs there are spherical *synaptic vesicles,* containing a chemical, the *neurotransmitter,* which is released into synaptic clefts. Neurotransmitters are synthesised by nerve cells, actively transported along the axons and stored in the synaptic vesicles.

They are released by exocytosis in response to the action potential and diffuse across the synaptic cleft. They act on specific receptor sites on the postsynaptic membranes. Their action is short lived as immediately they have stimulated the post-synaptic neurone or effector organ, such as a muscle fibre; they are either inactivated by enzymes or taken back into the synaptic knob.

The Brain 2.4.2

The brain constitutes about one-fiftieth of the body weight and lies within the cranial cavity.

The Brain



The Parts Are:

- Cerebrum
- Midbrain (the brain stem)
- Pons (the brain stem)
- Medulla oblongata (the brain stem)
- Cerebellum

Blood Supply To The Brain

The circulus arteriosus and its contributing arteries play a vital role in maintaining a constant supply of oxygen and glucose to the brain even when a contributing artery is narrowed or the head is moved. The brain receives about 15% of the cardiac output, approximately 750ml of blood per minute.

Autoregulation keeps blood flow to the brain constant by adjusting the diameter of the arterioles across a wide range of arterial blood pressure (about 65-140 mmHg) with changes occurring only outside these limits.

Cerebrum

This is the largest part of the brain and it occupies the anterior and middle cranial fossae. It is divided by a deep cleft, the *longitudinal cerebral fissure,* into *right* and *left cerebral hemispheres,* each containing one of the lateral ventricles. Deep within the brain the hemispheres are connected by a mass of white matter (nerve fibres) called the *corpus callosum.* The falx cerebri is formed by the dura mater. It separates the two hemispheres and penetrates to the depth of the corpus callosum. The superficial (peripheral) part of the cerebrum is composed of nerve cell bodies or grey matter, forming the *cerebral cortex,* and the deeper layers consist of nerve fibres or white matter.

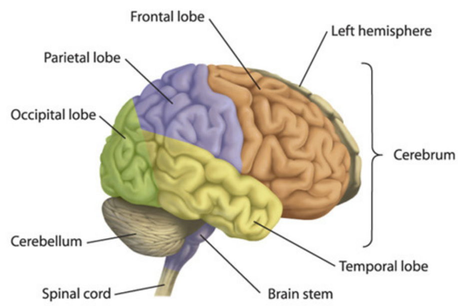
The cerebral cortex shows many infoldings or furrows of varying depth. The exposed areas of the folds are the *gyri* or *convolutions* and these are separated by *sulci* or *fissures.* These convolutions greatly increase the surface area of the cerebrum.

Each hemisphere of the cerebrum is divided into *lobes,* which take the names of the bones of the cranium under which they lie.

They Are:

- Frontal
- Parietal
- Temporal
- Occipital.

The Brain



Interior of the Cerebrum

The surface of the cerebral cortex is composed of grey matter (nerve cell bodies). Within the cerebrum the lobes are connected by masses of nerve fibres, or tracts, which make up the white matter of the brain.

Functions of the Cerebrum

There are three main varieties of activity associated with the cerebral cortex:

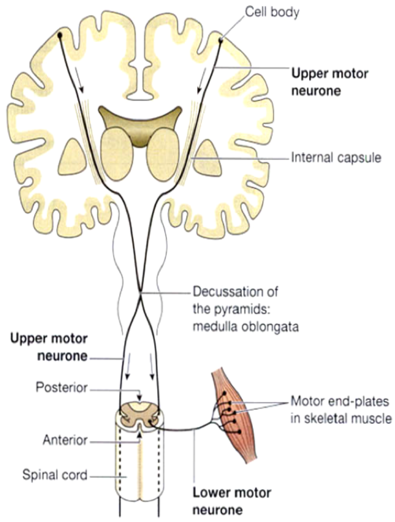
- Mental activities involved in memory, intelligence, sense of responsibility, thinking, reasoning, moral sense and learning are attributed to the *higher centres*
- Sensory perception, including the perception of pain, temperature, touch, sight, hearing, taste and smell
- Initiation and control of skeletal (voluntary) muscle contraction.

Functional Areas of the Cerebrum

The main areas of the cerebrum associated with sensory perception and voluntary motor activity are known but it is unlikely that any area is associated exclusively with only one function. Except where specially mentioned, the different areas are active in both hemispheres.

The Precentral (motor) Area

This lies in the frontal lobe immediately anterior to the *central sulcus.* The cell bodies are pyramid shaped (Betz's cells) and they initiate the contraction of skeletal muscles. A nerve fibre from a Betz's cell passes downwards through the internal capsule to the medulla oblongata where it crosses to the opposite side then descends in the spinal cord. At the appropriate level in the spinal cord the nerve impulse crosses a synapse to stimulate a second neurone, which terminates at the motor endplate of a muscle fibre. This means that the motor area of the *right hemisphere* of the cerebrum controls voluntary muscle movement on the left side of the body and vice versa. The neurone with its cell body in the cerebrum is the *upper motor neurone* and the other, with its cell body in the spinal cord, is the *lower motor neurone*. Damage to either of these neurones may result in paralysis.



In the motor area of the cerebrum the body is represented upside down, i.e. the cells nearest the vertex control the feet and those in the lowest part control the head, neck, face and fingers. The sizes of the areas of cortex representing different parts of the body are proportional to the *complexity of movement* of the body part, not to its size.

The Premotor Area

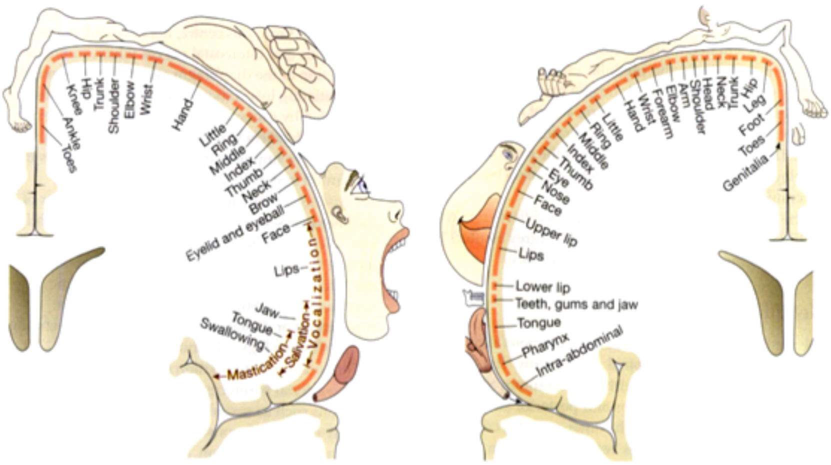
This lies in the frontal lobe immediately anterior to the motor area. The cells are thought to exert a controlling influence over the motor area, ensuring an orderly series of movements. For example, in tying a shoe lace or writing, many muscles contract but the movements must be coordinated and carried out in a particular sequence. Such a pattern of movement, when established, is described as *manual dexterity.*

In the lower part of this area just above the lateral sulcus there is a group of nerve cells known as the *motor speech (Broca's) area,* which controls the movements necessary for speech. It is dominant in the *left hemisphere* in *right-handed people* and vice versa.

The Frontal Area

This extends anteriorly from the premotor area to include the remainder of the frontal lobe. It is a large area and is more highly developed in humans than in other animals. It is thought that communications between this and the other regions in the cerebrum are responsible for the behaviour, character and emotional state of the individual. No particular behaviour, character or intellectual trait has, so far, been attributed to the activity of any one group of cells.

Sensory Centres



The Postcentral (sensory) Area

This is the area behind the central sulcus. Here sensations of pain, temperature, pressure and touch, knowledge of muscular movement and the position of joints are perceived.

The sensory area of the *right hemisphere* receives impulses from the *left side of the body* and vice versa. The size of the areas representing different parts of the body is proportional to the *extent of sensory innervation,* e.g. the large area for the face is consistent with the extensive sensory nerve supply by the three branches of the trigeminal nerves (5th cranial nerves).

The Parietal Area

This lies behind the postcentral area and includes the greater part of the parietal lobe of the cerebrum. Its functions are believed to be associated with obtaining and retaining accurate knowledge of objects.

It has been suggested that objects can be recognised by touch alone because of the knowledge from past experience (memory) retained in this area.

The Sensory Speech Area

Situated in the lower part of the parietal lobe and extends into the temporal lobe. It is here that the spoken word is perceived. There is a dominant area in the *left hemisphere* in *right-handed* people and vice versa.

The Auditory (hearing) Area

This lies immediately below the lateral sulcus within the temporal lobe. The cells receive and interpret impulses transmitted from the inner ear by the cochlear (auditory) part of the vestibulo-cochlear nerves (8th cranial nerves).

The Olfactory (smell) Area

This lies deep within the temporal lobe where impulses from the nose via the olfactory nerves (1st cranial nerves) are received and interpreted.

The Taste Area

This is thought to lie just above the lateral sulcus in the deep layers of the sensory area. This is the area where impulses from special nerve endings in taste buds in the tongue and in the lining of the cheeks, palate and pharynx are perceived as taste.

The Visual Area

This lies behind the parieto-occipital sulcus and includes the greater part of the occipital lobe. The optic nerves (2nd cranial nerves) pass from the eye to this area, which receives and interprets the impulses as visual impressions.

Other Areas Of The Cerebrum

Deep within the cerebral hemispheres there are groups of cell bodies called *nuclei* (previously called ganglia), which act as relay stations where impulses are passed from one neurone to the next in a chain.

Important Masses Of Grey Matter Include:

- Basal nuclei
- Thalamus
- Hypothalamus.

Basal Nuclei

These are areas of grey matter, lying deep within the cerebral hemispheres, with connections to the cerebral cortex and thalamus. The basal nuclei form part of the extrapyramidal tracts and are thought to be involved in initiating muscle tone in slow and coordinated activities. If control is inadequate or absent, movements are jerky, clumsy and uncoordinated.

Thalamus

The thalamus consists of two masses of nerve cells and fibres situated within the cerebral hemispheres just below the corpus callosum, one on each side of the third ventricle. Sensory input from the skin, viscera and special sense organs is transmitted to the thalamus before redistribution to the cerebrum.

Hypothalamus

The hypothalamus is composed of a number of groups of nerve cells. It is situated below and in front of the thalamus, immediately above the *pituitary gland.* The hypothalamus is linked to the posterior lobe of the pituitary gland by nerve fibres and to the anterior lobe by a complex system of blood vessels. Through these connections, the hypothalamus controls the output of hormones from both lobes of the gland.

Other Functions With Which The Hypothalamus Is Concerned Include Control Of:

- The autonomic nervous system.
- Appetite and satiety.
- Thirst and water balance.
- Body temperature.
- Emotional reactions, (e.g. pleasure, fear, rage).
- Sexual behaviour (including mating and child rearing).
- Biological clocks or circadian rhythms, (e.g. sleeping cycles, body temperature and secretion of some hormones).

Brain Stem

Midbrain

The midbrain is the area of the brain situated around the cerebral aqueduct between the cerebrum above and the *pons* below. It consists of groups of cell bodies and nerve fibres (tracts), which connect the cerebrum with lower parts of the brain and with the spinal cord. The cell bodies act as relay stations for the ascending and descending nerve fibres.

Pons

The pons is situated in front of the cerebellum, below the midbrain and above the medulla oblongata. It consists mainly of nerve fibres, which form a bridge between the two hemispheres of the cerebellum, and

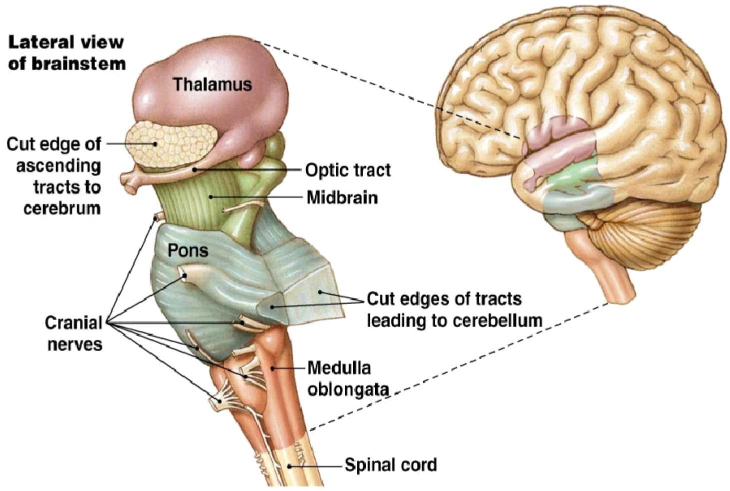
r levels of the brain and the spinal cord. There are groups of cells within the pons which act as relay stations and some of these are associated with the cranial nerves.

Medulla Oblongata

The medulla oblongata extends from the pons above and is continuous with the spinal cord below. It is about 2.5 cm long and it lies just within the cranium above the foramen magnum. Central fissures mark its anterior and posterior surfaces. The outer aspect is composed of *white matter,* which passes between the brain and the spinal cord, and *grey matter* lies centrally. Some cells constitute relay stations for sensory nerves passing from the spinal cord to the cerebrum.

The vital centres, consisting of groups of cells associated with autonomic reflex activity, lie in its deeper structure.

The Brain Stem



These Are The:

- Cardiac centre
- Respiratory centre
- Vasomotor centre
- Reflex centres of vomiting, coughing, sneezing and swallowing.

The Medulla Oblongata Has Several Special Features:

- *Decussation (crossing) of the pyramids.* In the medulla *motor nerves* descending from the motor area in the cerebrum to the spinal cord in the pyramidal (corticospinal) tracts cross from one side to the other. This means that the left hemisphere of the cerebrum controls the right half of the body, and vice versa. These tracts are the main pathways for impulses to skeletal (voluntary) muscles.
- *Sensory decussation.* Some of the *sensory nerves* ascending to the cerebrum from the spinal cord cross from one side to the other in the medulla. Others decussate at lower levels, i.e. in the spinal cord.
- *The cardiovascular centre* controls the rate and force of cardiac contraction. Sympathetic and parasympathetic nerve fibres originating in the medulla pass to the heart. Sympathetic stimulation increases the rate and force of the heartbeat and parasympathetic stimulation has the opposite effect.
- *The respiratory centre* controls the rate and depth of respiration. From this centre, nerve impulses pass to the phrenic and intercostal nerves, which stimulate contraction of the diaphragm and intercostal muscles, thus initiating inspiration. The respiratory centre is stimulated by excess carbon dioxide and, to a lesser extent, by deficiency of oxygen in its blood supply and by nerve impulses from the chemoreceptors in the carotid bodies.
- *The vasomotor centre* controls the diameter of the blood vessels, especially the small arteries and arterioles, which have a large proportion of smooth muscle fibres in their walls. Vasomotor impulses reach the blood vessels through the autonomic nervous system. Stimulation may cause either constriction or dilatation of blood vessels depending on the site.
- The sources of stimulation of the vasomotor centre are the arterial baroreceptors, body temperature and emotions such as sexual excitement and anger. Pain usually causes vasoconstriction although severe pain may cause vasodilatation, a fall in blood pressure and fainting.
- *Reflex centres.* When irritating substances are present in the stomach or respiratory tract, nerve impulses pass to the medulla oblongata, stimulating the reflex centres, which initiate the reflex actions of vomiting, coughing and sneezing to expel the irritant.

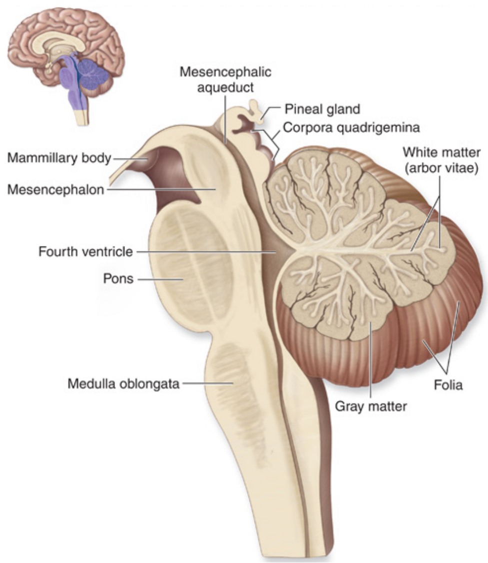
Reticular Formation

The reticular formation is a collection of neurones in the core of the brain stem, surrounded by neural pathways, which conduct ascending and descending nerve impulses between the brain and the spinal cord. It has a vast number of synaptic links with other parts of the brain and is therefore constantly receiving 'information' being transmitted in ascending and descending tracts.

The Reticular Formation Is Involved In:

- Coordination of skeletal muscle activity associated with voluntary motor movement and the maintenance of balance.
- Coordination of activity controlled by the autonomic nervous system and gastrointestinal activity.
- Selective awareness that functions through the *reticular activating system* (RAS), which selectively blocks or passes sensory information to the cerebral cortex, (e.g. the slight sound made by a sick child moving in bed may arouse his mother but the noise of regularly passing trains may be suppressed).

The Cerebellum



Cerebellum

The cerebellum is situated behind the pons and immediately below the posterior portion of the cerebrum occupying the posterior cranial fossa. It is ovoid in shape and has two hemispheres, separated by a narrow median strip called the *vermis.* Grey matter forms the surface of the cerebellum, and the white matter lies deeply.

The cerebellum is concerned with the coordination of voluntary muscular movement, posture and balance. Cerebellar activities are not under voluntary control. The cerebellum controls and coordinates the movements of various groups of muscles ensuring smooth, even, precise actions. It coordinates activities associated with the *maintenance of the balance and equilibrium* of the body.

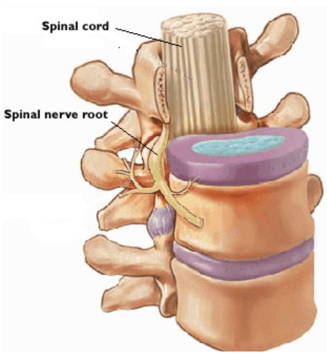
The sensory input for these functions is derived from the muscles and joints, the eyes and the ears. *Proprioceptor impulses* from the muscles and joints indicate their position in relation to the body as a whole and those impulses from the eyes and the semicircular canals in the ears pro- vide information about the position of the head in space. Impulses from the cerebellum influence the contraction of skeletal muscle so that balance and posture are maintained.

Damage to the cerebellum results in clumsy uncoordinated muscular movement, staggering gait and inability to carry out smooth, steady, precise movements.

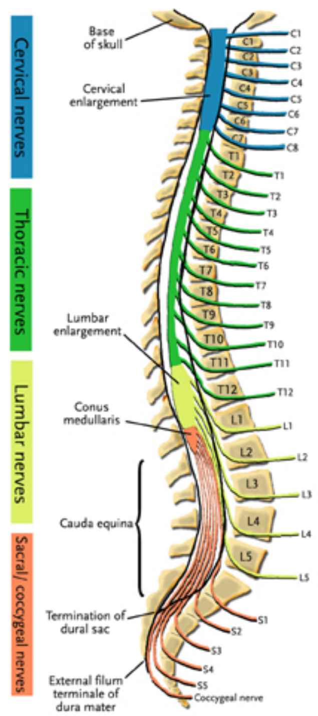
The Spinal Cord 2.4.3

The spinal cord is the elongated, almost cylindrical part of the central nervous system, which is suspended in the vertebral canal surrounded by the meninges and cerebroespinal fluid. It is continuous above with the medulla oblongata and extends from the *upper border of the atlas* to the lower border of the 1st *lumbar vertebra*. It is approximately 45 cm long, and is about the thickness of the little finger.

The Verterbrae



The Spinal Cord



Except for the cranial nerves, the spinal cord is the nervous tissue link between the brain and the rest of the body.

Nerves conveying impulses from the brain to the various organs and tissues descend through the spinal cord. At the appropriate level they leave the cord and pass to the structure they supply. Similarly, sensory nerves from organs and tissues enter and pass upwards in the spinal cord to the brain.

Some activities of the spinal cord are independent of the brain, i.e. *spinal reflexes.* To facilitate these there are extensive neurone connections between sensory and motor neurones at the same or different levels in the cord.

The spinal cord is incompletely divided into two equal parts, anteriorly by a short, shallow *median fissure* and posteriorly by a deep narrow septum, the *posteriormedian septum.*

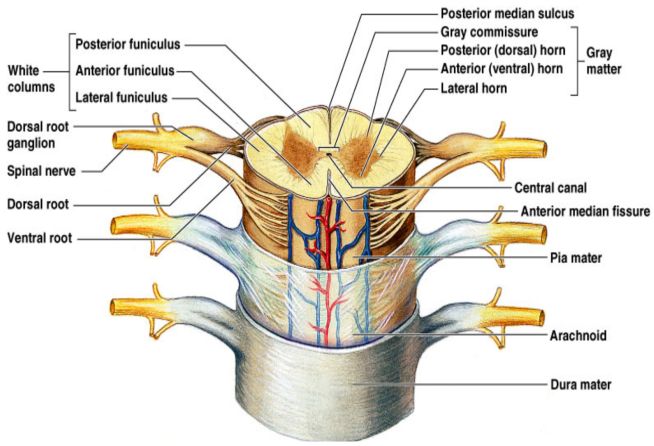
A cross-section of the spinal cord shows that it is composed of grey matter in the centre surrounded by white matter supported by neuroglia.
The other side is the same.

Grey Matter

The spinal cord resembles the shape of the letter H, having *two posterior, two anterior* and *two lateral columns.*

The area of grey matter lying transversely is the *transverse commissure* and the central canal, an extension from the fourth ventricle, containing cerebrospinal fluid, pierces it.

The Spinal Cord



The Cell Bodies May Be:

- *Sensory cells,* which receive impulses from the periphery of the body
- *Lower motor neurones,* which transmit impulses to the skeletal muscles
- *Connector neurones,* linking sensory and motor neurones, at the same or different levels, which form spinal reflex arcs.

At each point where nerve impulses are passed from one neurone to another there is a synaptic cleft and a neurotransmitter.

Posterior Columns Of Grey Matter

These are composed of cell bodies, which are stimulated by *sensory impulses* from the periphery of the body. The nerve fibres of these cells contribute to the formation of the white matter of the cord and transmit the sensory impulses upwards to the brain.

Anterior Columns Of Grey Matter

These are composed of the *cell bodies of the lower motor neurons,* which are stimulated by the axons of the upper motor neurones or by the *cell bodies of connector neurones* linking the anterior and posterior columns to form reflex arcs.

The posterior root (spinal) ganglia are composed of cell bodies, which lie just outside the spinal cord on the path- way of the sensory nerves. All sensory nerve fibres pass through these ganglia. The only function of the cells is to promote the onward movement of nerve impulses.

White Matter

The white matter of the spinal cord is arranged in three *columns* or *tracts;* anterior, posterior and lateral. These tracts are formed by *sensory nervefibres* ascending to the brain, *motor nerve fibres* descending from the brain and fibres of *connector neurones.*

Tracts are often named according to their points of origin and destination, e.g. spinothalamic, corticospinal.

Sensory Nerve Tracts (Afferent Or Ascending) In The Spinal Cord

There are two main sources of sensation transmitted to the brain via the spinal cord.

The Skin

Sensory receptors (nerve endings) in the skin, called *cutaneous receptors,* are stimulated by pain, heat, cold and touch, including pressure. Nerve impulses generated are conducted by three neurones to the sensory area in the *opposite hemisphere of the cerebrum* where the sensation and its location are perceived. Crossing to the other side, or *decussation,* occurs either at the level of entry into the cord or in the medulla.

The Tendons, Muscles and Joints

Sensory receptors are nerve endings in these structures, called *proprioceptors,* and they are stimulated by stretch. Together with impulses from the eyes and the ears they are associated with the maintenance of balance and posture and with perception of the position of the body in space.

These Nerve Impulses Have Two Destinations:

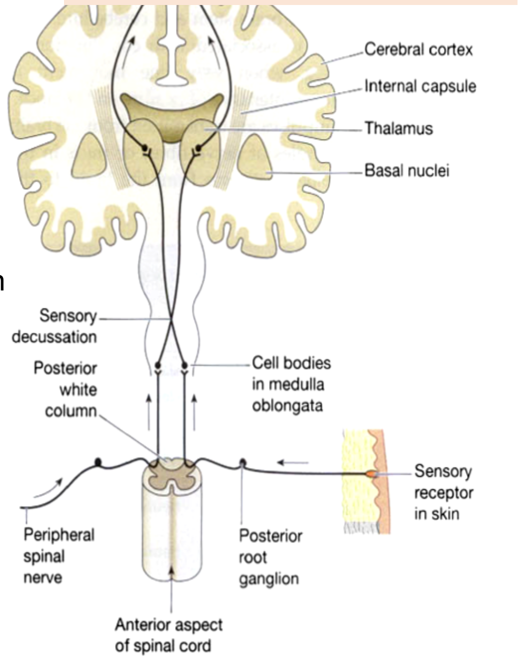
- By a three-neurone system the impulses reach the sensory area of the *opposite hemisphere of the cerebrum*
- By a two-neurone system the nerve impulses reach the *cerebellar hemisphere on the same side.*

Motor Nerve Tracts (Efferent Or Descending) In The Spinal Cord

Neurones, which transmit nerve impulses away from the brain, are motor (efferent or descending) neurones.

Motor Neurone Stimulation Results In:

- Contraction of skeletal (striated, voluntary) muscle.
- Contraction of smooth (involuntary) muscle, cardiac muscle and the secretion by glands controlled by the *autonomic nervous system*.



Voluntary Muscle Movement

The contraction of the muscles, which move the joints, is, in the main, under conscious (voluntary) control, which means that the stimulus to contract originates at the level of consciousness in the cerebrum.

However, some nerve impulses, which affect skeletal muscle contraction, are initiated in the midbrain, brain stem and cerebellum. This involuntary activity is associated with coordination of muscle activity, e.g. when very fine movement is required and in the maintenance of posture and balance.

Efferent nerve impulses are transmitted from the brain to the body via bundles of nerve fibres or *tracts* in the spinal cord.

The *motor pathways* from the brain to the muscles are made up of two *neurones*.

These Tracts Are Either:

- Pyramidal (corticospinal).
- Extrapyramidal.

The motor fibres that form the pyramidal tracts travel through the internal capsule and are the main pathway for impulses to voluntary (skeletal) muscles. Those motor fibres that do not pass through the internal capsule form the extrapyramidal tracts and have connections with multiple parts of the brain (including the basal nuclei and the thalamus).

The Upper Motor Neurone

This has its cell body (Betz's cell) in the *precentral sulcus area* of the cerebrum. The axons pass through the internal capsule, pons and medulla. In the spinal cord they form the *lateral corti-cospinal tracts* of white matter and the fibres terminate in close association with the cell bodies of the *lower motor neurones* in the anterior columns of grey matter.

The axons of these upper motor neurones make up the pyramidal tracts and decussate in the medulla oblongata, forming the pyramids.

The Lower Motor Neurone

This has its cell body in the *anterior horn of grey matter* in the spinal cord. Its axon emerges from the spinal cord by the *anterior root,* joins with the incoming sensory fibres and forms the *mixed spinal nerve* which passes through the *intervertebral foramen.* Near its termination in muscle the axon branches into a variable number of tiny fibres, which form *motor endplates,* each of which is in close association with a sensitive area on the wall of a muscle fibre. The motor endplates of each nerve and the muscle fibres they supply form a *motor unit*.

The neurotransmitter that conveys the nerve impulse across the synapse to stimulate the muscle fibre is *acetylcholine.* Motor units contract as a whole and the strength of contraction of a muscle depends on the number of motor units in action at a time.

The lower motor neurone has been described as the *final common pathway* for the transmission of nerve impulses to skeletal muscles. The cell body of this neurone is influenced by a number of upper motor neurones originating from various sites in the brain and by some neurons, which begin and end in the spinal cord.

Some of these neurones stimulate the cell bodies of the lower motor neurone while others have an inhibiting effect. The outcome of these influences is smooth, coordinated muscle movement, some of which is voluntary and some involuntary.

Involuntary Muscle Movement

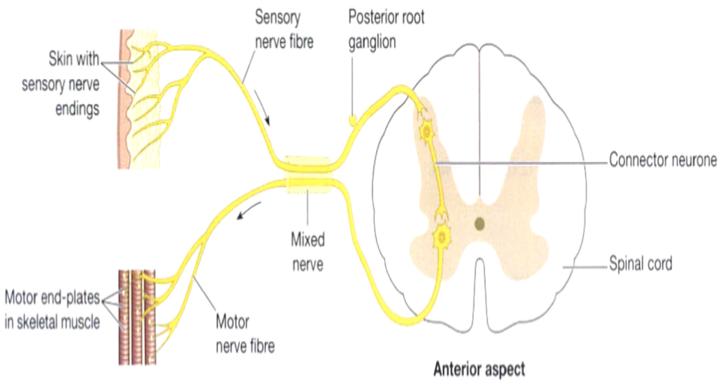
Upper Motor Neurones.

These have their cell bodies in the brain at a level *below* the cerebrum, i.e. in the midbrain, brain stem, cerebellum or spinal cord. They influence muscle activity in relation to the maintenance of posture and balance, the coordination of muscle movement and the control of muscle tone.

Spinal Reflexes

These Consist Of Three Elements:

- Sensory neurons.
- Connector neurones in the spinal cord.
- Lower motor neurones.



In the simplest *reflex arc* there is only one of each. A *reflex action* is an immediate motor response to a sensory stimulus. Many connector and motor neurones may be stimulated by afferent impulses from a small area of skin, e.g. the pain impulses initiated by touching a very hot surface with the finger are transmitted to the spinal cord by sensory nerves. These stimulate many connector and lower motor neurones in the cord, which results in the contraction of many skeletal muscles of the hand, arm and shoulder, and the removal of the finger.

Reflex action takes place very quickly, in fact, the motor response may have occurred simultaneously with the perception of the pain in the cerebrum. Reflexes of this type are invariably protective but they can on occasion be inhibited.

Stretch Reflexes

Only two neurones are involved. The cell body of the lower motor neurone is stimulated by the sensory neurone. There is no connector neurone involved. The *knee jerk* is one example, but this type of reflex can be demonstrated at any point where a stretched tendon crosses a joint. By tapping the tendon just below the knee when it is bent, the sensory nerve endings in the tendon and in the thigh muscles are stretched. This initiates a nerve impulse, which passes into the spinal cord to the cell body of the lower motor neurone in the anterior column of grey matter on the same side. As a result the thigh muscles suddenly contract and the foot kicks forward. This is used as a test of the integrity of the reflex arc. This type of reflex has a protective function it prevents excessive joint movement that may damage tendons, ligaments and muscles.

Peripheral Nervous System 2.4.4

This Part Of The Nervous System Consists Of:

- 31 pairs of spinal nerves.
- 12 pairs of cranial nerves.
- The autonomic part of the nervous system.

Most of the nerves of the peripheral nervous system are composed of *sensory nerve fibres* conveying afferent impulses from sensory end organs to the brain, and *motor nerve fibres* conveying efferent impulses from the brain through the spinal cord to the effector organs, e.g. skeletal muscles, smooth muscle and glands.

Each nerve consists of numerous nerve fibres collected into bundles. Each bundle has several coverings of protective connective tissue.

There Structure Includes:

- *Endoneurium* is a delicate tissue, surrounding each individual fibre, which is continuous with the septa that pass inwards from the perineurium.
- *Perineurium* is a smooth connective tissue, surrounding each *bundle* of fibres.
- *Epineurium* is the fibrous tissue, which surrounds and encloses a number of bundles of nerve fibres. Most large nerves are covered by epineurium.

Spinal Nerves

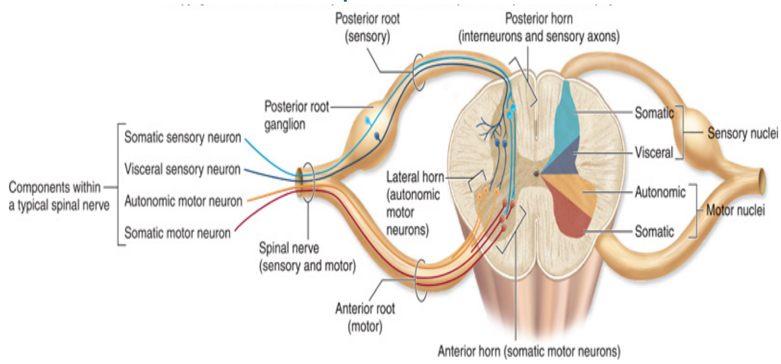
There are *31 pairs of spinal nerves* that leave the vertebral canal by passing through the intervertebral foramina formed by adjacent vertebrae. They are named and grouped according to the vertebrae they are associated with.

These Are:

- 8 cervical
- 12 thoracic
- 5 lumbar

- 5 sacral
- 1 coccygeal

Spinal Nerve



Although there are only seven cervical vertebrae, there are eight nerves because the first pair leaves the vertebral canal between the occipital bone and the atlas and the eighth pair leaves below the last cervical vertebra. Thereafter the nerves are given the name and number of the vertebra immediately *above.*

The lumbar, sacral and coccygeal nerves leave the *spinal cord* near its termination at the level of the first lumbar vertebra, and extend downwards inside the vertebral canal in the subarachnoid space, forming a sheaf of nerves, which resembles a horse's tail, the *cauda equina.* These nerves leave the vertebral canal at the appropriate lumbar, sacral or coccygeal level, depending on their destination.

The spinal nerves arise from both sides of the spinal cord and emerge through the inter-vertebral foramina. Each nerve is formed by the union of a *motor and a sensory nerve root* and is, therefore, a *mixed nerve.* Each spinal nerve has a contribution from the sympathetic part of the autonomic nervous system in the form of a *preganglionic fibre*.

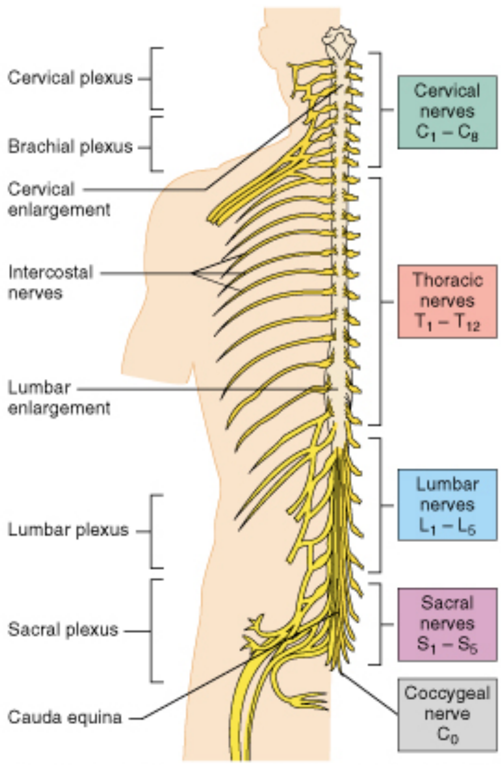
Nerve Roots

The anterior nerve root consists of *motor nerve fibres,* which are the axons of the nerve cells in the anterior column of grey matter in the spinal cord and, in the thoracic and lumbar regions, *sympathetic nerve fibres,* which are the axons of cells in the lateral columns of grey matter.

The posterior nerve root consists of *sensory nerve fibres.* Just outside the spinal cord there is a *spinal ganglion* (posterior root ganglion), consisting of a little cluster of cell bodies. Sensory nerve fibres pass through these ganglia before entering the spinal cord. The area of skin supplied by each nerve is called a *dermatome*.

For a very short distance after leaving the spinal cord the nerve roots have a covering of *dura* and *arachnoid maters.* These terminate before the two roots join to form the mixed spinal nerve. The nerve roots have no covering of pia mater.

Spinal Nerve Roots



Immediately after emerging from the intervertebral foramen each spinal nerve divides into a ramus commu- nicans, a posterior ramus and an anterior ramus.

The rami communicans are part of preganglionic sympathetic neurones of the autonomic nervous system. *The posterior rami* pass backwards and divide into medial and lateral branches to supply skin and muscles of relatively small areas of the posterior aspect of the head, neck and trunk. *The anterior rami* supply the anterior and lateral aspects of the neck, trunk and the upper and lower limbs.

In the cervical, lumbar and sacral regions the anterior rami unite near their origins to form large masses of nerves, or *plexuses,* where nerve fibres are regrouped and rearranged before proceeding to supply skin, bones, muscles and joints of a particular area. This means that these structures have a nerve supply from more than one spinal nerve and therefore damage to one spinal nerve does not cause loss of function of a region.

In the thoracic region the anterior rami do not form plexuses.

There are five large plexuses of mixed nerves formed on each side of the vertebral column.

They Are The:

- Cervical plexuses.
- Brachial plexuses.
- Lumbar plexuses.
- Sacral plexuses.
- Coccygeal plexuses.

Cervical Plexus

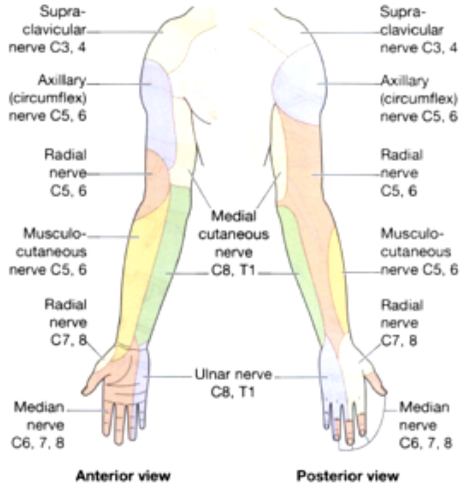
This is formed by the anterior rami of the first four cervical nerves. It lies opposite the 1st, 2nd, 3rd and 4th cervical vertebrae under the protection of the sterno-cleidomastoid muscle.

The superficial branches supply the structures at the back and side of the head and the skin of the front of the neck to the level of the sternum.

The deep branches supply muscles of the neck, e.g. the sternocleidomastoid and the trapezius.

The phrenic nerve originates from cervical roots 3,4 and 5 and passes downwards through the thoracic cavity in front of the root of the lung to supply the muscle of the diaphragm with impulses, which stimulate contraction.

Nerve Sensations Of The Arms



Brachial Plexus

The anterior rami of the lower four cervical nerves and a large part of the first thoracic nerve form the brachial plexus. The plexus is situated in the neck and shoulder above and behind the subclavian vessels and in the axilla.

The branches of the brachial plexus supply the skin and muscles of the upper limbs and some of the chest muscles. Five large nerves and a number of smaller ones emerge from this plexus, each with a contribution from more than one nerve root, containing sensory, motor and autonomic fibres.

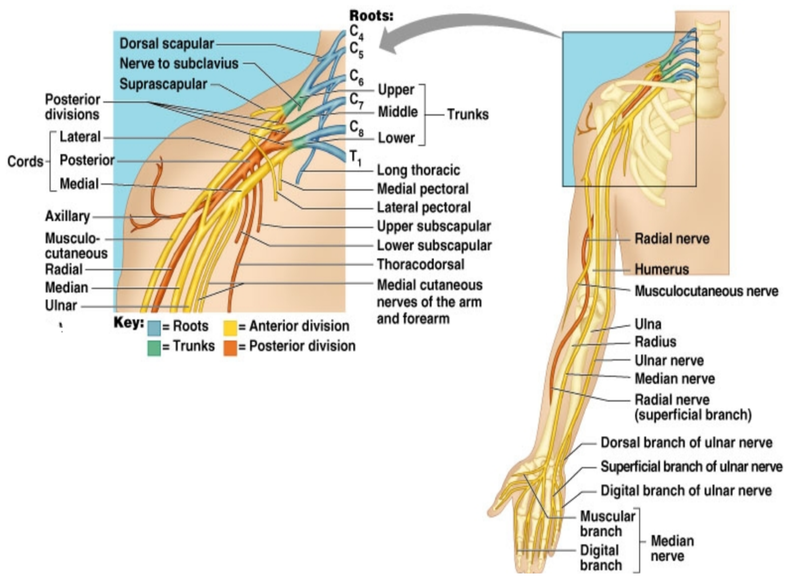
These Are:

- Axillary (circumflex) nerve: C5, C6.
- Radial nerve: C5, C6, C7, C8, T1.
- Musculo-cutaneous nerve: C5, C6, C7.
- Median nerve: C5, C6, C7, C8, T1.
- Ulnar nerve: C7, C8, T1.
- Medial cutaneous nerve: C8, T1.

The Axillary (Circumflex) Nerve

Winds round the humerus at the level of the surgical neck. It then breaks up into minute branches to supply the deltoid muscle, shoulder joint and overlying skin.

Nerve Roots Of The Arm



The Radial Nerve

The largest branch of the brachial plexus. It supplies the triceps muscle behind the humerus, crosses in front of the elbow joint then winds round to the back of the forearm to supply extensors of the wrist and finger joints.

It continues into the back of the hand to supply the skin of the thumb, the first two fingers and the lateral half of the third finger.

The Musculo-Cutaneous Nerve

Passes downwards to the lateral aspect of the forearm. It supplies the muscles of the upper arm and the skin of the forearm.

The Median Nerve

Passes down the midline of the arm in close association with the brachial artery. It passes in front of the elbow joint then down to supply the muscles of the front of the forearm. It continues into the hand where it supplies small muscles and the skin of the front of the thumb, the first two fingers and the lateral half of the third finger. It gives off no branches above the elbow.

The ulnar nerve descends through the upper arm lying medial to the brachial artery. It passes behind the medial epicondyle of the humerus to supply the muscles on the ulnar aspect of the forearm. It continues downwards to supply the muscles in the palm of the hand and the skin of the whole of the little finger and the medial half of the third finger. It gives off no branches above the elbow.

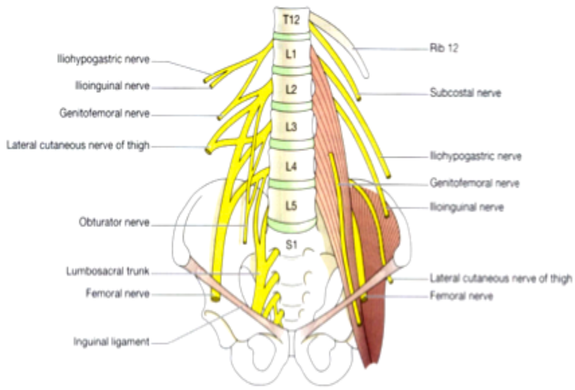
Lumbar Plexus

The lumbar plexus is formed by the anterior rami of the first three and part of the fourth lumbar nerves. The plexus is situated in front of the transverse processes of the lumbar vertebrae and behind the psoas muscle.

The Main Branches, And Their Nerve Roots Are:

- Iliohypogastric nerve: L1.
- Ilioinguinal nerve: L1.
- Genitofemoral: L1, L2.
- Lateral cutaneous nerve of thigh: L2, L3.
- Femoral nerve: L2, L3, L4.
- Obturator nerve: L2, L3, L4.
- Lumbosacral trunk: L4, L5.

Lumbar Plexus



Iliohypogastric, Ilioinguinal And Genito-Femoral Nerves

Supply muscles and the skin in the area of the lower abdomen, upper and medial aspects of the thigh and the inguinal region.

The Lateral Cutaneous Nerve Of The Thigh

Supplies the skin of the lateral aspect of the thigh including part of the anterior and posterior surfaces.

The Femoral Nerve

One of the larger branches. It passes behind the inguinal ligament to enter the thigh in close association with the femoral artery. It divides into cutaneous and muscular branches to supply the skin and the muscles of the front of the thigh. One branch, the *saphenous nerve,* supplies the medial aspect of the leg, ankle and foot.

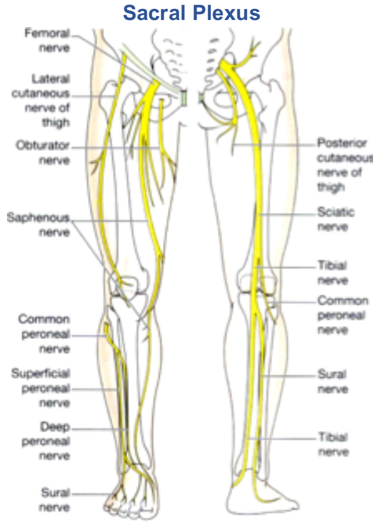
The Obturator Nerve

Supplies the adductor muscles of the thigh and skin of the medial aspect of the thigh. It ends just above the level of the knee joint.

The Lumbo-Sacral Trunk

Descends into the pelvis and makes a contribution to the sacral plexus.

Sacral Plexus



Sacral Plexus

The sacral plexus is formed by the anterior rami of the lumbosacral trunk and the first, second and third sacral nerves. The lumbosacral trunk is formed by the fifth and part of the fourth lumbar nerves. It lies in the posterior wall of the pelvic cavity.

The sacral plexus divides into a number of branches, supplying the muscles and skin of the pelvic floor, muscles around the hip joint and the pelvic organs. In addition to these it provides the *sciatic nerve* which contains fibres from L4, 5, S1, 2, 3.

Sciatic Nerve

The largest nerve in the body. It is about 2 cm wide at its origin. It passes through the greater sciatic foramen into the buttock then descends through the posterior aspect of the thigh supplying the hamstring muscles. At the level of the middle of the femur it divides to form the *tibial* and the *common-peroneal nerves.*

The tibial nerve descends through the popliteal fossa to the posterior aspect of the leg where it supplies muscles and skin. It passes under the medial malleolus to supply muscles and skin of the sole of the foot and toes.

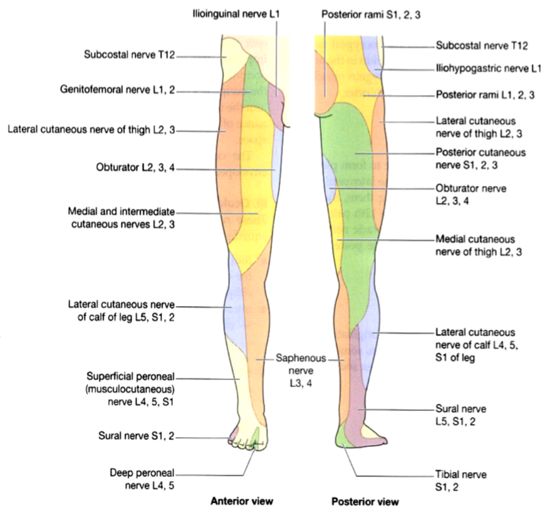
One of the main branches is the *sural nerve,* which supplies the tissues in the area of the heel, the lateral aspect of the ankle and a part of the dorsum of the foot.

Common Peroneal Nerve

Descends obliquely along the lateral aspect of the popliteal fossa, winds round the neck of the fibula into the front of the leg where it divides into the *deep peroneal* (anterior tibial) and the *superficial peroneal* (musculocutaneous) nerves. These nerves supply the skin and muscles of the anterior aspect of the leg and the dorsum of the foot and toes.

Pudendal Nerve (S2, S3, S4)

The perineal branch supplies the external anal sphincter, the external urethral sphincter and adjacent skin



Coccygeal Plexus

The coccygeal plexus is a very small plexus formed by part of the fourth and fifth sacral and the coccygeal nerves. The nerves from this plexus supply the skin in the area of the coccyx and the levators ani and coccygeus muscles of the pelvic floor and the external anal sphincter.

Thoracic Nerves

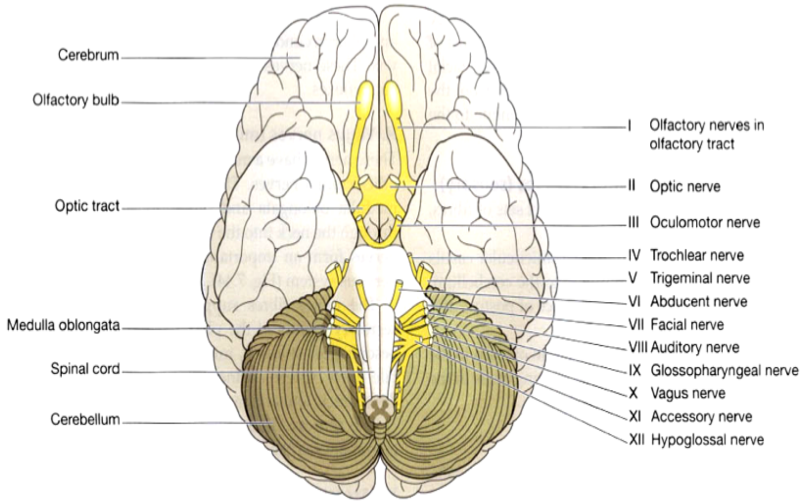
The thoracic nerves *do not* intermingle to form plexuses. There are 12 pairs and the first 11 are the *inter-costal nerves.* They pass between the ribs supplying them, the inter- costal muscles and overlying skin. The 12th pair are the *sub-costal nerves.* The 7th to the 12th thoracic nerves also supply the muscles and the skin of the posterior and anterior abdominal walls.

The Cranial Nerves 2.4.5

There are 12 pairs of cranial nerves originating from nuclei in the inferior surface of the brain, some sensory, some motor and some mixed.

Their Names And Numbers Are:

I. Olfactory: sensory
II. Optic: sensory
III. Oculomotor: motor
IV. Trochlear: motor
V. Trigeminal: mixed
VI. Abducent: motor
VII. Facial: mixed
VIII. Vestibulocochlear (auditory): sensory
IX. Glossopharyngeal: mixed
X. Vagus: mixed
XI Accessory: motor
XII. Hypoglossal: motor.



I. Olfactory Nerves (Sensory)

These are the nerves of the *sense of smell.* Their nerve endings and fibres originate in the upper part of the mucous membrane of the nasal cavity, pass upwards through the cribriform plate of the ethmoid bone and then go to the *olfactory bulb*.

The nerves then proceed backwards as the olfactory tract, to the area for the perception of smell in the temporal lobe of the cerebrum.

i. Olfactory Nerve

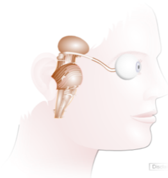
II. Optic Nerves (Sensory)

These are the nerves of the *sense of sight.* The fibres originate in the retinae of the eyes and they combine to form the optic nerves. They are directed backwards and medially through the posterior part of the orbital cavity. They then pass through the *optic foramina* of the sphenoid bone into the cranial cavity and join at the *optic chiasma.*

The nerves proceed backwards as the *optic tracts* to the *lateral geniculate bodies* of the thalamus. Impulses pass from these to the centre for sight in the occipital lobes of the cerebrum and to the cerebellum. In the occipital lobe sight is perceived, and in the cerebellum the impulses from the eyes contribute to the maintenance of balance, posture and orientation of the head in space.

The central retinal artery and vein enter the eye enveloped by the fibres of the optic nerve.

II. Optic Nerve



III. Oculomotor Nerves (Motor)

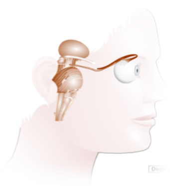
These nerves arise from nerve cells near the cerebral aqueduct. They supply:

- Four extraocular muscles, which move the eyeball, i.e. the *superior, medial* and *inferior recti* and the *inferior oblique muscle.*

III. Oculomotor Nerve

- Intraocular muscles:
  - *Ciliary muscles,* which alter the shape of the lens, changing its refractive power.
  - *Circular muscles of the iris,* which constrict the pupil
- The *levator palpebrae* muscle, which raises the upper eyelid.

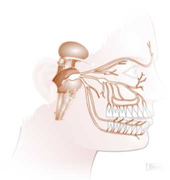
IV. Trochler Nerve



IV. Trochlear Nerves (Motor)

These nerves arise from nerve cells near the cerebral aqueduct. They supply the *superior oblique muscles* of the eyes.

V. Trigeminal Nerve



V. Trigeminal Nerves (Mixed)

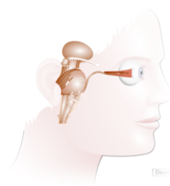
These nerves contain motor and sensory fibres and are among the largest of the cranial nerves. They are the chief sensory nerves for the face and head (including the oral and nasal cavities and teeth), receiving impulses of pain, temperature and touch. The motor fibres stimulate the muscles of mastication.

There are three main branches of the trigeminal nerves. *The ophthalmic nerves* are sensory only and supply the lacrimal glands, conjunctiva of the eyes, forehead, eyelids, anterior aspect of the scalp and mucous membrane of the nose.

The maxillary nerves are sensory only and supply the cheeks, upper gums, upper teeth and lower eyelids.

The mandibular nerves contain both sensory and motor fibres. These are the largest of the three divisions and they supply the teeth and gums of the lower jaw, pinnae of the ears, lower lip and tongue. The motor fibres supply the muscles of mastication.

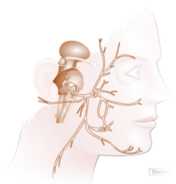
VI. Abducent Nerve



VI. Abducent Nerves (Motor)

These nerves arise from a group of nerve cells lying under the floor of the fourth ventricle. They supply the *lateral rectus muscles* of the eyeballs.

VII. Facial Nerve



VII. Facial Nerves (Mixed)

These nerves are composed of both motor and sensory nerve fibres, arising from nerve cells in the lower part of the pons. The motor fibres supply the muscles of facial expression.

The sensory fibres convey impulses from the taste buds in the anterior two-thirds of the tongue to the taste perception area in the cerebral cortex.

VIII. Vestibulochlear Nerve

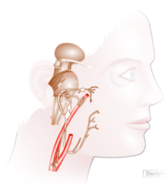
VIII. Vestibulocochlear (Auditory) Nerves (Sensory)

These nerves are composed of two distinct sets of fibres, vestibular nerves and cochlear nerves.

The vestibular nerves arise from the semicircular canals of the inner ear and convey impulses to the cerebellum. They are associated with the maintenance of posture and balance.

The cochlear nerves originate in the organ of Corti in the inner ear and convey impulses to the hearing areas in the cerebral cortex where sound is perceived.

IX. Glossopharyngeal Nerve



IX. Glossopharyngeal Nerves (Mixed)

These nerves arise from nuclei in the medulla oblongata. The motor fibres stimulate the muscles of the tongue and pharynx and the secretory cells of the parotid (salivary) glands.

The sensory fibres convey impulses to the cerebral cortex from the posterior third of the tongue, the tonsils and pharynx and from taste buds in the tongue and pharynx.

These nerves are essential for the swallowing and gag reflexes.

X. Vagus Nerve

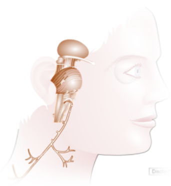
X. Vagus Nerves (Mixed)

These nerves have a more extensive distribution than any other cranial nerves. They arise from nerve cells in the medulla oblongata and other nuclei, and pass down through the neck into the thorax and the abdomen. These nerves form an important part of the parasympathetic nervous system.

The motor fibres supply the smooth muscles and secretory glands of the pharynx, larynx, trachea, heart, oesophagus, stomach, intestines, pancreas, gall bladder, bile ducts, spleen, kidneys, ureter and blood vessels in the thoracic and abdominal cavities.

The sensory fibres convey impulses from the lining membranes of the same structures to the brain.

XI. Accessory Nerve



XII. Hypoglossal Nerve

XI. Accessory Nerves (Motor)

These nerves arise from cell bodies in the medulla oblongata and in the spinal cord. The fibres supply the *sternocleidomastoid* and *trapezius muscles.*

Branches join the vagus nerves and supply the *pharyngeal* and *laryngeal muscles.*

XII. Hypoglossal Nerves (Motor)

These nerves arise from cells in the medulla oblongata.

They supply the muscles of the tongue and muscles surrounding the hyoid bone and contribute to swallowing and speech.

Summary of the cranial nerves			
Name *and* no.	**Central connection**	**Peripheral connection**	**Function**
I. Olfactory (sensory)	Smell area in temporal lobe of cerebrum through olfactory bulb	Mucous membrane in roof of nose	Sense of smell
II. Optic (sensory)	Sight area in occipital lobe of cerebrum Cerebellum	Retina of the eye	Sense of sight Balance
III. Oculomotor (motor)	Nerve cells near floor of aqueduct of midbrain	Superior, inferior and medial rectus muscles of the eye Ciliary muscles of the eye Circular muscle fibres of the iris	Moving the eyeball. Focusing Regulating the size of the pupil
IV. Trochlear (motor)	Nerve cells near floor of aqueduct of midbrain	Superior oblique muscles of the eye	Movement of the eyeball
V. Trigeminal (mixed)	Motor fibres from the pons Sensory fibres from the trigeminal ganglion	Muscles of mastication Sensory to gums, cheek, lower jaw, iris, cornea	Chewing Sensation from the face
VI. Abducent (motor)	Floor of fourth ventricle	Lateral rectus muscle of the eye	Movement of the eye
VII. Facial (mixed)	Pons	Sensory fibres to the tongue Motor fibres to the muscles of the face	Sense of taste Movements of facial expression
VIII. Vestibulocochlear (sensory) (a) Vestibular (b) Cochlear	Cerebellum Hearing area of cerebrum	Semicircular canals in the inner ear Organ of Corti in cochlea	Maintenance of balance Sense of hearing
IX. Glossopharyngeal (mixed)	Medulla oblongata	Parotid gland Back of tongue and pharynx	Secretion of saliva Sense of taste Movement of pharynx
X. Vagus (mixed)	Medulla oblongata	Pharynx, larynx; organs, glands ducts, blood vessels in the thorax and abdomen	Movement and secretion
XI. Accessory (motor)	Medulla oblongata	Sternocleidomastoid, trapezius, laryngeal and pharyngeal muscles	Movement of the head, shoulders, pharynx and larynx
XII. Hypoglossal (motor)	Medulla oblongata	Tongue	Movement of tongue

THE AUDITORY SYSTEM 2.5

The Ear

The ear is the organ of hearing. It is supplied by the 8th *cranial nerve,* i.e. the *cochlear part* of the *vestibulocochlear* nerve, which is stimulated by vibrations caused by sound waves.

With the exception of the auricle (pinna), the structures that form the ear are encased within the petrous portion of the temporal bone.

The Ear Is Divided Into Three Distinct Parts:

- Outer ear.
- Middle ear (tympanic cavity).
- Inner ear.

Outer Ear

The outer ear consists of the auricle (pinna) and the external acoustic meatus.

The Auricle (pinna)

The auricle is the expanded portion projecting from the side of the head. It is composed of *fibroelastic cartilage* covered with skin. It is deeply grooved and ridged and the most prominent outer ridge is the *helix.*

The lobule (earlobe) is the soft pliable part at the lower extremity, composed of fibrous and adipose tissue richly supplied with blood.

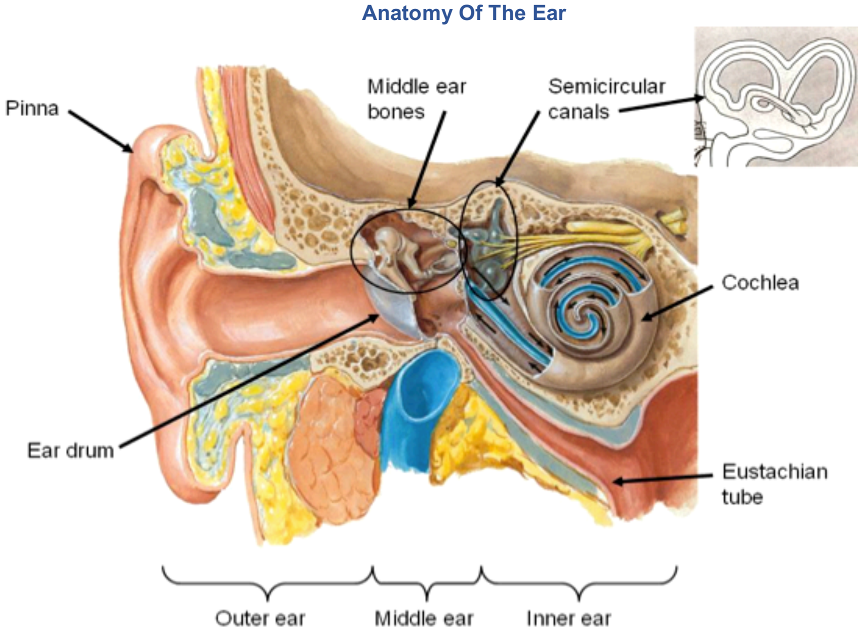
External Acoustic Meatus (Auditory Canal)

This is a slightly 'S'-shaped tube about 2.5cm long extending from the auricle to the *tympanic membrane* (eardrum). The lateral third is cartilaginous and the remainder is a canal in the temporal bone. The meatus is lined with skin containing hairs continuous with that of the auricle. There are numerous *sebaceous* and *ceruminous glands* in the skin of the lateral third.

Ceruminous glands are modified sweat glands that secrete *cerumen* (wax), a sticky material containing lysozyme and immunoglobulins. Foreign materials, e.g. dust, insects and microbes, are prevented from reaching the tympanic membrane by wax, hairs and the curvature of the meatus. Movements of the temporomandibular joint during chewing and speaking 'massage' the cartilaginous meatus, moving the wax towards the exterior.

The tympanic membrane (eardrum) completely separates the external acoustic meatus from the middle ear. It is oval-shaped with the slightly broader edge upwards and is formed by three types of tissue: the outer covering of *hairless skin,* the middle layer of *fibrous tissue* and the inner lining of *mucous membrane* continuous with that of the middle ear.

Anatomy Of The Ear



Middle Ear (Tympanic Cavity)

This is an irregular-shaped *air-filled* cavity within the petrous portion of the temporal bone. The cavity, its con- tents and the air sacs, which open out of it are lined with either simple squamous or cuboidal epithelium.

The lateral wall of the middle ear is formed by the tympanic membrane.

The roof and floor are formed by the temporal bone.

The posterior wall is formed by the temporal bone with openings leading to the *mastoid antrum* through which air passes to the air cells within the mastoid process.

Tympanic Membrane

The medial wall is a thin layer of temporal bone in which there are two openings:

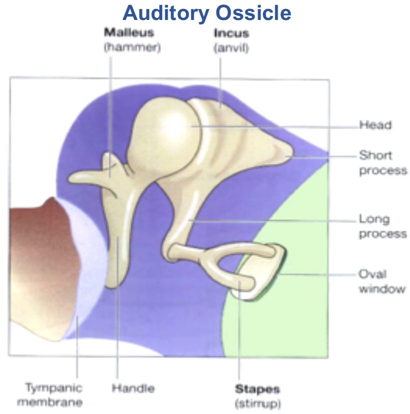
- Oval window.
- Round window.

The oval window is occluded by part of a small bone called the *stapes* and the round window, by a fine sheet *of fibrous tissue.*

Air reaches the cavity through the *pharyngotympanic* (*auditory or Eustachian)* tube, which extends from the nasopharynx. It is about 4 cm long and is lined with ciliated epithelium. The presence of air at atmospheric pressure on both sides of the tympanic membrane is maintained by the pharyngotympanic tube and enables the membrane to vibrate when sound waves strike it. The pharyngotympanic tube is normally closed but when there is unequal pressure across the tympanic membrane, e.g. at high altitude, swallowing opens it or yawning and the ears 'pop', equalising the pressure again.

Auditory Ossicles

Auditory Ossicle



These are three very small bones that extend across the middle ear from the tympanic membrane to the oval window. They form a series of movable joints with each other and with the medial wall of the cavity at the oval window. They are named according to their shapes. *The malleus.* This is the lateral hammer-shaped bone.

The handle is in contact with the tympanic membrane and the head forms a movable joint with the incus.

The incus. This is the middle anvil-shaped bone. Its body articulates with the malleus, the long process with the stapes, and it is stabilised by the short process, fixed by fibrous tissue to the posterior wall of the tympanic cavity.

The stapes. This is the medial stirrup-shaped bone. Its head articulates with the incus and its footplate fits into the oval window.
The three ossicles are held in position by fine ligaments.

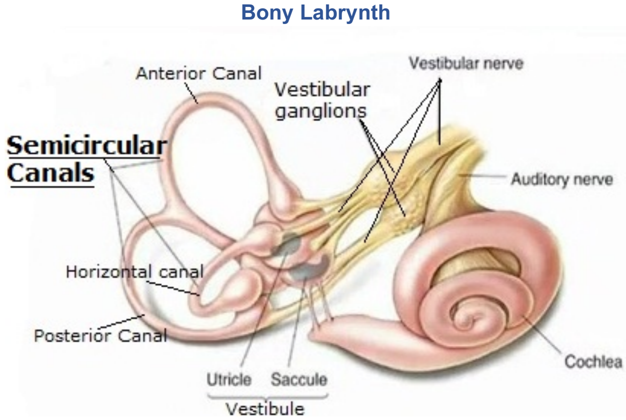
Inner Ear

The inner (internal) ear or labyrinth (meaning 'maze') ear contains the organs of hearing and balance. It is generally described in two parts, the *bony labyrinth* and the *membranous labyrinth.*

Bony Labyrinth

This is a cavity within the temporal bone lined with periosteum. It is larger than, and encloses, the membranous labyrinth of the same shape, which fits into it, like a tube within a tube. Between the bony and membranous labyrinth there is a layer of watery fluid called *perilymph* and within the membranous labyrinth there is a similarly watery fluid, *endolymph.*

Bony Labrynth



The Bony Labyrinth Consists Of:

- 1 vestibule.
- 1 cochlea.
- Semicircular canals.

The Vestibule

This is the expanded part nearest the middle ear. It contains the oval and round windows in its lateral wall.

The Cochlea

This resembles a snail's shell. It has a broad base where it is continuous with the vestibule and a narrow apex, and it spirals round a central bony column.

The Semicircular Canals

These are three tubes arranged so that one is situated in each of the three planes of space. They are continuous with the vestibule.

Membranous Labyrinth

This contains endolymph and lies within its bony counterpart.

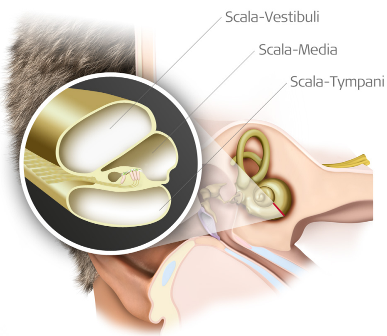
It Comprises:

- The vestibule, which contains the *utricle* and *saccule*
- The cochlea
- Three semicircular canals.

The Cochlea

A Cross-Section Of The Cochlea Contains Three Compartments:

The Cochlea



- The Scala vestibule.
- The scala media, or *cochlear duct.*
- The scala tympani.

In cross-section the bony cochlea has two compartments containing perilymph: the scala vestibuli, which originates at the oval window, and the scala tympani, which ends at the round window. The two compartments are continuous with each other.

The cochlear duct is part of the membranous labyrinth and is triangular in shape. On the *basilar membrane,* or base of the triangle, there are *supporting cells* and specialised *cochlear hair cells* containing auditory receptors. These cells form the *spiral organ* (of Corti), the sensory organ that responds to vibration by initiating nerve impulses that are then perceived as hearing by the brain.

The *auditory receptors* are dendrites of efferent nerves that combine forming the cochlear (auditory) part of the vestibul-ocochlear nerve (8th cranial nerve), which passes through a foramen in the temporal bone to reach the hearing area in the temporal lobe of the cerebrum

The Semicircular Canals and Vestibule

The semicircular canals have no auditory function although they are closely associated with the cochlea. They provide information about the position of the head in space, contributing to maintenance of posture and balance.

There are three semicircular canals, one lying in each of the three planes of space. They are situated above and behind the vestibule of the inner ear and open into it.

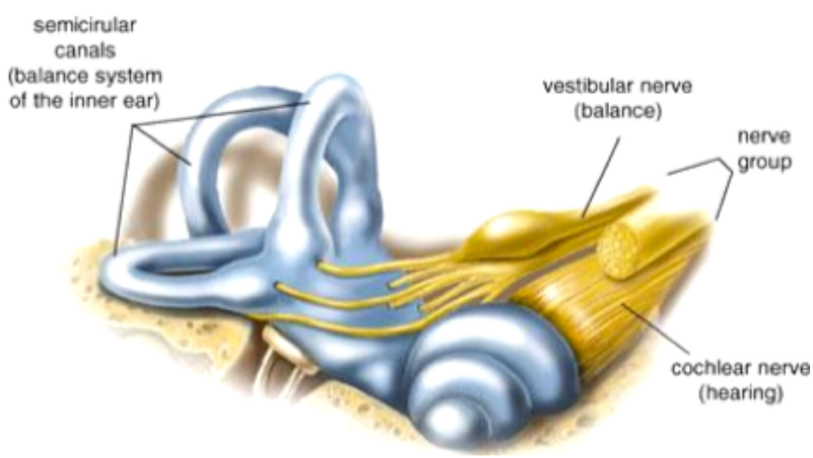
The semicircular canals, like the cochlea, are composed of an outer bony wall and inner membranous tubes or *ducts.* The membranous ducts contain endolymph and are separated from the bony wall by perilymph.

The utricle is a membranous sac, which is part of the vestibule and the three membranous ducts open into it at their dilated ends, the *ampullae.* The *saccule* is a part of the vestibule and communicates with the utricle and the cochlea.

In the walls of the utricle, saccule and ampullae there are fine specialised epithelial cells with minute projec- tions, called *hair cells.* Amongst the hair cells there are sensory nerve endings, which combine forming the *vestibular part* of the vestibulocochlear nerve.

Physiology of Balance

The Organ Of Ballance



The semicircular canals and the vestibule (utricle and saccule) are concerned with balance. Any change of position of the head causes movement in the perilymph and endolymph, which bends the hair cells and stimulates the sensory nerve endings in the utricle, saccule and ampullae.

The resultant nerve impulses are transmitted by the vestibular nerve, which joins the cochlear nerve to form the vestibulocochlear nerve. The vestibular branch passes first to the *vestibular nucleus,* then to the *cerebellum.*

The cerebellum also receives nerve

impulses from the eyes and proprioceptors (sensory receptors) in the skeletal muscles and joints. Impulses from these three sources are coordinated and efferent nerve impulses pass to the cerebrum and to skeletal muscles. This results in awareness of body position, maintenance of upright posture and fixing of the eyes on the same point, independently of head movements.

THE URINARY SYSTEM 2.6

The urinary system is one of the excretory systems of the body.

It Consists Of The Following Structures:

- 2 kidneys (which secrete urine).
- 2 ureters (which convey the urine from the kidneys to the urinary bladder).
- 1 urinary bladder (where urine collectsand is temporarily stored).
- 1 urethra (through which the urine is discharged from the urinary bladder to the exterior).

The urinary system plays a vital part in maintaining homeostasis of water and electrolyte concentrations within the body. The kidneys produce urine that contains metabolic waste products, including water, the nitrogenous compounds urea and uric acid, excess ions and some drugs.

The Main Functions Of The Kidneys Are:

- Formation and secretion of urine.
- Production and secretion of erythropoietin (the hormone responsible for controlling the rate of formation of red blood cells).
- Production and secretion of renin (an important enzyme in the control of blood pressure).
- Assisting in acid base balance.

Urine is stored in the bladder and excreted by the process of *micturition.*

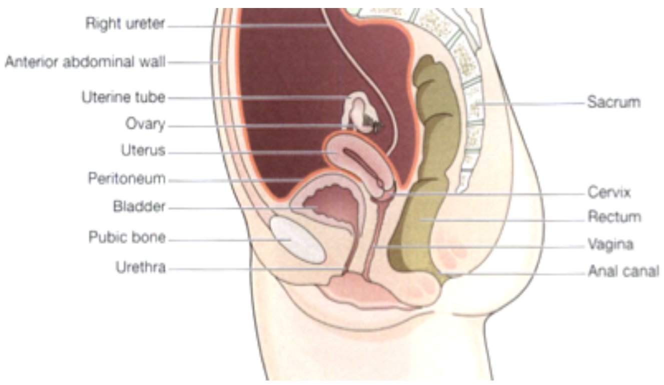
The urinary bladder is a reservoir for urine. It lies in the pelvic cavity and its size and position vary, depending on the amount of urine it contains. When distended, the bladder rises into the abdominal cavity.

The bladder is roughly pear-shaped, but becomes more oval as it fills with urine. It has anterior, superior and posterior surfaces. The posterior surface is the *base.*

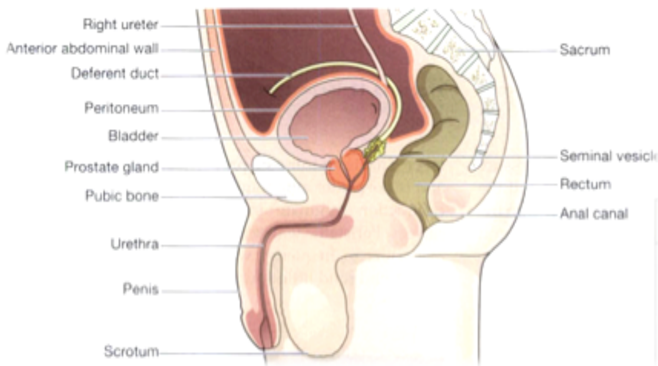
The bladder opens into the urethra at its lowest point, *the neck.*

The *peritoneum* covers only the superior surface before it turns upwards as the parietal peritoneum, lining the anterior abdominal wall. Posteriorly it surrounds the uterus in the female and the rectum in the male.

The Female Urinary System



The Male Urinary System

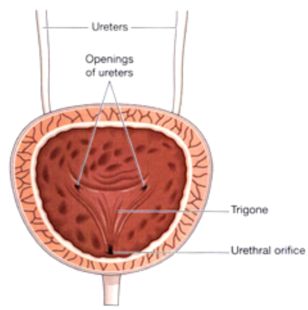


The Bladder

The Bladder Wall Is Composed Of Three Layers:

- The outer layer of loose connective tissue, containing blood and lymphatic vessels and nerves, covered on the upper surface by the peritoneum.
- The middle layer, consisting of a mass of interlacing smooth muscle fibres and elastic tissue loosely arranged in three layers. This is called the *detrusor muscle* and it empties the bladder when it contracts.
- The mucosa, lined with transitional epithelium.

The Bladder



When the bladder is empty the inner lining is arranged in folds, or rugae, and these gradually disappear as the bladder fills. The bladder is distensible but when it con- tains 300 to 400 ml the awareness of the desire to urinate is initiated. The total capacity is rarely more than about 600 ml.

The three orifices in the bladder wall form a triangle or *trigone*. The upper two orifices on the posterior wall are the openings of the ureters. The lower orifice is the point of origin of the urethra. Where the urethra commences is a thickening of the smooth muscle layer forming the *internal urethml sphincter.* This sphincter is not under voluntary control.

Urethra

The urethra is a canal extending from the neck of the bladder to the exterior, at the external urethral orifice. Its length differs in the male and in the female.

The female urethra is approximately 4 cm long. It runs downwards and forwards behind the symphysis pubis and opens at the *external urethral orifice* just in front of the vagina. The external urethral sphincter guards the external urethral orifice, which is under voluntary control. Except during the passage of urine, the walls of the urethra are in close apposition.

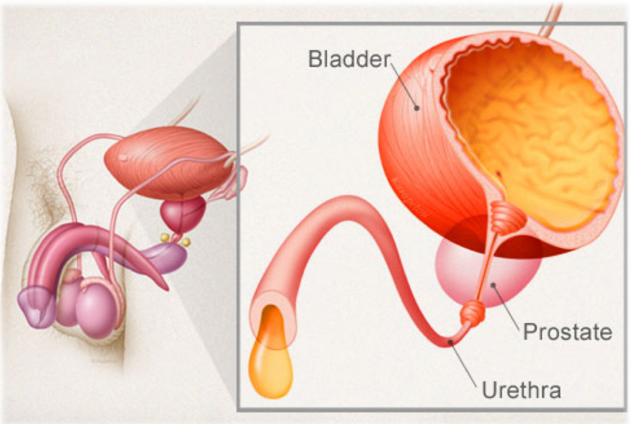
The male urethra provides a common pathway for the flow of urine and semen, the combined secretions of the male reproductive organs. It is about 19 to 20 cm long and consists of three parts. The *prostatic urethra* originates at the urethral orifice of the bladder and passes through the prostate gland. The *membranous urethra* is the shortest and narrowest part and extends from the prostate gland to the bulb of the penis, after passing through the perineal membrane. The *spongiose* or *penile urethra* lies within the corpus spongiosum of the penis and terminates at the external urethral orifice in the *glans penis.*

There are two urethral sphincters. The *internal sphincter* consists of smooth muscle fibres at the neck of the bladder above the prostate gland. The *external sphincter* consists of skeletal muscle fibres surrounding the membranous part.

Prostate Gland (Males)

The prostate gland lies in the pelvic cavity in front of the rectum and behind the symphysis pubis, surrounding the first part of the urethra. It consists of an outer fibrous covering, a layer of smooth muscle and glandular substance composed of columnar epithelial cells.

Male Urinary Tract



The prostate gland secretes a thin, milky fluid that makes up about 30% of *semen,* and gives it its milky appearance. It is slightly alkaline, which provides a protective local environment for sperm arriving in the acidic vagina. It also contains a clotting enzyme, which thickens the semen in the vagina, increasing the likelihood of semen being retained in the vicinity of the cervix.

Penis (Males)

The penis has a *root* and a *body.* The root lies in the perineum and the body surrounds the urethra. It is formed by three cylindrical masses of *erectile tissue* and involuntary muscle. The erectile tissue is supported by fibrous tissue and covered with skin and has a rich blood supply.

The two lateral columns are called the *corpora caver-nosa* and the column between them, containing the urethra, is the *corpus spongiosum.* At its tip it is expanded into a triangular structure known as the *glans penis.* Just above the glans the skin is folded upon itself and forms a movable double layer, t*he foreskin* or *prepuce.* Arterial blood is supplied by deep, dorsal and bulbar arteries of the penis, which are branches from the internal pudendal arteries. A series of veins drain blood to the internal pudendal and internal iliac veins. Autonomic and somatic nerves supply the penis. Parasympathetic stimulation leads to filling of the spongy erectile tissue with blood, caused by arteriolar dilatation and venoconstriction, which increases blood flow into the penis and obstructs outflow. The penis therefore becomes engorged and erect, an essential prerequisite for coitus.

Micturition

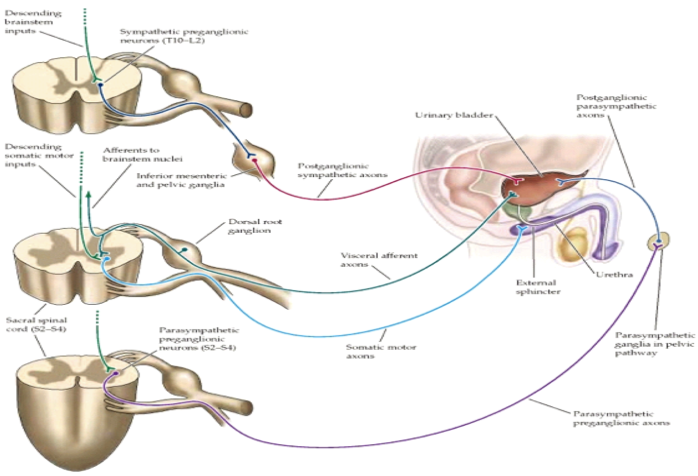
The urinary bladder acts as a reservoir for urine. When 300 to 400 ml of urine has accumulated, afferent autonomic nerve fibres in the bladder wall sensitive to stretch are stimulated. In the infant this initiates a *spinal reflex action* and micturition occurs. Micturition occurs when autonomic efferent fibres convey impulses to the bladder causing contraction of the detrusor muscle and relaxation of the internal urethral sphincter.

When the nervous system is fully developed the micturition reflex is stimulated but sensory impulses pass upwards to the brain and there is an awareness of the desire to pass urine. By conscious effort, reflex contraction of the bladder wall and relaxation of the internal sphincter can be inhibited for a limited period of time.

In adults, micturition occurs when the detrusor muscle contracts, and there is reflex relaxation of the internal sphincter and voluntary relaxation of the external sphincter. It can be assisted by increasing the pressure within the pelvic cavity, achieved by lowering the diaphragm and contracting the abdominal muscles (Valsalva's manoeuvre).

Over-distension of the bladder is extremely painful, and when this stage is reached there is a tendency for involuntary relaxation of the external sphincter to occur and a small amount of urine to escape, provided there is no mechanical obstruction.

Urinary Micturition



THE SKIN 2.7

The skin completely covers the body and is continuous with the membranes lining the body orifices.

It Provides:

- Protects the underlying structures from injury and from invasion by microbes.
- Contains sensory *(somatic)* nerve endings of pain, temperature and touch.
- Is involved in the regulation of body temperature.

The skin has a surface area of about 1.5 to 2 m^2 in adults and it contains glands, hair and nails.

There Are Two Main Layers:

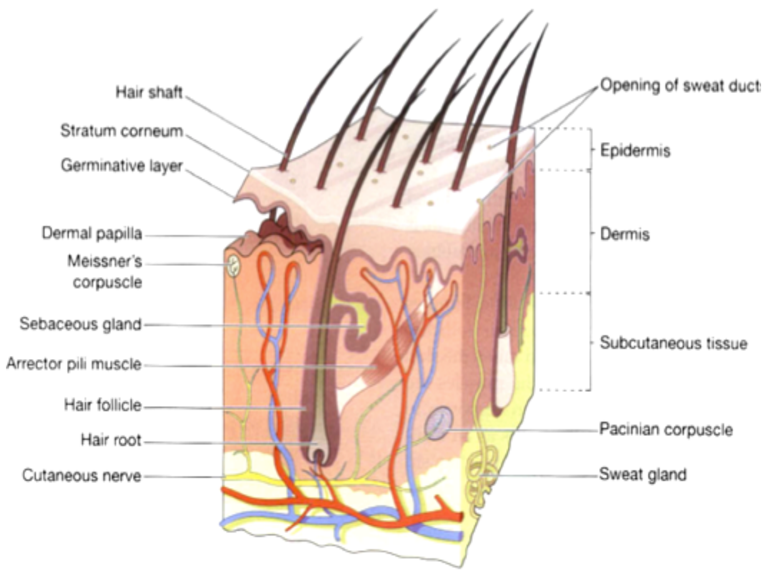
- Epidermis
- Dermis.

Between the skin and underlying structures there is a layer of subcutaneous fat.

Epidermis

The epidermis is the most superficial layer of the skin and is composed of *stratified keratinised squamous epithelium,* which varies in thickness in different parts of the body. It is thickest on the palms of the hands and soles of the feet. There are no blood vessels or nerve endings in the epidermis, but its deeper layers are bathed in interstitial fluid from the dermis, which provides oxygen and nutrients, and is drained away as lymph.

Skin Anatomy



There are several layers (strata) of cells in the epidermis, which extend from the deepest *germinative layer* to the surface *stratum corneum* (a thick horny layer). The cells on the surface are flat, thin, non-nucleated, dead cells

These cells are constantly being rubbed off and replaced by cells. Complete replacement of the epidermis takes about 40 days.

The Maintenance Of Healthy Epidermis Depends Upon Three Processes Being Synchronised:

- Desquamation (shedding) of the keratinised cells from the surface.
- Effective keratinisation of the cells approaching the surface.
- Continual cell division in the deeper layers with newly formed cells being pushed to the surface.

Hairs, secretions from sebaceous glands and ducts of sweat glands pass through the epidermis to reach the surface.

The surface of the epidermis is ridged by projections of cells in the dermis called the *papillae.* The pattern of ridges is different in every individual and the impression made by them is the 'fingerprint'.

The downward projections of the germinative layer between the papillae are believed to aid nutrition of epidermal cells and stabilise the two layers, preventing damage due to shearing forces.

Blisters develop when acute trauma causes separation of the dermis and epidermis and serous fluid collects between the two layers.

The Colour Of The Skin Is Affected By Three Main Factors:

- *Melanin,* (A dark pigment derived from the amino acid tyrosine and secreted by *melanocytes* in the deep germinative layer). The amount is genetically determined and varies between different parts of the body, between members of the same race and between races. Exposure to sunlight promotes synthesis of increased amounts of melanin.
- *The level of oxygenation of haemoglobin* and the amount of blood circulating in the dermis give the skin its pink colour.
- *Bile pigments* in blood and *carotenes* in subcutaneous fat give the skin a yellowish colour.

Dermis

The dermis is tough and elastic. It is formed from connective tissue and the matrix contains *collagen fibres* inter- laced with *elastic fibres.* Rupture of elastic fibres occurs when the skin is overstretched, resulting in permanent *striae,* or stretch marks, that may be found in pregnancy and obesity.

Collagen fibres bind water and give the skin its tensile strength, but as this ability declines with age, wrinkles develop. Fibroblasts, macrophages and mast cells are the main cells found in the dermis. Underlying its deepest layer there is areolar tissue and varying amounts of adipose tissue (fat).

The Structures In The Dermis Are:

- Blood vessels.
- Lymph vessels.
- Sensory (somatic) nerve endings.
- Sweat glands and their ducts.
- Hairs, arrector pili muscles and sebaceous glands.

Blood Vessels

Arterioles form a fine network with capillary branches supplying sweat glands, sebaceous glands, hair follicles and the dermis. The epidermis has no blood supply. It obtains nutrients and oxygen from interstitial fluid derived from blood vessels in the papillae of the dermis.

Lymph Vessels

These form a network throughout the dermis.

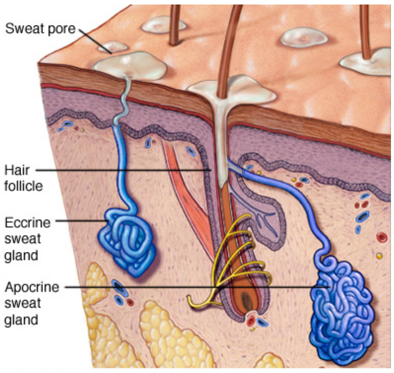
Sensory Nerve Endings

Sensory receptors (specialised nerve endings), which are sensitive to *touch, change in temperature, pressure* and *pain* are widely distributed in the dermis. Incoming stimuli activate different types of sensory receptors. The skin is an important sensory organ through which individuals receive information about their environment.

Nerve impulses, generated in the sensory receptors in the dermis, are conveyed to the spinal cord by sensory *(somatic cutaneous)* nerves, then to the sensory area of the cerebrum where the sensations are perceived.

Sweat Glands

Sweat Glands



Sweat glands are found widely distributed throughout the skin and are most numerous in the palms of the hands, soles of the feet, axillae and groins. They are composed of epithelial cells. The bodies of the glands lie coiled in the subcutaneous tissue. Some ducts open onto the skin surface at tiny depressions, or pores, and others open into hair follicles.

Glands opening into hair follicles do not become active until puberty. In the axilla they secrete an odourless milky fluid, which if decomposed by surface microbes, causes an unpleasant odour.

Sympathetic nerves in response to raised body temperature and fear stimulate sweat glands.

The most important function of sweat secreted by glands opening on to the skin surface is in the regulation of body temperature. Evaporation of sweat from body surfaces takes heat from the body and the temperature-regulating centre in the hypothalamus governs the amount of sweat produced.

Excessive sweating may lead to dehydration and serious depletion of body sodium chloride unless intake of water and salt is appropriately increased. After 7 to 10 days' exposure to high environmental temperatures the amount of salt lost is substantially reduced but water loss remains high.

Functions Of The Skin

Protection

The skin forms a relatively waterproof layer that protects the deeper and more delicate structures. As an important non-specific defence mechanism.

It Acts As A Barrier Against:

- Invasion by microbes.
- Chemicals.
- Physical agents, e.g. mild trauma, ultraviolet light.
- Dehydration.

The dermis contains specialised immune cells called Langerhans cells. They phagocytose intruding antigens and travel to lymphoid tissue, where they present antigen to T-lymphocytes, thus stimulating an immune response.

Due to the presence of the sensory nerve endings in the skin the body reacts by reflex action to unpleasant or painful stimuli, protecting it from further injury.

Regulation of Body Temperature

The temperature of the body remains fairly constant at about 36.8°C across a wide range of environmental temperatures. In health, variations are usually limited to between 0.5 and 0.75°C, although it is raised slightly in the evening, during exercise and in women just after ovulation. When metabolic rate increases body temperature rises and when it decreases body temperature falls.

A constant temperature balance is maintained between heat produced in the body and heat lost to the elements.

Heat Production

Some of the energy released in the cells during metabolic activity is in the form of heat. The most active organs, chemically and physically, produce the most heat.

The Principal Organs Involved Are As Follows:

- *The muscles.* Contraction of skeletal muscles produces a large amount of heat and the more strenuous the muscular exercise the greater the heat produced. Shivering involves muscle contraction and produces heat when there is the risk of the body temperature falling below normal.
- *The liver* is very chemically active, and heat is produced as a by-product. Metabolic rate and heat production are increased after eating.
- *The digestive organs* produce heat during peristalsis and by the chemical reactions involved in digestion.

Heat Loss

Most of the heat loss from the body occurs through the skin. Small amounts are lost in expired air, urine and faeces.

Only the heat lost through the skin can be regulated to maintain a constant body temperature. There is no control over heat lost by the other routes.

Heat loss through the skin is affected by the difference between body and environmental temperatures, the amount of the body surface exposed to the air and the type of clothes worn. Air is a poor conductor of heat and when layers of air are trapped in clothing and between the skin and clothing they act as effective insulators against excessive heat loss.

A balance is maintained between heat production and heat loss. Control is achieved mainly by thermo-receptors in the hypothalamus.

Mechanisms of Heat Loss

- In *evaporation* (the body is cooled when sweat converts to water vapour).
- In *radiation* (exposed parts of the body radiate heat away from the body).
- In *conduction* (clothes and other objects in contact with the skin take up heat).
- In *convection* (air passing over the exposed parts of the body is heated and rises, cool air replaces it and convection currents are created).

Control of Body Temperature

Nervous Control

The *temperature regulating centre* in the hypothalamus is responsive to the temperature of circulating blood. This centre controls body temperature through autonomic nerve stimulation of the sweat glands.

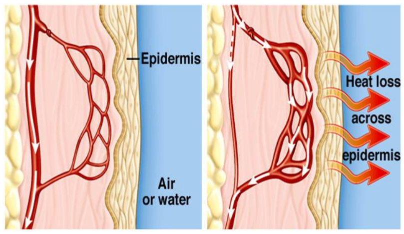
The *vasomotor centre* in the medulla oblongata controls the diameter of the small arteries and arterioles, and therefore the amount of blood, which circulates in the capillaries in the dermis. The vasomotor centre is influenced by the temperature of its blood supply and by nerve impulses from the hypothalamus. When body temperature rises the skin capillaries dilate and the extra blood near the surface increases heat loss by radiation, conduction and convection. The skin is warm and pink in colour. When body temperature falls arteriolar constriction conserves heat and the skin is whiter and feels cool.

Activity of the Sweat Glands

When the temperature of the body is increased by 0.25 to 0.5°C the sweat glands are stimulated to secrete sweat, which is conveyed to the surface of the body by ducts. When sweat droplets can be seen on the skin the rate of production is exceeding the rate of evaporation. This is most likely to happen when the environmental air is humid and the temperature high.

Loss of heat from the body by unnoticeable evaporation of water through the skin and expired air occurs even when the environmental temperature is low. This is called *insensible water loss* (around 500 ml per day) and is accompanied by insensible heat loss.

Vasoconstriction - Vasodilation



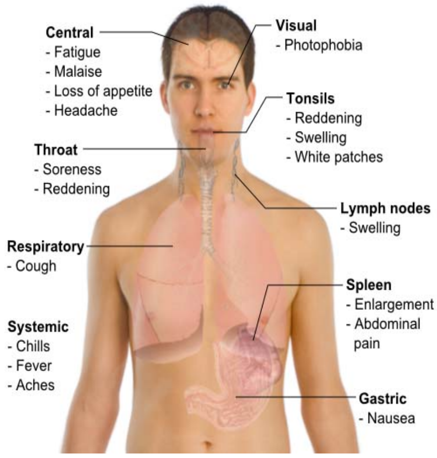
Effects of Vasodilatation

The amount of heat lost from the skin depends to a great extent on the amount of blood in the vessels in the dermis. As heat production increases, the arterioles become dilated and more blood pours into the capillary network in the skin. In addition to increasing the amount of sweat produced the temperature of the skin is raised and there is an increase in the amount of heat lost by radiation, conduction and convection.

If the external environmental temperature is low or if heat production is decreased, vasoconstriction is stimulated by sympathetic nerves. This decreases the blood flow near the body surface, conserving heat.

Fever

Viral Fever



This is often the result of infection and is caused by release of chemicals *(pyrogens)* from damaged tissue and the cells involved in inflammation. Pyrogens act on the hypothalamus, which releases prostaglandins that reset the hypothalamic thermostat to a higher temperature. The body responds by activating heat-promoting mechanisms, e.g. shivering and vasoconstriction until the new higher temperature is reached. When the thermostat is reset to the normal level, heat-loss mechanisms are activated. There is profuse sweating and vasodilatation accompanied by warm, pink (flushed) skin until body temperature falls to the normal range again.

Hypothermia

This is present when core temperature, e.g. the rectal temperature, is below 35°C. At a rectal temperature below 32°C, compensatory mechanisms to restore body temperature usually fail, e.g. shivering is replaced by muscle rigidity and cramps, vasoconstriction fails to occur and there is lowered blood pressure, pulse and respiration rates. Mental confusion and disorientation occur.

Death usually occurs when the temperature falls below 25°C.

THE MUSCULO-SKELETAL SYSTEM 2.8

The Skeletal System 2.8.1

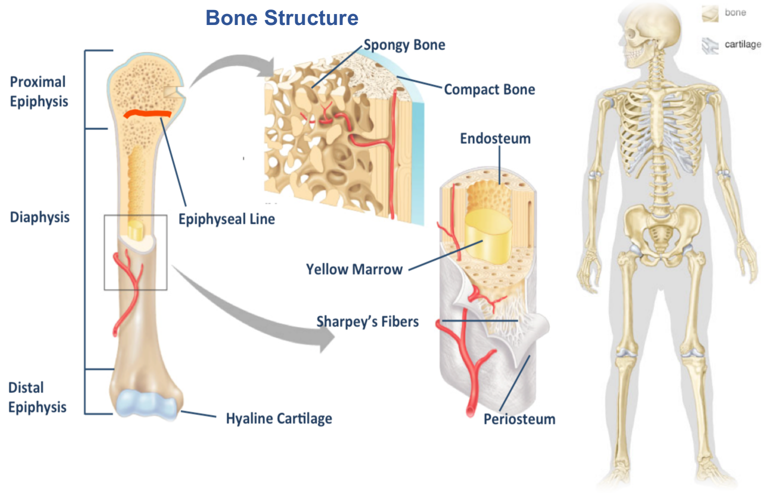
The skeletal system consists of bones and associated connective tissues, including cartilage, tendons and ligaments. The skeletal system provides a rigid framework for support and protection and provides a system of levers on which muscles act to produce body movements. The skeletal system contains 206 individual bones.

Bone Structure

Bones are rigid organs that constitute part of the endoskeleton of vertebrates. They support and protect the various organs of the body, produce red and white blood cells and store minerals.

Bone tissue is a type of dense connective tissue. Bones come in a variety of shapes and have a complex internal and external structure, are lightweight yet strong and hard, and serve multiple functions.

One of the types of tissue that makes up bone is the mineralized osseous tissue, also called bone tissue that gives it rigidity and a coral-like internal structure.



Other types of tissue include marrow, endosteum, periosteum, nerves, blood vessels and cartilage.

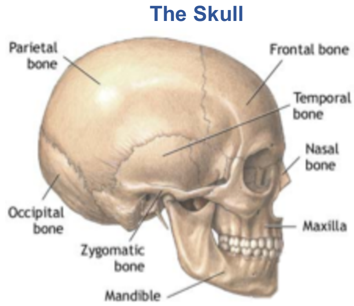
Bones Are Divided Into Two Categories:

- The axial skeleton.
- The appendicular skeleton.

Axial Skeleton

The Axial Skeleton Consists Of:

- The skull.
- The hyoid bone.
- The vertebral column.
- The thoracic cage.



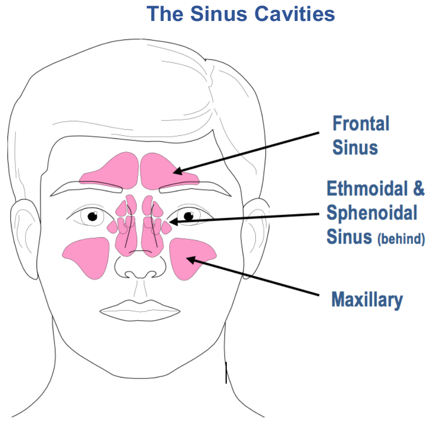
The Skull

The skull is composed of 28 separate bones divided into the following groups: the auditory ossicles, cranial vault, and facial bones. The 6 auditory ossicles (3 on each sides of the head) are located inside the cavity of the temporal bone. The auditory ossicles function in hearing.

The cranial vault consists of 6 bones that surround and protect the brain. They are the parietal, temporal, frontal, occipital, sphenoid, and ethmoid bones.

The 14 facials bones from the structure of the face in the anterior skull but do not contribute to the cranial vault. The bones include the maxilla, mandible, zygomatic, palatine, nasal, lacrimal, vomer, and inferior concha bones. The frontal and ethmoid bones contribute to both the cranial vault and the face.

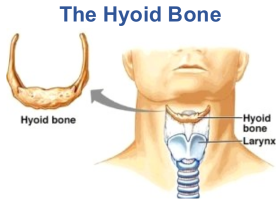
Air spaces are present in certain bones in the skull, which decrease the weight of those bones and give resonance to the voice. These are called the **sinuses**. Each person has 4 pairs of sinuses, and while the size and shape is variable between individuals, the positions are normally similar.



The 4 Pairs Are:

- The Frontal Sinuses (located above the eyebrows)
- The Maxillary Sinuses (the largest pair, located in the cheekbones).
- The Sphenoid Sinuses (set deep in the head behind the nose).
- The Ethmoid Sinuses (located beside the bridge of the nose).

Tiny canals connect the sinuses with the nasal cavity allowing any pressure differences between the sinuses and the nasal passages to be equalised. Each sinus is lined with a mucous membrane, which is continuous with that of the nose and throat. Mucous produced by the sinuses normally drains into the nasal passage but, if the connecting canal becomes blocked, pressure within the sinus can build up to cause pain. If an infection of the membrane lining occurs, the painful condition called **sinusitis** results.



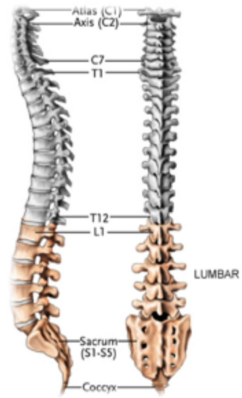
The Hyoid Bone

The hyoid bone is attached to the skull by muscles and ligaments and floats in the superior aspect of the neck, just below the mandible. The hyoid bone serves as the attachment point for several important neck and tongue muscles.

The Vertebrae

The vertebral column consists of 26 bones, which can be divided into five regions: 7 cervical vertebrae, 12 thoracic vertebrae, 5 lumbar vertebrae, 1 sacral bone, and 1 coccygeal bone. A total of 34 vertebrae originally from during development, but the 5 sacral vertebrae fuse to form 1 bone, as do the 4 or 5 coccygeal bones.

The Vertebral Column



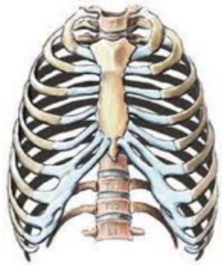
The weight-bearing portion of the vertebrae is a bony disk called the body. Intervertebral disks, located between the bodies of adjacent vertebrae, serve as shock absorbers for the vertebral column, provide additional support for the body, and prevent the vertebral bodies from rubbing against each other.

The vertebral arch and the dorsal portion of the body protect the spinal chord. A transverse process extends laterally from each side of the arch, and a single spinous process is present at the point of junction. Much vertebral movement is accomplished by the contraction of skeletal muscles attached to the transverse and the spinous processes.

The Thoracic Cage

The thoracic cage protects vital organs within the thorax and prevents the collapse of the thorax during respiration. It consists of the thoracic vertebrae, ribs with their associated costal cartilages, and sternum.

The Thoracic Cage



The 12 pairs of ribs can be divided into true or false ribs. The superior 7 (the true ribs) articulate with the thoracic vertebrae and attach directly through their costal cartilages to the sternum. The inferior 5 (the false ribs) articulate with the thoracic vertebrae but do not attach directly to the sternum. The eight, ninth, and tenth ribs are joined to a common cartilage, which is attached to the sternum. The eleventh and twelfth ribs are "floating" ribs that have no attachment to the sternum.

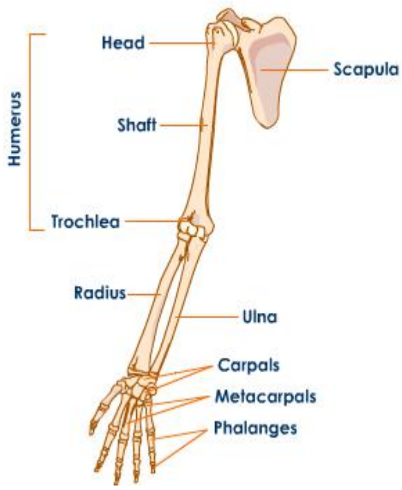
The sternum is divided into three parts: the manubrium, body, and xyphoid process. At the superior margin of the manubrium is the jugular notch, which can easily be palpated at the anterior base of the neck. The point at which the manubrium joins the body of the sternum is the sternal angle. The second rib is found lateral to the sternal angle and is used clinically as starting point for counting the other ribs.

Appendicular Skeleton

The Appendicular Skeleton Consists Of The:

- Upper extremities.
- Lower extremities.
- And their girdles (by which they are attached to the body).

The Upper Extremities



The Upper Extremities

The scapula and clavicle constitute the pectoral girdle, which attaches the upper limbs to the axial skeleton. The direct point of attachment between the bones of occurs at the sterno-clavicular joint between the clavicle and the sternum.

The humerus is the second longest bone in the body. The head of the humerus articulates with the scapula the greater and the lesser tubercles are on the lateral and anterior surfaces of the proximal end of the humerus, where they function as sites of muscles attachment. The humerus articulates with the radius and the ulna at its distal end. The capilatulum (lateral aspect of the humerus) articulates with the head of the radius, and the trochlea (medial aspect of the humerus) articulates with the ulna. Proximal to the trochlea and capitulum are the medial and lateral epicondyles, respectively, which function as muscles attachments for the muscles of the forearm.

The large bony process of the ulna (the olecranon process) can be felt at the point of the elbow. This process fits in a large depression on the posterior surface of the humerus known as the olecranon fossa. The structural relationship between these two processes makes movement of the joint possible. The distal end of the ulna has a small head that articulates with the radius and the wrist bones. The posterior medial side of the head has a small stilloid process to which the ligament of the wrist is attached. The proximal end of the radius articulates with the humerus, and the medial surface of the head constitutes a smooth cylinder where the radius rotates against the radial notch of the ulna. Major anterior arm muscles (biceps brachii) are attached to the radial tuberosity.

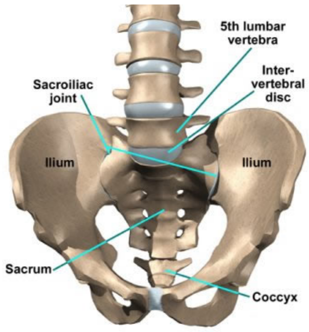
The wrist is composed of 8 carpal bones, which are arranged in two rows of 4 each. A total of 5 metacarpals are attached to the carpal bones and constitute the bony framework of the hand.

A total of 28 phalanges make up the 10 digits of the hands. There are two phalanges for each thumbs and 3 for each finger.

The Lower Extremities

The pelvic girdle attaches the leg to the trunk. The girdle consists of two coxa (hip bones), one located on each side of the pelvis. Each coxa surrounds a large obturator foramen, through which muscles, nerves and blood vessels pass to the leg. A fossa called the acetabulum is located on the lateral surface of each coxa and is the point of articulation of the lower limb with the girdle. During development, each coxa is formed by the fusion of 3 separate bones: the ilium, ischium and pubis. The superior portion of the ilium is the iliac crest. The crest ends anteriorly as the anterior-superior iliac spine and posteriorly as the superior-posterior spine.

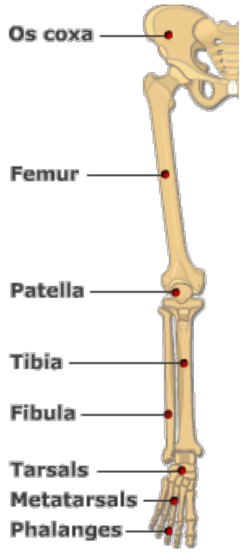
The Pelvis



The femur is the longest bone in the body. It has a well-defined neck and a prominent rounded head that articulates with the acetabulum. The proximal shaft has 2 tuberosities: a great trochenter lateral to the neck and a smaller or lesser trochenter inferior and posterior to the neck. Both trochenters are attachment sites for muscles that attach the hip to the thigh. The distal end of the femur has medial and lateral condyles that articulate with the tibia. Located laterally and proximally to the condyles are the medial and lateral epicondyles, which are sites of muscle and ligament attachment.

Distally, the femur also articulates with the patella, which is located in a major tendon of the thigh muscle. The patella allows the tendon to turn the corner over the knee.

The Lower Extremities



The 2 bones of the lower leg are the tibia and the fibula.

The tibia is the largest of the 2 and supports most of the weight of the leg. A tibial tuberosity can be seen and palpated just inferior to the patella. The proximal end of the tibia has flat medial and lateral condyles that articulate with the condyles of the femur. The distal end of the tibia forms the medial malleolus, which helps to form the medial side of the ankle joint.

The foot consists of 7 bones. The talus articulates with the tibia and the fibula to form the ankle joint. The calcaneus is located inferior and jus lateral to the talus, supporting the bone. It protrudes posteriorly where the calf muscles attach to it and easily identified as the heel.

The foot consists of tarsals, metatarsals, and phalanges, which are arranged in a manner similar to the metacarpals and phalanges of the hand, the great toe being analogous to the thumb. The ball of the foot is the junction between the metatarsals and the phalanges. Strong ligaments and leg muscles tendons normally hold the foot bones firmly in their arched position.

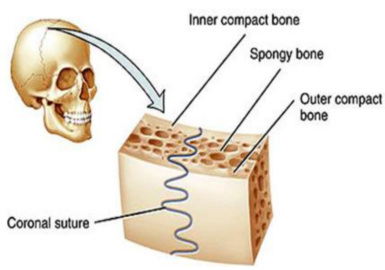
Joints

With the exception of the hyoid bone, every bone in the body connects to at least 1 other bone.
The connections or joints commonly are named according to the bones or portions of the bones that are united at the joint.

The Three Major Classifications Of Joints Are:

- Fibrous.
- Cartilaginous.
- Synovial.

Fibrous Joints



Fibrous Joints

Fibrous joints consists of 2 bones united by fibrous tissue that have little or no movement. The joints are further divided on the basis of structure into sutures, syndesmosomes, or gomphoses. Structures (seams between flat bones) are located in the skull bones and may be completely immobile in adults. In newborns, the sutures have gaps between them, called fontanelles; these gaps are fairly wide to allow give to the skull during birth and allow growth of the head during development.

A syndesmosis is a fibrous joint in which the bones are separated by a greater distance than in a suture and are joined by ligaments. These ligaments may provide some movement of the joint. An example of these joints is the radioulnar syndesmosis that binds the radius and the ulna together.

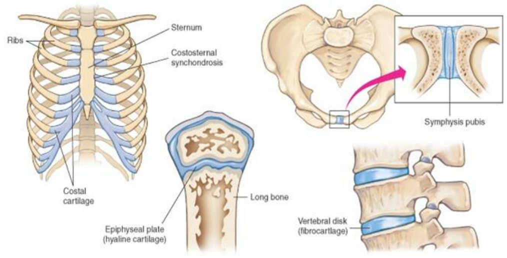
A gomphosis joint consists of a peg that fits into a socket. The peg is held in place by fine bundles of collagenous connective tissue. The joints between the teeth and the sockets along the processes of the mandible and maxillae are examples of gomphoses joints.

Cartilaginous Joints

Cartilaginous joints unit two bones by means of hyaline cartilage (synchondrose) or fibrocartilage (symphyses). A synchondrosis allows only slight movement at the joint. Common examples of this type of joint are epiphysial plate of a growing bone and the cartilage rod between most of the ribs and the sternum.

Symphyses joint are slightly moveable because of flexible nature of the fibrocartilage. Symphyses include the junction between the manubrium and the body of the sternum in adults, the symphisis pubis of the coxae, and the Intervertebral disks.

Cartilaginous Joints



Synovial Joints

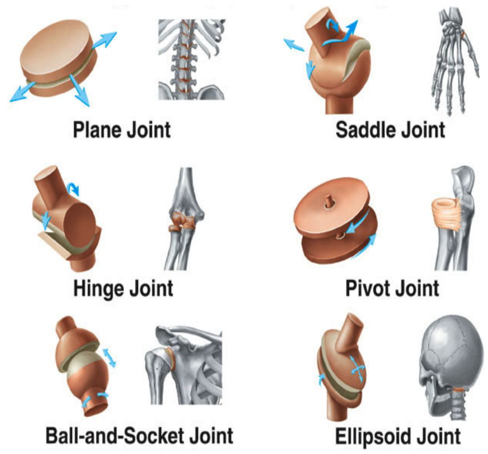
Synovial joints contain synovial fluid, a thin, lubrificating film that allows considerable movement between articulating bones. Most joints that unite the bones of the appendicular skeleton are synovial. The articular surfaces of bones within synovial joints are covered with a thin layer of hyaline cartilage, which provides a smooth surface where the bones meet. The joint is enclosed by a joint capsule, which consists of an outer fibrous capsule and an inner synovial membrane.

The synovial membrane lines the joint and produces synovial fluid.

Synovial Joints Are Classified Into Six Divisions According To The Shape Of The Adjoining Articular Surfaces:

- Plane or gliding joints (consist of two opposed flat surfaces that are about equal in size. Examples of these joints are the articular processes between vertebrae).
- Saddle joints (consist of two saddle-shaped articulating surfaces oriented at right angles to one another. Movement in these joints can occur in two planes. An example of saddle joint is the carometacarpal joint of the thumb).
- Hinge joints (consist of a convex cylinder in one bone applied to a corresponding concavity in another bone. These joints permit movement in one plane only. Examples of hinge joints are those of the elbow and the knee).
- Pivot joints (consist of a relatively cylindrical bony process that rotates within a ring composed partly of bone and partly of ligament. An example of pivot joint is the head of the radius articulating with the proximal end of the ulna).
- Ball-and-socket joints (consist of a ball (head) at the end of one bone and a socket into an adjacent bone into which a portion of the ball fits. These joints allow wide ranges of movement in almost any direction. Examples are the shoulder and the hip joints).
- Ellipsoid joints (modified ball-and-socket joint where the articular surfaces are ellipsoid. The shape of the joint limits the movement, making it similar to a hinge motion, but the motion occurs in two planes. The atlantooccipital joint is an ellipsoid joint).

Sinovial Joints

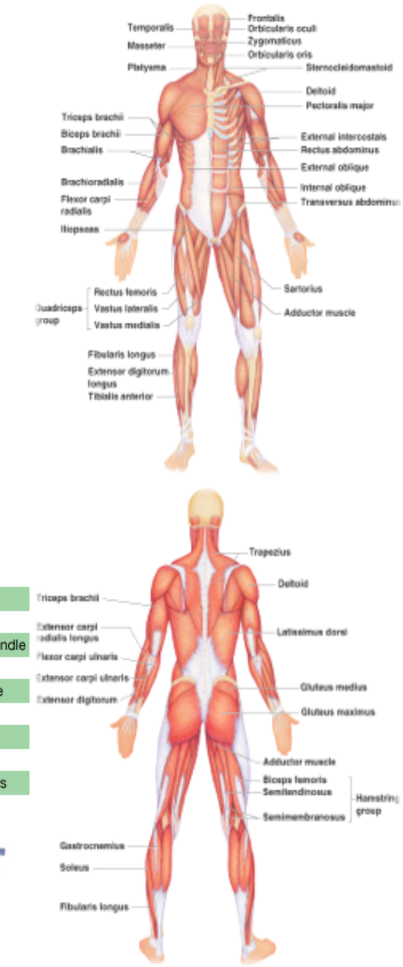


The Muscular System 2.8.2

Muscle comprises of approximately 40% of the bodys total bio-mass.

Muscle cells contain protein filaments that slide past one another, producing a contraction that changes both the length and the shape of the cell. Muscles function to produce force and cause motion. They are primarily responsible for maintenance of and changes in posture, locomotion of the organism itself, as well as movement of internal organs, such as the contraction of the heart and movement of food through the digestive system via peristalsis.

Body Muscle



The Three Primary Functions Of The Muscular System Are:

- Movement.
- Postural maintenance.
- Heat production.

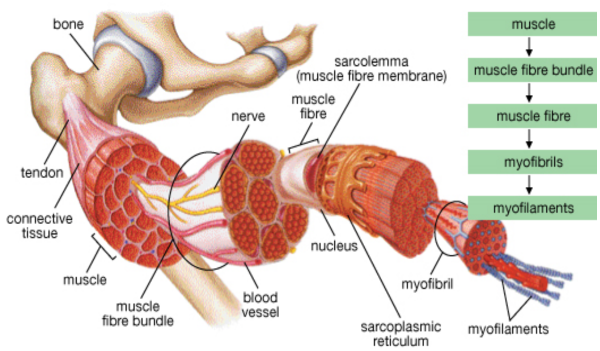
The major types of muscles are skeletal, cardiac, and smooth muscle. Skeletal muscle is far more common than other types of muscles in the body and is the focus of this section.

Physiology Of Skeletal Muscle

Muscle tissue consists of specialized contractile cells or muscle fibers. Skeletal muscle contracts in response to electrochemical stimuli. Nerve cells regulate the function of skeletal muscle fibres by controlling the series of events that result in muscle contraction.

Each skeletal muscle fiber is filled with thick and thin myofilaments, which are fine, threadlike structures. The thick myofilaments are formed from the protein myosin, and the thin myofilaments are composed of the protein actin.

Muscle Anatomy



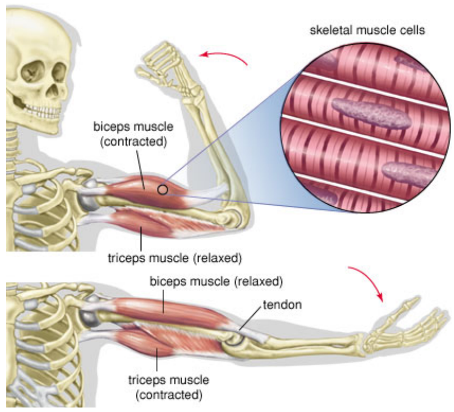
The sarcomere is the contractile unit of skeletal muscle, containing thick and thin myofilaments.

During the contraction process, energy obtained from ATP molecules enables the two types of myofilaments to slide toward each other and shorten the sarcomere and eventually the entire muscle.

Neuromuscular Junction

A nervous impulse enters the muscle fiber through a specialized nerve known as the motoneuron. The point of contact between the nerve ending and the muscle fiber is the neuromuscular junction or synapse. Each muscle fiber receives a branch of an axon, and each axon innervates more than a single muscle fiber. When a nerve impulse passes through this junction, specialized chemicals are released, causing the muscle to contract.

Muscle Movement



Skeletal Muscle Movement

Most muscles extend from one bone to another and cross at least one joint. Muscles contraction causes most body movement by pulling one of the bones toward the other across the moveable joint. The points of attachment of each muscle are the origin and insertion. The origin is the end of the muscle attached to the more stationary of the two bones. The insertion is the end of the muscle attached to the bone undergoing the greatest movement.

Some muscles of the face are not attached to bone at both ends but attach to the skin, which moves when muscles contract.

The contraction of some muscles with the simultaneous relaxation of others produces movement. Muscle that work in cooperation with one other to cause movement are called synergist, and a muscle working in opposition to another muscle (moving the structure to an opposite direction) is called an antagonist.

The muscle that is primarily responsible for a particular movement is called the prime mover. For example, the biceps brachii, brachialis, and triceps brachii muscles are all involved in flexion and extension of the forearm at the elbow joint. The biceps brachii is the prime mover during flexion, and the brachialis is the synergic muscle.

When the biceps brachii and the brachialis muscles flex the forearm, the triceps brachii relaxes (antagonistic muscle). During extension of the forearm, the triceps brachii becomes the prime mover, and the biceps and the brachialis become the antagonisic muscles. The coordinated activity of synergists and antagonists is what makes muscular movement smooth and gracefull.

Types Of Muscle Contraction.

Muscle contractions are classified as either isometric or isotonic, depending on the type of contraction that predominates. In isometric contractions, the length of the muscle does not change, but amount of tension increases during the contraction process. Isometric contractions are responsible for the constant length of the postural muscles of the body.

During isotonic contractions, the amount of tension produced by the muscle is constant during contraction, but the length of the muscle changes. An example of isotonic contraction is the movement of the arms or fingers. Most muscle contractions are a combination of isotonic and isometric contractions.

TRAUMA TRAINING

Section 3

Effects of Pressure

BAROTRAUMA SQUEEZE'S 3.1

Injury or discomfort resulting from the effects of pressure imbalance is called barotrauma. This imbalance is caused by the inability to equalise the gas spaces of the body with the pressure of the external environment.

A *squeeze* occurs whenever fixed volume gas spaces within the body or diving gear are not pressure counterbalanced to surrounding depth.

The human body automatically adjusts to any change in the pressure of the surrounding environment; it usually does so without the person involved noticing the change.

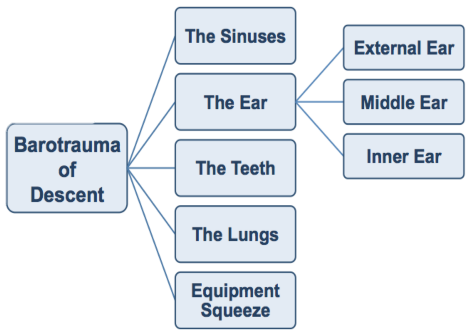
Most of the body is composed of watery tissue that can transmit imposed pressure without deformation, but there are a few areas where this is not true. If the gas pressure within some air-filled cavities of the body, such as the middle ear or the bony sinuses of the skull, is not easily equalised with the surrounding pressure, an individual undergoing even mild pressure changes (such as those that occur diving or flying) may be aware of the pressure difference.

In more severe cases, pain, accompanied by fluid and blood in the middle ears and sinuses, may be the result of a "squeeze" in these areas.

Such effects are exaggerated in divers because the water that surrounds them is much denser and heavier than air. The ability of diving equipment automatically to deliver breathing gases that are the same pressure as the surrounding depth of water makes diving possible, but these compressed gases must infiltrate into all the rigid bony cavities (the middle ear, sinuses, and chest cavity) to equalise the pressure inside, or the resulting deformations will lead to pain caused by compression and contraction of tissues.

If the pressure difference is allowed to increase, blood vessels may haemorrhage and rupture.

Barotrauma Squeeze's



Types of Squeezes Include:

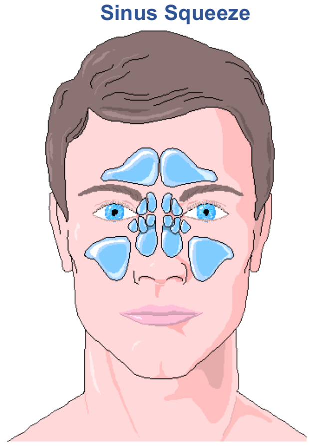
- Sinus Squeeze.
- Ear squeeze.
- Thoracic Squeeze.
- Face or Body Squeeze.
- Tooth Cavities Squeeze.

Sinus Squeeze 3.1.1

The sinus cavities are air pockets located within the skull bones that have openings into the nasal passages. These cavities are lined with a mucous membrane.

Sinus squeeze normally is the result of diving with a cold or head congestion. Adequate ventilation and pressure equalisation in the para-nasal sinuses are important in diving. Both descent and ascent depend to a large degree on adequate nasal function. Inflammation and congestion of the nasal mucosa caused by allergies, smoking, chronic irritation from prolonged or excessive use of nose drops, upper respiratory tract infections, or structural deformities of the nose can result in blockage of the para-nasal sinus openings.

Sinus Squeeze



The inability to equalise pressure on descent creates negative relative pressure within the sinus cavity, deforming the mucous membrane and causing swelling, fluid exudation, haemorrhage, and pain. Para-nasal sinus barotrauma also may occur during ascent. In this case, the key mechanism is thought to be one-way blockage of the sinus opening by cysts or polyps located within the sinus that allow pressure equalisation during descent but not during ascent.

Figure 1. Normal on the surface at 1 bar. The sinus duct is clear and no pressure gradient is present.

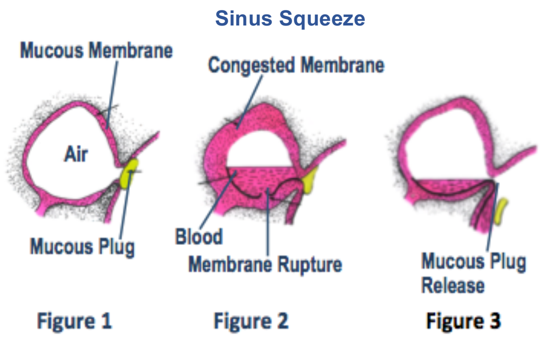
Figure 2. Shows a blockage obstructing the duct, preventing equalisation of the cavity with the increased external pressure. This increase in pressure to 2 bar absolute has reduced the gas to one half of its original volume (Boyle's Law). The increased solubility of gases with increasing pressure (Henry's Law) has reduced the volume further. This has caused a partial vacuum in the cavity which has ruptured the membrane lining causing internal bleeding.

The diver, unable to clear his sinuses will be in severe pain.

Figure 3. A drop in pressure resolves the problem. A reduction to 1.5 bar results in the gas volume increasing and the obstruction being cleared. Where there has been membrane rupture, this removal of the blockage is accompanied by bleeding from the sinuses into the nasal cavity.

Presentation of Sinus Squeeze:

- Sensation of fullness or pain over the involved sinus or in the upper teeth.
- Numbness of the front of the face.
- Bleeding from the nose.



Management of Sinus squeeze:

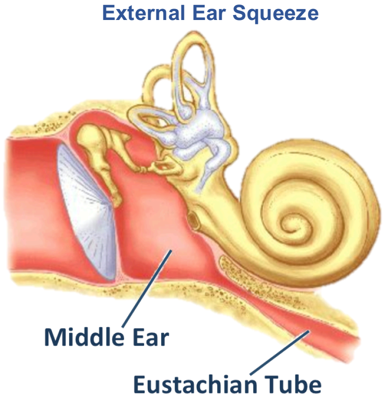
- Appropriate equalization technique.
- Cessation of compression / ascending.
- Nasal vasoconstrictors / oral antihistamines (To promote nasal mucosal shrinkage of the sinus.)
- Divers who have symptoms for longer than 5 to 10 days should see a specialist.
- If severe pain and nasal bleeding are present or if there is a yellow or greenish nasal discharge, with or without fever, a specialist should be seen promptly.
- Divers with a history of nasal-sinus disease should have an E.N.T. evaluation before beginning to dive.

External Ear Squeeze 3.1.2

Injury to the external ear canal due to inability to equalise the external ear space as a result of an obstruction. This is generally caused by tight hoods, ear-plugs, and most commonly wax. In this case, if the Eustachian tube is functioning normally, the pressure in the external ear canal is negative relative to the outside atmosphere, the air in the nose and in the middle ear. The ear drum bulges outwards, blood and tissue fluid is forced under the skin of the external ear canal forming blood blisters and ultimately the ear drum may rupture.

Notable presentation includes severe ear pain and possible inflammation of the external ear canal. Worsening of this condition by increasing the pressure differential may lead to a ruptured eardrum resulting from the squeeze.

Rupture may occur with as little as 100hGmm difference between the external auditory canal and the middle ear (only 1metre of sea water).



Presentation Of External Ear Squeeze:

- Fullness or pressure in region of the external ear canals.
- Pain.
- Blood or fluid from external ear.
- Rupture of ear-drum (entrance of cold water into the middle ear).
    - Extreme dizziness (vertigo).
    - Nausea, and possible vomiting.

Management of External Ear Squeeze:

- Appropriate equalization technique.
- Cessation of compression / ascending.
- Ear-drum rupture should be treated according to the procedures for treating middle ear barotraumas.

Middle Ear Squeeze 3.1.3

This is the most common transient ear problem associated with diving or barotrauma. It is defined as physical damage between the eardrum and eustachian tube, which is caused by inadequate pressure equalisation between the middle ear and the external environment.

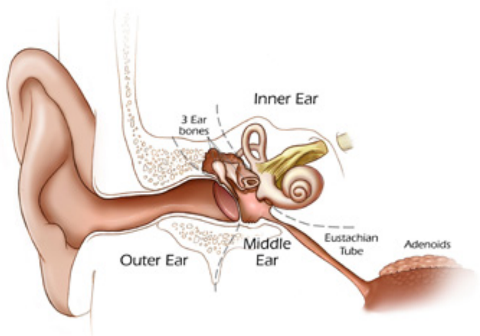
Most commonly it is due to blockage of the Eustachian tubes, with catarrh or mucus. Nasal conditions such as congestion and discharge increase the likelihood of poor eustachian tube function during the dive. Absence of pre-dive symptoms does not guarantee that a diver will not develop middle ear barotrauma.

Presentation Of A Middle Ear Squeeze:

- The symptoms of middle ear squeeze consist initially of pain and a sensation of ear blockage.
- Conductive hearing loss (but may not be the primary complaint because of the intense ear pain).

- Mild tinnitus and vertigo.
- Blood in middle ear / eardrum.
- If the ear drum ruptures;
  - The pain is usually relived.
  - Cold water may enter the middle ear causing:
    - Dizziness.
    - Nausea.
    - Ringing in ears.
    - Acute or chronic infection with resultant temporary or permanent deafness.
- Excessive Valsalva manoeuvre may cause damage to the oval window.

Middlr Ear Squeeze



Management of Middle Ear Squeeze:

- Divers should attempt to re-establish pressure balance as quickly as possible.
- If unable to resolve this difficulty quickly, the diver should ascend to the surface.
- Often, returning to the surface is all that is necessary to relieve the symptoms of mild ear squeeze, (but it may take a few days for the fluid or blood to drain from or be absorbed from the middle ear cavity).
- A nasal decongestant spray, nose drops, a mild vasoconstrictor medication, or an antihistamine taken by mouth may help.
- Chewing gum, yawning, or swallowing may also help.
- If examination reveals that the diver has a rupture of the ear drum, the diver should:
  - Be seen by a physician.
  - Stay out of the water until the tear has healed, which usually occurs quickly (unless infected).
  - Monitor the healing process and take steps to control infection in the damaged ear.

Barodontalgia (Tooth Cavities Squeeze) 3.1.4

Pain or injury in a tooth and a filling caused by increased pressure on faulty fillings or decayed teeth.

Airspace underneath a filling may cause implosion on descent, a venting tooth cavity may fail on ascent leading to explosion of filling from tooth, or in extreme cases the tooth itself may explode.

Barodontaglia

Presentation Of Tooth Squeeze:

- Pain in affected tooth.
- Maxillary sinus pain.
- Tooth may implode.

Management Of Tooth Squeeze:

- Stop descent - return to surface.
- Analgesic management as required.
- Dental review.

Face or Body Squeeze 3.1.5

This is caused by sudden non-equalisation of a facemask, suit, or hardhat resulting from failure of surface gas supply / non-functioning of non-return valve, or a rapid increase in depth without compensating gas pressure.

Pain caused by local tissue compression and possible haemorrhage of blood vessels in affected tissue.

Face Squeeze

Presentation of Face / Body Squeeze:

- Pain around eyes.
- Pain at the site of the squeeze.
- Blood-shot eyes.
- Bleeding into skin, around eyes, or from nose may occur.
- Puffed-swollen cheeks.

Management of Face / Body Squeeze:

- Mild - none.
- Severe - stop diving until clear.
- Analgesia medication as necessary.

Thoracic (Lung) Squeeze 3.1.6

This barotrauma is caused by compression of lungs to less than their residual volume resulting from an extremely deep free dive (breath holding) or pronounced body squeeze.

May produce significant lung damage due to blood and tissue fluids being forced into the alveoli and air passages.

Thoracic Squeeze

Presentation Of Thoracic Squeeze:

- Feeling of chest compression during descent.
- Pain in the chest.
- Difficulty in breathing on return to the surface.
- Bloody sputum.

Management Of Thoracic Squeeze:

- In severe cases, the diver requires assistance to the surface.
- Implement reduced consciousness care.
- Implement airway / breathing interventions.
- Medically assess & evaluate

G.I.T. Barotrauma 3.1.7

Discomfort in the stomach and / or bowel due to distension with expanding gas. This is caused by trapped gas expanding on ascent.

Divers become more susceptible to this condition after air swallowing at depth, drinking fizzy drinks (particularly during a chamber dive) or using effervescent medication before the dive.

G.I.T.

Presentation of Gastrointestinal Expansion

- Abdominal discomfort.
- Abdominal pain (sharp in nature.).

Management of Gastrointestinal Expansion

- Usually self-curing by belching or passing wind.
- If severe, slow down rate of ascent.
- If occurring in chamber, chew peppermints

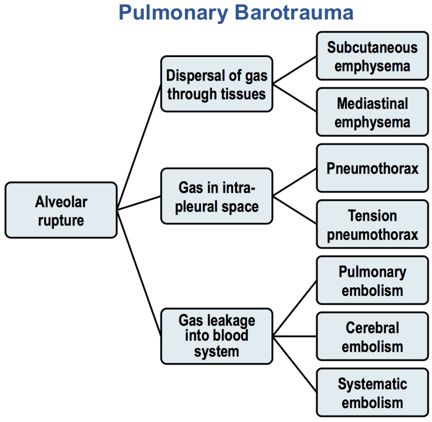
PULMONARY BAROTRAUMA'S 3.2

Barotrauma is physical damage to body tissues caused by a difference in pressure between an air space inside or beside the body and the surrounding fluid.

Barotrauma typically occurs to air spaces within a body when that body moves to or from a higher pressure environment, such as when a diver or an airplane passenger ascends or descends, or during uncontrolled decompression of a pressure vessel. Boyle's law defines the relationship between the volume of the air space and the ambient pressure.

Damage occurs in the tissues around the body's air spaces because gases are compressible and the tissues are not. During increases in ambient pressure, the internal air space provides the surrounding tissues with little support to resist the higher external pressure. During decreases in ambient pressure, the higher pressure of the gas inside the air spaces causes damage to the surrounding tissues.

Pulmonary Barotrauma

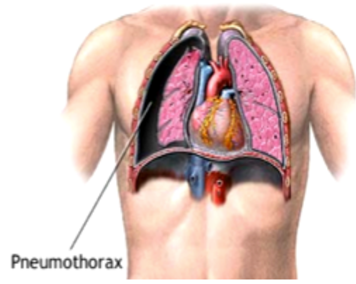


Pneumothorax 3.2.1

A pneumothorax occurs when alveolar gas escapes into the pleural space. This is an over expansion injury which has caused alveolar over expansion & rupture.

This is not a life-threatening condition because it is possible to survive with one intact lung and it is most unusual for both lungs to be involved simultaneously. Occasionally, however, the leak is such that gas escapes into the pleural space with each breath, but is unable to return to the lung. The volume of the pneumothorax gradually increases.
This is known as a tension pneumothorax.

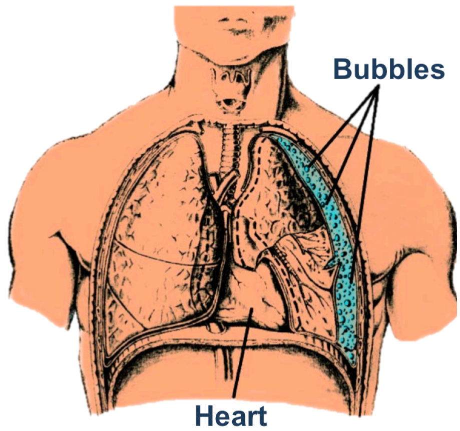
Over-expansion Pneumothorax



Presentation of a Pneumothorax (severe)

- Commonly the pneumothorax is small and there are fewsigns.
- Abnormal airway signs: **Distress / wheeze.**
- Neck Signs: **Trachea deviation** (late sign) / **distended neck Veins / Emphysema present / L**arynx intact.
- Breathing (RISE – FALL): **rapid Rate** / **aSymmetrical movement** / **gross Effort & accessory muscle use** / **Feel emphysema / hyper-resonant on affected side** / breath sounds: **absent on affected side.**
- Difficulty speaking (will need to take a breath in the middle of a sentence).
- Painful breathing / complain of chest pain.
- Rapid pulse rate (tachycardia).
- Non-palpable radial pulse (Reduced blood pressure).
- Reduced conscious level (cerebral hypoxia).
- Pale, clammy skin / Grey or blue lips and skin (cyanosis).

Closed Pneumothorax



Management of a Pneumothorax

A Small Pneumothorax Can Be Treated Conservatively:

- Contact duty medic / supervisor.
- Conduct primary / secondary survey & record observations.
- Administer high flow O_2 on the surface.

All Tension Pneumothoraces Require Draining.

- Conduct primary / secondary survey & record observations.
- Implement compromised airway / breathing management.
- Alert Medical personnel / supervisor & prepare to evacuate.
- Observe for & treat A.G.E.'s.
- Assess for tension pneumothorax & implement treatment.
- Treat Shock. (Always Insert an I.V. cannula, give I.V. fluid as instructed).
- Continually assess casualty.

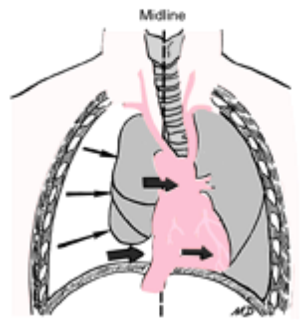
Tension Pneumothorax 3.2.2

A Tension Pneumothorax is almost exclusively an over expansion event. The presence of a diving over expansion tension pneumothorax is related an increased incidence of A.G.E's and D.C.I. in the victim.

Presentation of Tension Pneumothorax

- Standard Tension Pneumothorax presentation.
- Possible P.A.G.E. / C.A.G.E.
- Possible Neurological / musco-skeletal D.C.I.
- Mediastinal and subcutaneous emphysema in neck / shoulders.

Over-Expansion Tension Pneumothorax



Management Of Tension Pneumothorax

- Contact duty medic / supervisor.
- Conduct primary / secondary survey & record observations.
- Administer high flow O_2 on the surface.
- Implement Tension Pneumothorax treatment.
- Implement shock management. (O_2, I.V.I. etc).
- Implement A.G.E. / D.C.I. / subcutaneous emphysema management.
- Continually assess casualty & record observations.
- Prepare to evacuate (as per company S.O.P's).
- A trained medic should place a chest drain on the affected side as soon as possible.

Mediastinal and Subcutaneous Emphysemia 3.2.3

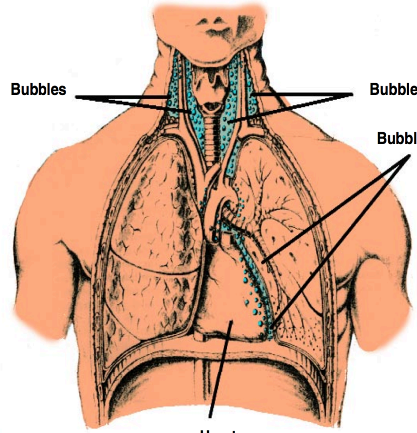
If gas escapes into the interstitial tissue space, it may track along the outside of the airways and blood vessels to the hila of the lungs and from there into the mediastinum.

This is the space between the lungs, which contains the heart, great vessels, and major airways. The presence of a little gas in the mediastinum is often symptomless.

Occasionally, considerable quantities of gas escape from the lung and this may track down into the abdomen and, rarely, the pelvis. The gas is retroperitoneal and may outline the liver and kidneys. It is unusual for such gas to generate symptoms.

However, if tissues are stretched by a substantial amount of gas, may be felt.

Mediastinal Emphysema



Presentation of Mediastinal And Subcutaneous Emphysemia.

- Often symptomless.
- A change in the tone of the voice or hoarseness.
- Swelling or crepitation (the skin “crackles') in the neck & face.
- A sensation of fullness in the chest or throat.
- Mild to moderate retrosternal pain.

Management Of Mediastinal And Subcutaneous Emphysemia.

- Usually resolves gradually without specific treatment.
- If there are troublesome symptoms:
  - Giving 100% O_2 on the surface.
  - Recompression as per company S.O.P. (in the very rare instances where there are serious symptoms).

HISTORY OF DECOMPRESSION ILLNESS 3.3

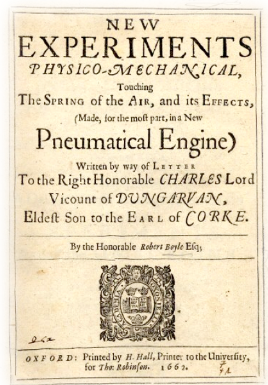
The "bends" is today readily associated with SCUBA diving. It is, in fact, an old-fashioned term used originally to describe the appearance of workers returning from 'caissons' during the construction of bridges in the 19th century. The air inside these underwater enclosures was pressurised to counteract the weight of the surrounding water. Following their shifts, some men would return to the surface suffering joint pain that made it difficult for them to stand straight. Their appearance was similar to the 'Grecian bend' adopted by fashionable women of the time - hence the name. Many workers died or suffered permanent disability because of "Caisson disease", as the condition became known.

Caisson Workers

The connection between the workers' return to the surface and their symptoms led to the introduction of surface based recompression chambers to treat the afflicted. However, the reason for the condition was not fully recognised until 1878, when Paul Bert published his theory that the cause was the formation of nitrogen bubbles within the body. He also correctly stated that it was possible to avoid their harmful affects by ascending to the surface gradually - and that hyperbaric chambers worked, in part, because they decreased the size of bubbles.

Bert noted the work of the scientist Robert Boyle. In 1667, Boyle observed that following exposure to a compressed atmosphere, and subsequent decompression, a bubble formed in the eye of a viper. The animal also appeared distressed by the experience.

As stated by Boyle's Law, ascending from a hyperbaric environment towards the surface results in an increase in the volume of a fixed amount of gas, including those found in the body. In the case of oxygen, the body quickly reabsorbs the extra volume as the cells use it up. Carbon dioxide, a waste product of metabolism, is excreted through the lungs very efficiently and therefore does not present a problem when decompressing.


NEW
EXPERIMENTS
PHYSICO-MECHANICAL,
Touching
The SPRING of the AIR, and its EFFECTS,
(Made, for the most part, in a New
Pneumatical Engine)
Written by way of LETTER
To the Right Honorable CHARLES Lord
Vicount of DUNGARVAN,
Eldest Son to the EARL of CORKE.
By the Honorable Robert Boyle Esq;
OXFORD: Printed by H. Hall, Printer to the University, for Tho. Robinson. 1662.

The body does not use nitrogen, however, which forms almost 79% of the air. For the purposes of discussing decompression, it is an 'inert' gas, as is helium. Unless enough time is allowed for the inert gas to be excreted through the lungs, any collection within the body's tissues can increase in volume to the point where bubbles are formed.

These can lead to the formation of emboli (singular: embolus) that cause adverse physiological effects by impeding blood flow and/or damaging tissues or nerves. It should be noted that the presence of inert gas bubbles does not in itself lead to problems - what is important is the eventual size of these bubbles, their location, and the ability (or inability) of the body to rid itself of them before they cause damage.

Steel Ball Hospital

The first recorded chamber was built and run by a British clergyman named Henshaw. He built a structure called the *domicilium* that was used to treat a multitude of diseases. The chamber was pressurized with air using bellows.

The French surgeon Fontaine, who built a pressurized, mobile operating room in 1879, continued the idea of treating patients under increased pressure.

Dr. Orville Cunningham, a professor of anaesthesia, ran what was known as the "Steel Ball Hospital." The structure, erected in 1928, was 6 stories high and 64 feet in diameter. The hospital could reach 3 atmospheres of pressure. The hospital was closed in 1930 because of the apparent lack of scientific evidence indicating that such treatment alleviated disease. It was deconstructed during World War II for scrap to aid the war effort.

DYSBARISM 3.4 (The Diseases of Diving)

Dysbarism refers to medical conditions resulting from changes in ambient pressure. Various activities are associated with pressure changes. Diving is the most common, but pressure changes also affect people who work in other pressurized environments (caisson workers).

Within diving the term dysbarism can be used to describe a host of diving conditions.

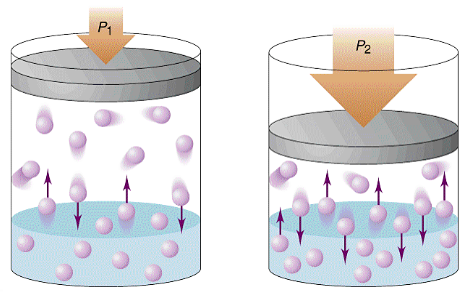
These Include;

- Barotraumas.
- Arterial Gas Embolisms (A.G.E.)
- Decompression Sickness.

Acute Decompression Illness 3.4.1

Decompression Illness (DCI) is a term that has been used for over 50 years. DCI includes both A.G.E.'s and Decompression Sickness.

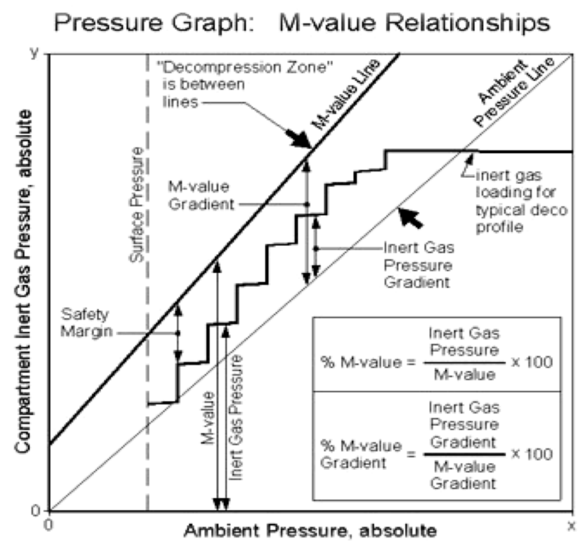
Acute decompression illness (DCI) is a syndrome of numerous possible manifestations, which may develop following decompression. It is thought to be initiated by the presence of bubbles of inert gas in the body tissues and blood stream. Although the means where, by these bubbles cause tissue dysfunction have yet to be fully understood, the manifestations have been recognised for many years and are described below.



Disease Mechanisms

There Are A Number Of Sources Of These Gas Bubbles:

Dissolved gas. The partial pressure of inert gas in arterial blood is approximately the same as the partial pressure in the gas mixture, which is being breathed. For example, at sea level, both air and arterial blood contain approximately 0.79 bar of nitrogen. During most dives or hyperbaric exposures, the partial pressure of the inert gas being breathed increases with depth and the concentration of that gas in arterial blood increases accordingly. For example the partial pressure of nitrogen in air at 2 bar is approximately 1.58; when this is breathed the partial pressure of nitrogen in the arterial blood is also approximately 1.58 bar. This effect is the same with different mixes and inert gases such as helium. Under these circumstances, the partial pressure of inert gas in tissues will gradually increase due to blood/tissue gas transfer until it equals the ambient partial pressure. In this state the tissues are considered to be saturated.



During decompression, inert gas moves in the opposite direction, from the tissues into the blood, where it is carried to the alveoli in the lungs and exhaled. If this process occurs in a controlled manner, so that the inert gas tension in the tissues does not reach a sufficient level of super saturation (exceeding M values) then bubbles of gas will not form and the decompression will progress uneventfully. However, if the rate of decompression is such that the capacity of the tissues, cardiovascular system and lungs to remove inert gas is exceeded, bubbles of that gas may start to form in tissues or blood.

The human body is capable of tolerating a certain bubble burden. Bubbles in venous blood, for example, are efficiently removed from the circulation by the lungs and numerous studies have demonstrated the presence of such bubbles in asymptomatic divers. Furthermore, bubbles may form in some tissues (such as adipose tissue) without causing overt disease. However, other tissues, particularly nervous tissue, are much more sensitive and the presence of even a small number of gas bubbles may result in abnormal tissue function.

Arterial gas bubbles. The lungs are excellent filters of gas bubbles. However, this capacity is finite; if the bubble burden is such that this is exceeded, they will transit the lungs and enter the arterial circulation. This can occur after heavy gas tissue loading and a rapid decompression.

The transit of venous bubbles to arterial blood may occur before the pulmonary filter is overwhelmed. In approximately 25-30% of the normal, adult population, the septum that separates the upper chambers of the heart contains a potential or actual defect, which is known as a Patent Foramen Ovale or PFO (This is a relic of the foetal circulation and normally results in no ill effects). However, it does offer a possible route for bubbles to bypass the pulmonary filter and consequently, along with other right-to-left shunts, has the potential to promote the arterialization of otherwise relatively harmless venous bubbles.

Bubbles in arterial blood physically obstruct small blood vessels and thereby cause tissue ischaemia (oxygen starvation through reduced blood flow).

This Localised Ischaemia Create A Cascade Reaction Which;

- Initiates local tissue inflammatory reaction.
- Increases localised tissue ischaemia.
- Increased endothelial permeability + leakage of plasma.
- Increased local pressure.
- Resulting in further inflammatory reaction & activation of the immunological complement.

Although it is recognised that tissue bubbles may arise from two fundamentally different processes it is often difficult, in individual cases, to be certain of the origins of the disease-provoking gas. Indeed, with respect to some organ systems, such as the ear and lungs, it may occasionally be difficult to distinguish between a bubble-induced condition and the results of barotrauma.

Consequently, it is now recognised that, for practical purposes, the distinction between the conditions that used to be known as decompression sickness and arterial gas embolism was artificial. As a result, the term decompression illness, which encompasses the two, is increasingly being used to reflect this.

Manifestation of D.C.I. 3.4.2

DCI type	Bubble location	Signs & symptoms (clinical manifestations)
Musculoskeletal	Mostly large joints (elbows, shoulders, hip, wrists, knees, ankles)	• Localized deep pain, ranging from mild to excruciating. Sometimes a dull ache. • Active and passive motion of the joint aggravates the pain. • The pain may be reduced by bending the joint to find a more comfortable position.
Neurologic	Brain	• Altered sensation, tingling or numbness paresthesia, increased sensitivity hyperesthesia. • Confusion or memory loss. • Visual abnormalities. • Unexplained mood or behaviour changes. • Seizures, unconsciousness.
Neurologic	Spinal cord	• Ascending weakness or paralysis in the legs. • Girdling abdominal or chest pain. • Urinary incontinence and fecal incontinence.
Audio-vestibular (Neurologic)	Inner ear	• Loss of balance. • Dizziness, vertigo, nausea, vomiting. • Hearing loss.
Constitutional (Probable Neurologic)	Whole body	• Headache. • Unexplained fatigue. • Generalised malaise, poorly localised aches.
Pulmonary	Lungs	• Dry persistent cough. / Shortness of breath. • Burning chest pain under the sternum, aggravated by breathing.
Cutaneous	Skin	• Itching, usually around the ears, face, neck, arms, and upper torso. • Sensation of tiny insects crawling over the skin. • Mottled or marbled skin usually around the shoulders, chest and abdomen, with itching. • Swelling of the skin, accompanied by tiny scar-like skin depressions (pitting odeama).
Lymphatic	Lymphatic Vessel	• Localised tissue swelling / oedema. • Possibly due to blockage of the lymphatic vessels draining a specific group of lymph nodes (usually in trunk, head or neck).

How DCI manifests is generally complicated. DCI is a multi-system disease with single organ involvement is uncommon. The effects of the gas bubble load tends to attack the densest of tissue (or the slowest compartments), these are the nervous system, tendons / synovial joints, lymphatic tissue and adipose (fat).

DCI may present with a bewildering array of symptoms, which can lead the clinician to suspect what the underlying system effected is.

Traditional Classification Of DCI 3.4.3

As discussed, DCI as a disease / syndrome has been in existence for over 150 years. It is not surprising then that the disease has had many names and tools to describe its effects.

In addition to the "bends", the effects of "Caisson disease" have several other descriptive terms, the "chokes", "staggers" and "niggles".

From the 1950's the label 'decompression sickness' (DCS) was introduced in place of "Caisson disease".

Decompression Sickness Was Divided Into Three Subsections:

- Arterial Gas Embolisms.
- Type 1.
- Type 2.

The different classification reflects the effect, and therefore the severity, of the condition. Diagnosing DCS as one (or both) of just two categories does not enable proper identification or discrimination.

Arterial Gas Embolisms are discussed in Barotraumas. However, the two types are described here.

Type 1 D.C.I.

Type 1 DCS can occur when bubbles affect the tissues around skeletal joints. Decompression sickness might also present as a skin (cutaneous) .

- Local pain, usually in joints of arms or legs (knees, elbows and shoulders).
- Pain made worse by exercise.
- Itching, blotchy skin rash, mottling, raised section of the skin.

Type 2 D.C.I.

Type 2 Decompression Sickness reflects involvement of the Central Nervous System (CNS) and / or the cardio-respiratory system.

More than half of those diagnosed with DCS will be classified as Type 2. Cerebral symptoms arise from interruption of the blood supply to the main part of the brain, and include confusion, reduced mental function and unconsciousness.

Involvement of the cerebellum may lead to tremors, loss of balance ("staggers") and a lack of co-ordination (ataxia). Balance may also be affected by damage to the vestibular part of the inner ear.

Symptoms Include:

- Dizziness.
- Ringing in ears.
- Difficulty in seeing.
- Shortness of breath.
- Rapid breathing.
- Choking.
- Severe pain.
- Pain in abdomen.
- Extreme fatigue.
- Loss of sensation (numbness).
- Weakness of extremities.
- Collapse or unconsciousness.

The advantages of using the 'classical' classification system are overall familiarity, for over 50 years it has been the accepted description of the manifestation of DCI.

However there are multiple disadvantages in the use of this classification system; precise mechanistic diagnosis is often impossible due to the fact that DCI frequently have multiple manifestations.

It is common for multiple physicians to describe a condition as both Type 1 & Type 2 leading to a wide variations in diagnosis and ultimate treatment.

Modern Terminology Of DCI 3.4.4

Since the late 1990's a much more modern, descriptive-manifestation system of classifying DCI was introduced (At a 1991 Undersea and Hyperbaric Medical Society workshop)

Since decompression illness can interfere with the function of a wide range of body tissues, the number of potential signs and symptoms is truly enormous. Rather than using a somewhat artificial classification on the decompression disorders (types I and II), a better understanding of DCI is likely to result if a descriptive system is used.

This System Is Split Into Three Components:

- Time of **onset** of symptoms.
- The **evolution** of symptoms.
- The actual **symptoms**.

Onset

The time of symptom onset is a key factor in the diagnosis of DCI 98% of all DCI's will present within exit from the water. The term "acute" is used to distinguish these conditions from possible "chronic" consequences of diving such as dysbaric osteonecrosis.

- **Acute.** The condition has manifested recently.
- **Chronic.** The condition has manifested some time ago.

Evolution

The evolution term is used to describe the development of the condition PRIOR TO RECOMPRESSION. DCI is frequently a rapidly changing condition.

The Evolution Of The Symptoms May Be Described As:

- **Progressive.** A progressive condition would be if the number or severity of symptoms or signs is increasing.
  - Increasing severity of limb pain and the involvement of additional joints.
  - A neurological presentation in which the loss of motor or sensory function is becoming more profound.
  - The development of a new manifestation.
  - Terms such as "rapidly" or "slowly" may be used to enhance the description of this evolution.
- **Static.** This is self-explanatory. Neither the severity nor number of manifestations is changing substantially.
- **Spontaneously Improving.** DCI that improves, without recompression.
  - Cutaneous skin bends. (Substantial improvement must occur for this term to be applied).
  - As with other evolution terms, "improving" should only be used to describe events prior to recompression.
- **Relapsing.** Occasionally, cases that have improved spontaneously undergo a secondary deterioration.
  - Common with neurological manifestations.
  - When a condition gets worse in the absence of spontaneous improvement it is described as "progressive".
  - "Relapsing" should be reserved for cases, which have, at some stage in their evolution, undergone substantial and spontaneous improvement.

Symptom Manifestations

There are a number of manifestations of decompression illness, which occur commonly, and these are outlined below. They may occur alone or in combination.

- **Limb Pain**. One the most frequent manifestation of DCI (second to lethargy / fatigue).
  - Deep aching pain in or around one or more joints.
  - Following 'bounce' dives, the upper limbs and the shoulder is involved particularly frequently.
  - Conversely, in saturation divers, it is the lower limbs and the knees, which are involved most commonly.
  - The pain is usually poorly localised; it may resolve spontaneously and is then known as a 'niggle'. Niggles may flit from joint to joint.
  - If the pain gets worse, it becomes more readily localised and is described as a dull, boring ache, similar in character to tooth ache. Sometimes the joint is held in a particular position that is least painful, but pain is seldom made worse by movement.
  - If the pain is in a lower limb, weight bearing may be poorly tolerated on that limb.
  - The 'classical' signs of inflammation: redness, swelling, warmth to the touch and tenderness are **missing.**
- **Girdle Pain**. This is a poorly localised, aching or 'constricting' sensation, generally in the abdomen or pelvis.
  - Girdle pain is generally considered ominous since it frequently portends neurological deterioration.
- **Neurological.** Involvement of the nervous system may be subtle and multi-focal. Consequently symptoms can be of bewildering variety and very difficult to localise. Both the central and peripheral nervous systems may be involved and the manifestations can be broken down into the loss of certain functions:

- Aberration of thought processes, loss of memory, speech disorders, alteration to the level of consciousness including seizures; loss of co-ordination; loss of strength or sensation.
- Dysfunction of special senses and loss of sphincter control, especially of the bladder.
- Loss of consciousness to the point of disorientation is a frequent finding and coma may occasionally ensue.
- Motor and other sensory deficits.
- Signs such as a change of mood, dulling of intellect and loss of short-term memory.

- **Neurological (Spinal).** Spinal cord is involved in neurological DCI with some frequency. It may appear to be involved alone or with other parts of the nervous system.
  - Short, deep dives with a rapid ascent to the surface are commonly involved.
  - The onset of symptoms commonly occurs shortly after dive (about half of cases are symptomatic within 10 minutes).
  - Less than 10% of serious cases present more than 4 hours after completing the dive.
  - In severe cases, the condition is often heralded by the onset of girdle pain.
  - Shortly afterwards, the patient may notice pins and needles, numbness and muscular weakness in the legs.
  - Which may rapidly progresses to paraplegia.
  - Neurogenic (spinal) shock may complicate the clinical picture.
  - The bladder is frequently involved (difficulty to void or full retention).

- **Audio-Vestibular (Neurological).** This is a unique subclass of neurological decompression illness. It is thought that there are two mechanisms whereby the audio-vestibular system may be involved: barotrauma (perilymph fistula / oval round window rupture) and tissue injury resulting from the formation of bubbles from dissolved gas.
  - Targets of these micro-bubbles include; the cochlea, the eighth nerve nuclei and cortical pathways.
  - It is very difficult to distinguish between these mechanisms or sites of injury by clinical examination alone.
  - The syndrome includes: vertigo (a sense of rotation), tinnitus, nystagmus or loss of hearing after a dive.
  - Nausea and vomiting may accompany these symptoms.
  - Previously there has been hesitation before prescribing recompression in such cases for fear of further tissue damage.
  - Recompression does not have an adverse effect on pathology due to round or oval window rupture.
- **Pulmonary. (The Chokes)** Related to the lungs: decompression pulmonary barotrauma and the cardiopulmonary consequences of massive venous gas embolism.
  - The mechanisms are distinctly different; it may be difficult to distinguish between them immediately in a clinical setting, because many of the symptoms and some of the signs are shared.
  - Those which imply pulmonary (or, rarely, cardiac) involvement in decompression illness are: chest pain, cough, haemoptysis, shortness of breath, cyanosis and, rarely, cardiogenic shock.
  - Progressive disease (where the symptoms are worsening) may be due either to a tension pneumothorax or massive gas embolism of the lungs.
  - Where there has been a dive, which has induced a low gas burden, it is most likely that a pneumothorax. This may be diagnosed clinically from the classic signs (described in the Gas Embolism section).
- **Cutaneous.** The skin may be affected in two manifestations of decompression:
  - Cutaneous DCI generally presents with severe itching around the shoulders or over the trunk.
  - This develops into an erythematous rash, which may progress to cyanotic mottling or marbling of the skin.
- **Lymphatic.**
  - Lymph nodes may become enlarged and tender and this may be associated with oedema.
  - The skin feels thickened and may have the 'pitted' appearance of orange peel.
  - If pressure is applied to the skin for about a minute or so, a visible indentation remains.
- **Constitutional.** There are a number of non-specific symptoms that occur after diving and which, if severe or accompanied by other manifestations, may be considered part of the decompression illness syndrome.
  - Symptoms include headache, fatigue, malaise (may include nausea and vomiting) and anorexia (loss of appetite)

Applying The Terminology

By including the onset, evolution and manifestation terms in the phrase "decompression illness", a highly flexible diagnostic label can be applied to any case. This label imparts a great deal of information and because it does not require the observer to guess at either a mechanism of the disease or location of the lesion, it should be possible for these terms to be applied consistently.

This is an important tool because the diagnosis of DCI is overall a clinical one (there is no diagnostic blood test or xray).

The disadvantage of this system is that it is generally verbose and it marginally ignores pathophysiology (rather than distinguish between musculo-skeletal and neurological pain, it simply uses 'limb pain').

> **Example Diver**
> 25 year old male, diving on air.
> - 2 dives:
>   - 32 metres for 45 minutes total dive time.
>   - 2 hour surface interval.
>   - 32 metres for 35 minutes total dive time.
>
> Worsening pain in left shoulder, with associated tingling in left hand, 30 mins after surfacing from 2nd dive.
> **Description:**
> Acute Progressive Neurological and Limb Pain DCI.

The advantages of this system are; an improved data collection with regards to manifestations of DCI, No real need for precise mechanistic diagnosis, a uniformity of reporting cases of DCI and once a clinician is use to the system it is relatively easy to use.

Examples Of How The Terminology Is Used Include:

Acute , Relapsing, Neurological, DCI

or:

Acute, Progressive, Limb Pain And Cutaneous DCI

In rare, highly complex cases, rather than enumerate a long list of manifestations, it may be appropriate to use the term 'multi-system'.

Additional DCI Factors 3.4.5

While the descriptive diagnostic terminology imparts a considerable amount of information, it is inadequate, of itself, to summarise a case of decompression illness. As was mentioned above, this a poorly understood syndrome and if a better understanding is to evolve, it is important that additional information is collected:

The Time Of Symptom Onset

DCI usually presents within a 24hr period following a dive although rarely it can present outside of this. Symptoms may become apparent before surfacing in saturation and occasionally in bounce dives, particularly where decompression has been omitted.

Most symptoms occur after surfacing and the majority of serious neurological or pulmonary symptoms are usually manifest within about 30 minutes.

% Cases	First Symptoms
42%	Within 1 Hour
60%	Within 3 Hours
83%	Within 8 Hours
98%	Within 24 Hours
100%	Within 48 Hours

The onset of limb pain also occurs in this time period but this may be delayed for many hours after a dive. It should be remembered that decompression illness might be provoked or made worse many hours after a dive if the diver takes a flight. If a diver has been asymptomatic for 48 or more hours after a dive and has not flown, then symptoms, which develop subsequently, are probably not DCI.

The time of onset of symptoms influences prognosis, a short latency implies severe disease (e.g A.G.E. / C.A.G.E.), late severe symptoms indicates a secondary pathology (such as haemorrhage).

An exceptionally delayed DCI should not be completely discounted due to the possibility of ‘diver denial’, this is a basic reluctance of an individual diver to admit that they have relevant symptoms.

Gas Burden

When considering possible mechanisms for DCI, it is desirable to estimate the amount of gas that is likely to be present in the various tissues. Consequently it is important that the dive profile is recorded as accurately as possible with the inclusion of the gas mix breathed. Where a dive computer or depth-time recorder was worn, the information should be retrieved from this source.

Presence of Risk Factors

It is important to evaluate the possible risk factors associated with the dive, these risk factors include;

- **Dive profiles** (Sawtooth pattern / shallow to deep dives / rapid ascent / multiple daily dives / omitted decompression / new dive / exercise at depth / during or after decompression).
- **Individual diver** (Age-fitness-weight of diver / dehydration / Patent foramen ovale (PFO) / Limb tourniquetion).
- **Temperature** (High temperatures lead to dehydration > blood plasma loss > reduced venous off-gassing. Low temperatures cause vasoconstriction & reduced off-gassing, particularly in adipose tissue).
- **Altitude exposure** (This does not have to be flying alone; a mountain ascent is an equal risk factor).

Treatment of D.C.I. 3.4.6

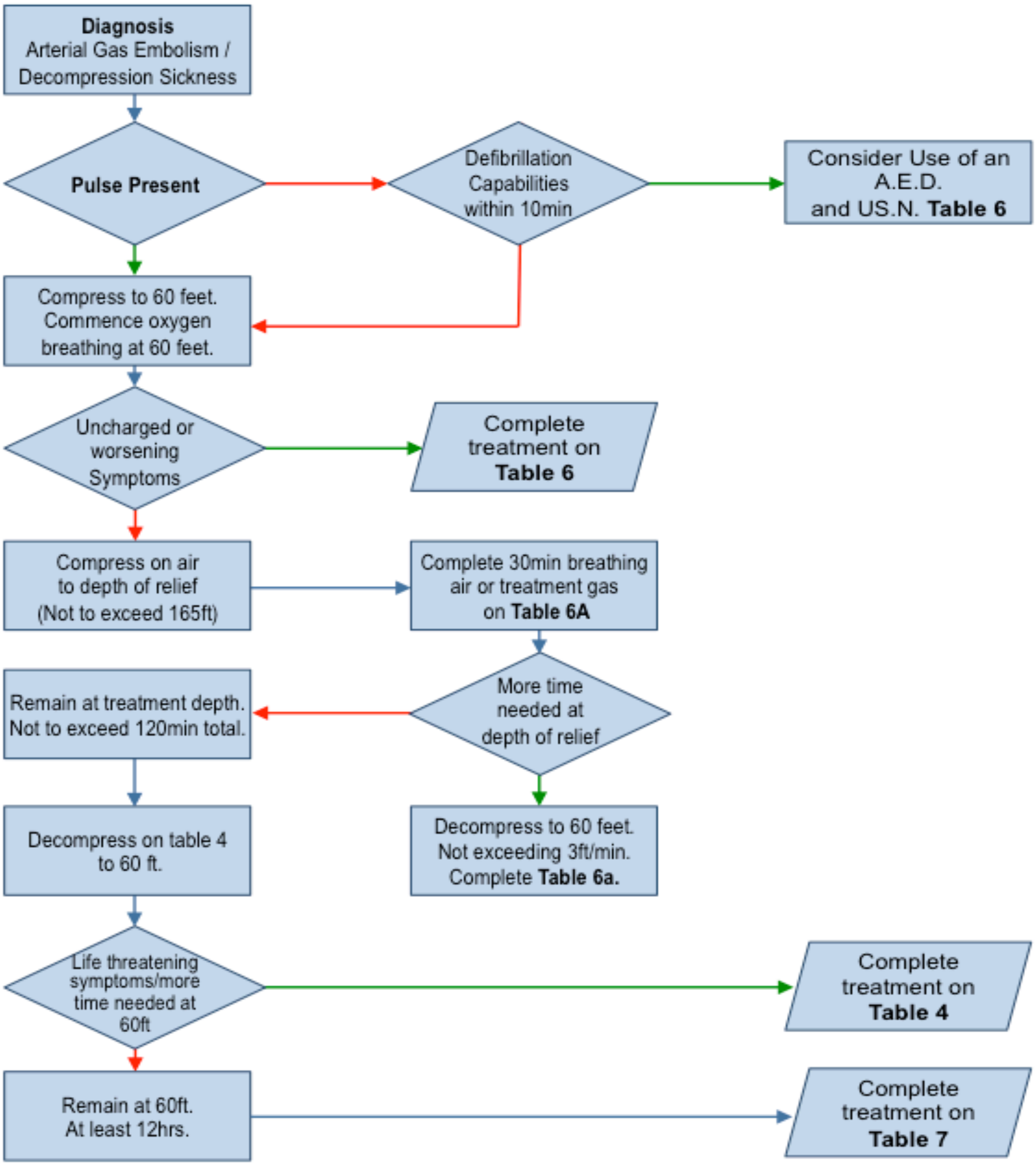
Immediate Actions in D.C.I.

If a diver is suspected of suffering decompression illness the following immediate actions should take place.

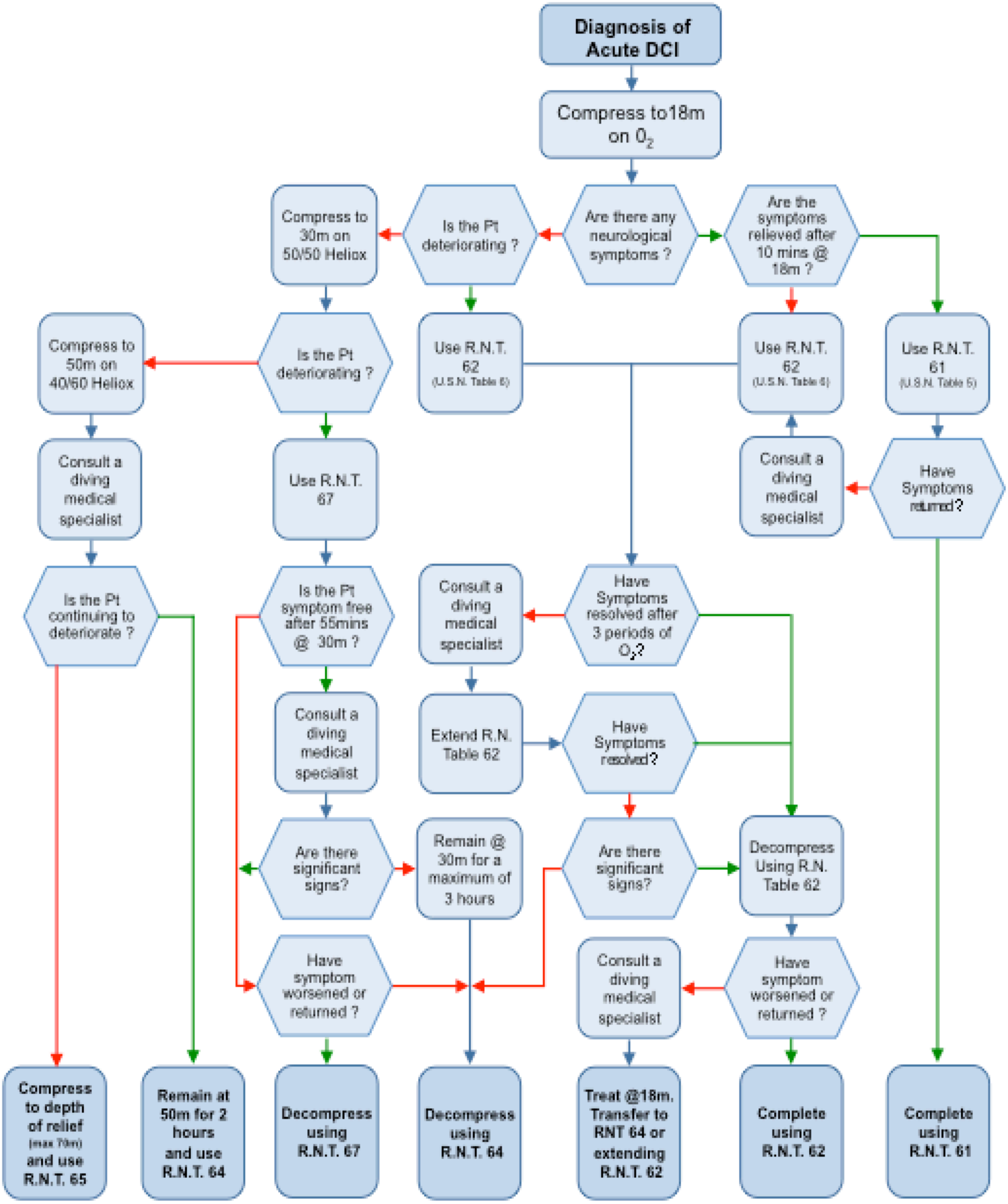
- Contact duty medic / supervisor.
- Conduct primary / secondary survey (including full neuro exam) & record observations.
  - Apply D.C.I. manifestation criteria (ONSET – EVOLUTION – SYMPTOMS).
- Lay the casualty flat and administer high flow O_2.
- Implement airway / breathing management.
- Implement Shock Management as indicated.
- Start immediate recompression on appropriate treatment table (as advised by medical specialist or if unavailable company SOP).
  - Use appropriate treatment algorithm such as the R.N or U.S.N.

- Repeat, and complete physical examination when patient is at treatment depth in recompression chamber.
  - Continue to apply treatment algorithm in accordance with the divers condition.

United States Navy D.C.I. Treatment Algorithm



Royal Navy D.C.I. Treatment Algorithm



ARTERIAL GAS EMBOLISM'S (A.G.E.) 3.5

A gas embolism occurs when a bubble of gas causes a blockage of the blood supply to the heart, brain or other vital tissue. The condition is worsened if the embolism occurs at depth, as the bubble will increase in size as the pressure decreases.

When divers hold their breath or have local air trapped in their lungs during ascent, the pressure-volume relationships will cause a rapid over expansion.

Alveoli can rupture or air can be forced across apparently intact alveoli. If air bubbles enter the pulmonary veins, they are swept to the left side of the heart and pumped out into the aorta. Bubbles can enter the coronary arteries supplying the heart muscle, but they are more commonly swept up the carotid arteries to embolise the brain.

As the bubbles pass into smaller arteries, they reach a point where they can move no further and here they occur immediately or within 5 minutes after surfacing.

Pulmonary Arterial Gas Embolism (P.A.G.E.) 3.5.1

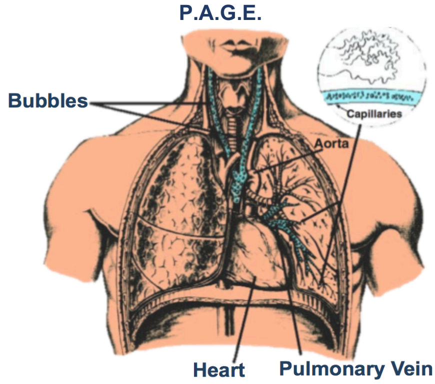
Decompression pulmonary barotrauma is a syndrome, which results in dissolved gas rapidly coming out of solution and entering either the interstitial space within the lung, the pleural cavity or the blood stream.

At the simplest level, if gas that has been breathed while at depth is trapped within the lung during ascent, then the resulting expansion in volume of that gas, in accordance with Boyle's Law, may be sufficient to cause the architecturally delicate pulmonary tissue to rupture and overwhelming the pulmonary filter.

The gas may be trapped as a result of breath holding, or as a result of pulmonary pathology.

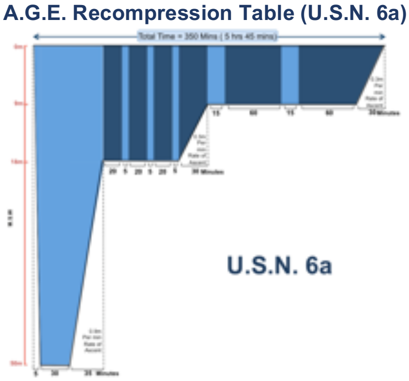
Presentation of Pulmonary Arterial Gas Embolism

P.A.G.E.



- Rapid onset symptoms (usually < 10 minutes):
  - 9% occur during ascent.
  - 83% occur in less than 5 minutes of surfacing.
  - 8% occur between 5-10 minutes.
- Possible pneumothorax (associated pulmonary barotrauma rupture).
- Abnormal airway signs: **Distress / wheeze / Haemoptesis** (Bloody, frothy sputum).
- Neck Signs: **Trachea Deviation** possible / **distended neck Veins / possible Emphysema.**
- Breathing (RISE – FALL): **rapid Rate** / **possible aSymmetrical movement** / **gross Effort & accessory muscle use** / **hypo-resonant on affected side** / breath sounds: **absent or crepitus.**
- Difficulty speaking (will need to take a breath in the middle of a sentence).
- Low SPO_2 levels.
- Cardiogenic shock.
- Chest pain (usually behind the breastbone).
- Neurological signs:
  - Confusion.
  - Visual disturbances such as blurring.
  - Seizure (Focal / Generalised).
  - Sudden unconsciousness (usually immediate after surfacing but sometimes before surfacing).
- Pulmonary / Cardiac Arrest.

A.G.E. Recompression Table (U.S.N. 6a)



Management of Pulmonary Arterial Gas Embolism

- Conduct primary / secondary survey (Including neuro exam) & record observations.
- Contact duty medic / supervisor (URGENTLY).
- Implement tension pneumothorax management as indicated.
- Implement airway / breathing management (ALWAYS initiate O_2, R.S.I. is often required for intubation).
- Implement Shock Management as indicated. (O_2, I.V.I. etc).
- Positioning the patient in a horizontal -15% inclination.
- Start immediate recompression (as advised by medical specialist or if unavailable company SOP often USN 6a is appropriate).
- Continually assess casualty & record observations.
- Prepare to evacuate (as per company S.O.P's).

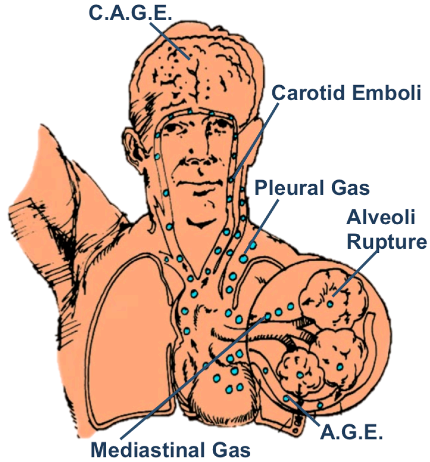
Cerebral Arterial Gas Embolism (C.A.G.E.) 3.5.2

Arterial gas emboli arise from gas bubbles in the pulmonary capillaries, which then pass to the pulmonary veins to the left side of the heart (possibly causing coronary artery emboli). The gas will pass via the internal carotid and vertebro-basilar arteries to the brain.

The gaseous foam or bubbles block arteries of the 30-60 micron and cause distal ischemia and neuronal swelling. As the bubble passes over the endothelium, there are direct cellular effects (within 1-2 minutes). The bubble itself has surface effects causing local swelling, downstream coagulopathy with focal hemorrhages.

There is immediate increased permeability of the blood-brain barrier, loss of cerebral auto-regulation, rise in CSF and a rise in the systemic blood pressure.

CAGE is a life-threatening emergency with the clinical picture of a stroke and requires immediate medical treatment in line with a P.A.G.E.



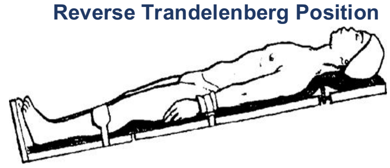
Presentation of Cerebral Arterial Gas Embolism

- Symptoms of P.A.G.E. (including rapid onset).
- Neurological changes;
  - Stroke (F.A.S.T.).
  - Headache.
  - Blindness (partial or complete).
  - Numbness and tingling.
  - Weakness or paralysis.
  - Seizure (Focal / Generalised).
  - Sudden unconsciousness (usually immediate after surfacing but sometimes before surfacing).
- Pulmonary / Cardiac Arrest.

Management of Cerebral Arterial Gas Embolism

- Implement P.A.G.E. management.
- Contact duty medic / supervisor (URGENTLY often evacuation for neurosurgical review is necessary).
- Implement seizure management.
- Implement stroke & cerebral compression management.
  - Often stabilization with ventilation & sedation is mandatory.
  - Maintain a flat or a 15° reverse trandelenberg position.
- Prepare to evacuate (as per company S.O.P's).

Reverse Trandelenberg Position



DECOMPRESSION THERAPY 3.6

It is important that a A.L.S.T. orientates themselves to their company's S.O.P.'s with regards to treatment of DCI with compression therapy.

Standard recompression algorithms are readily available, but it is not uncommon for specific operators to modify or enhance treatment algorithms.

We have included a 'Tender Responsibilities' section in this chapter, which highlights the R.N. Tables 66, 62 & 67. These responsibilities can be altered to suit any chamber.

Personnel Requirements For Chamber Operations

The minimum team for conducting any recompression operation consists of a Diving Supervisor, an inside Tender, outside Chamber Assistant and depending on the circumstances, a Diving Physician.

Diving Supervisor

The diving supervisor is in charge of the operation and must be familiar with all phases of chamber operation and treatment procedures. The supervisor must ensure that communication, logging, and all phases of treatment are as per company SOP's.

Diving Physician

The diving physician is trained in the treatment of diving accidents. Although it may not be possible to have a diving physician present during all treatments, it is essential that the diving supervisor be able to consult by telephone or radio with a diving physician.

Chamber Tender

The inside tender must be familiar with all treatment procedures and with the signs, symptoms and treatment of diving related injuries and illnesses. They are responsible for the direct care of the casualty & communicating their condition with the dive supervisor / duty medic.

Choosing the Right Personnel

When a recompression treatment is conducted for pain-only decompression illness, an experienced physician or DMT should tend the patient inside the chamber.

If it is known before the treatment begins that specialised medical aid must be administered to the patient, or if a gas embolism is suspected an appropriately trained medic should accompany the patient inside the chamber. If the chamber is sufficiently large, a second tender may also enter the chamber to assist during treatment. Inside the chamber, the tender ensures that the patient is lying down and positioned to permit free blood circulation to all limbs.

When a diver is being recompressed, all the tending personnel must work as a team for the benefit of the patient. Whether the inside or the outside tender operates the chamber will be dictated by the availability of qualified personnel and the circumstances of the casualty being treated.

If the patient has symptoms of serious DCI or gas embolism, the team will require additional personnel. If the treatment if prolonged, a second team may have to relieve the first.

Whenever possible, patients with serious DCI or gas embolism should be accompanied inside the chamber by a DMT or a diving physician, but treatment **should not** be delayed to comply with this recommendation.

Effective recompression treatment requires that all members of the treatment team be thoroughly trained and practised in their particular duties. It is also advisable to cross train members to carry out the duties of their teammates.

Chamber Attendant Responsibilities 3.6.1

State Of readiness

Since a recompression chamber is emergency equipment, it must be kept in a state of readiness. The chamber needs to be well maintained and equipped with all necessary accessory equipment. *A chamber is not to be used as a storage compartment.*

Key Responsibilities Include:

- Ensuring that the pre-dive checklist is completed.
- Ensuring the cleanliness of the chamber interior.
- Ensuring provision of chamber medical supplies in line with SOP's / DMAC regulations.
    - Ensure medical specific items are available in line with patient needs.
- Effectively communicating with the chamber supervisor.
- Ensuring the patient does not carry forbidden items into the chamber.
- Are there factors that preclude the casualty from the treatment:- of a cold or a toothache.
- Fully assess patient:
    - Providing assistance with the patient's activities of daily living as required.
- Ensuring exhaust & equalization valves are in the 'closed' position.
- The tender manually ensures the seal of the inner lock.
- Ensuring the patient's wear hearing protection during various treatment stages (descent, and flushing).
- Monitor the patient's for ear discomfort, halting the ascent as required until pain has been relieved.
    - Administrating treatment gas to the patient when instructed by the chamber supervisor.
    - Monitor effects of treatment gas.
    - Ensuring that the patient's are in a position that permits free blood circulation to all extremities.
    - Ensuring that BIBS mask is comfortable, well sealed and free of gas leaks.
- Discontinuing treatment gas to the patient when instructed by the chamber supervisor.
- Providing normal assistance to the patient's as required.
- Providing first aid as required by the patient's.
- Responding to any internal chamber emergencies in accordance with S.O.P's.
- Assisting in post treatment chamber / BIBS cleaning.
- Preparing chamber for subsequent treatment.
- Ensure the completion of the post-dive checklist.

General Chamber Safety Precautions:

- Do not use petroleum based products on or anywhere near the chamber or associated equipment.
- Ensure the securing dogs (medical lock) are in good operating condition and seals are tight.

- Do not allow open flames, smoking materials, or any flammables to be carried in the chamber.
- Do not permit electrical appliances to be used in the chamber (unless verified by SLST).

Tender Decompression Needs

The experience of being in a hyperbaric chamber physiologically is identical to diving. And just like scuba diving the length of time an attendant can stay at depth is dictated by how much nitrogen they absorb from the air (79% of air is nitrogen).

All chamber supervisors are highly experienced diving supervisors who are experts at calculating tenders decompression needs in accordance with internationally recognized dive tables.

During various stages of the treatment table the chamber attendant is instructed to 'go on oxygen'.

This has two actions. Firstly, no further nitrogen is being breathed and therefore any accumulation of the gas ceases. Secondly the attendant will actually 'off gas', as absorbed nitrogen will be removed at an accelerated rate due to an increased osmotic pull.

Tenders should not fasten the oxygen masks to their heads, but should hold them on their faces. The risk of the tender experiencing oxygen toxicity is amazingly low (they only consume a fraction of the oxygen that the patient does). If however the tender does experience oxygen toxicity, the exclusion of head straps ensures that the oxygen will simply fall away from the airway.

U.S. Navy Dive Tables

Table 9-9. *Air Decompression Table (Continued).*
(DESCENT RATE 75 FPM—ASCENT RATE 30 FPM)

Bottom Time (min)	Time to First Stop (M:S)	Gas Mix	DECOMPRESSION STOPS (FSW) Stop times (min) include travel time, except first air and first O_2 stop									Total Ascent Time (M:S)	Chamber O_2 Periods	Repet Group
			100	90	80	70	60	50	40	30	20			
170 FSW														
5	5:40	AIR									0	5:40	0	D
		AIR/O_2									**0**	5:40		
10	5:00	AIR									2	7:40	0.5	G
		AIR/O_2									**1**	6:40		
15	5:00	AIR									7	12:40	0.5	J
		AIR/O_2									**4**	9:40		
In-Water Air/O_2 Decompression or SurDO_2 Recommended														
20	4:40	AIR								1	29	35:20	1	L
		AIR/O_2								**1**	**15**	21:20		
25	4:20	AIR							1	6	46	58:00	1	N
		AIR/O_2							1	**4**	**23**	33:20		

Royal Navy Table 62 Recompression Therapy (U.S.N. Table 6) 3.6.2

This table is used for the great majority of cases of DCI. Its use is dictated by patient response in the treatment algorithm.

Proceed As Follows:

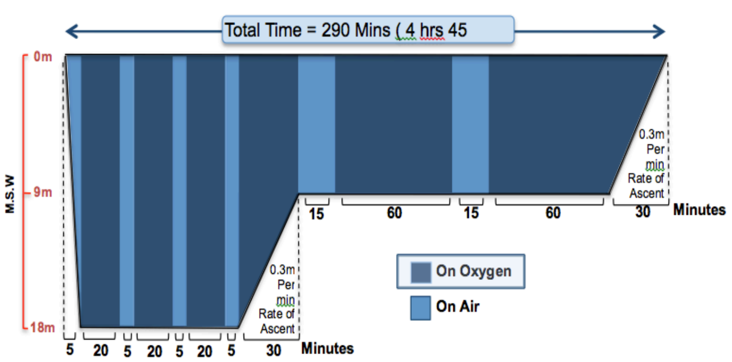
- Descend to 18m over 3-5 minutes stopping only if the patient or attendant has difficulty in clearing their ears.
- The timing of the treatment starts on reaching 18m.
- Upon reaching 18m the patient is re-assessed.
  - The assessment should take no more than 2-3 minutes.
  - The patient's condition to have stabilised or improved, if the algorithm is followed strictly, the decision to change to R.N. Table 61 may be made (however many specialist believe that the R.N.T. should always be completed).
  - However, patients who have presented with serious symptoms may continue to deteriorate at 18m. In such cases, the chamber should be compressed to 30m on air with the patient breathing 50/50 Heliox (50% oxygen / 50% helium). Decompression will then normally be completed using RN Table 67.
- If the time between reporting symptoms and receiving treatment is greater than 8 hours or if the symptoms have remained static or improved incompletely after three 20 minute periods on 100% O_2 at 18m, RN Table 62 may be extended with one or two further O_2 breathing periods, separated by a 5 minute air break.
- If the signs and symptoms have not resolved after 2 extensions at 18m further advice from the diving medicine specialist should be sought.
- Symptoms may recur during ascent to 9m or at 9m. In such circumstances;
  - STOP THE ASCENT and return to 18m.
  - Consult a Diving Medicine Specialist.
- RN Table 62 may be extended for one or two 1hour O_2 breathing periods at 9m, separated by 15 minutes air breaks.

Attendant Decompression Needs;

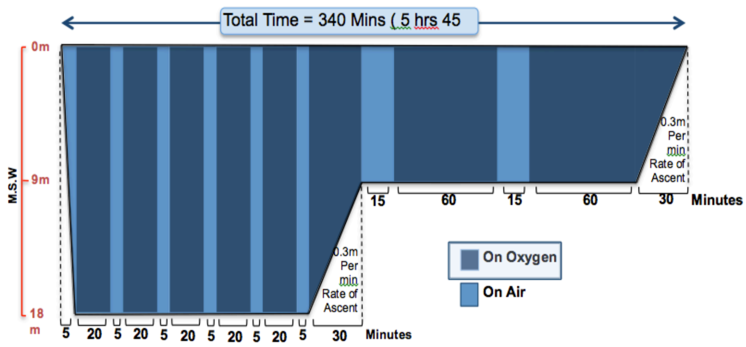
- For an unmodified R.N.T. 62 or a R.N.T 62 with one extension, at 9m or 18m, the attendant must:
- Breathe O_2 for the last 30 minutes at 9m and during the ascent from 9m to the surface (60 minutes in total). If RN Table 62 is extended more than once, then the attendant should breathe O_2 for the whole of the final O_2 period at 9m and the ascent to the surface (90 minutes in total).

- If the attendant has undergone a hyperbaric exposure in the preceding 24 hours, an additional 60 minute period breathing O_2 at 9m (150 minutes in total) should be undertaken.

Royal Navy Table 62



Royal Navy Table 62++ (with 2 extensions)



Royal Navy Table 67 Recompression Therapy 3.6.3 (Comex 30 Heli/Ox)

This table, a modified version of the COMEX 30 table, is to be used for the treatment of more serious or more threatening cases of D.C.I.

These Cases Include;

- Gross Neurological symptoms within 24hrs of diving.
- Diving deeper than 50m.
- Diving on mixed gas.
- The patient continues to deteriorate following an initial compression of 18m on 100% O_2.
- Omitted decompression on very deep dives, when the diver has completed less than 15 minutes of stops and the stops missed were at depths in excess of 18m.
- On the advice of a Diving Medicine Specialist for the treatment of DCI.

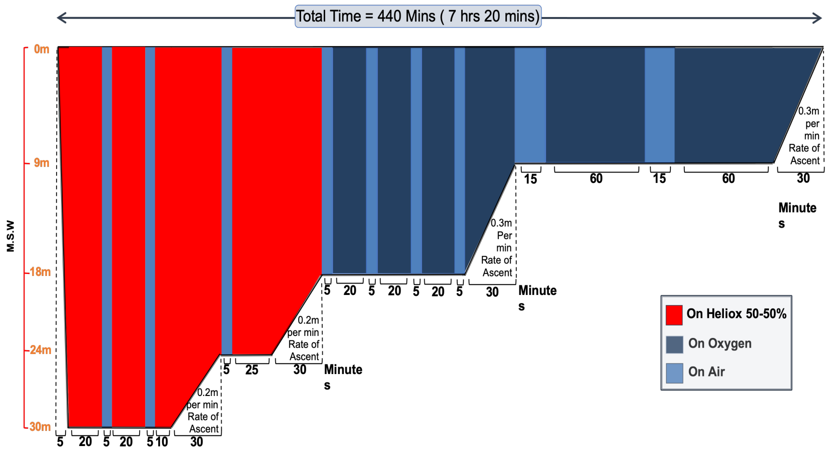
Proceed As Follows:

- The patient breathes 50:50 O_2:He on the surface, or from 18m when transferring from RN Table 62.
- Descend to 30m over 5-10 minutes (stopping only if the patient or attendant has difficulty in clearing their ears).
- The timing of the treatment starts on reaching 30m.
- Upon reaching 30m the patient must be reassessed.
  - This assessment should take no more than 2-3 minutes.
- If symptoms have remained static or improved incompletely after 55 minutes at 30m up to 5 additional 20 minute periods breathing 50:50 O_2:He, separated by 5 minute air breaks, may be added on the advice of Diving Medicine Specialist.
  - On completion of extensions decompression should be by RN Table 64 with 50:50 O_2:He breathed during the ascent from 30-24m.
  - A 5 minute air break is taken on arrival at 24m with 50:50 O_2:He breathed during the remaining 25 minutes of the 24m stop and the ascent from 24-18m.

Attendant Decompression Needs;

- For an unmodified RN Table 67 the attendant must breathe O_2 during both 60-minute O_2 periods at 9m and during the ascent from 9m to the surface (total 150 minutes).
- If the RN Table 67 is extended at 18m, by either one or two additional O_2 periods, it must also be extended by an additional 60 minute O_2 period at 9m during which time the attendant is to breathe O_2 (210 minutes).
- If the RN Table 67 is extended at 9m the attendant must breathe O_2 for an additional 60-minute period (total 210 minutes).
- If the attendant has undergone a hyperbaric exposure in the preceding 24 hours RN Table 67 should be extended at 9m to permit the attendant to breathe O_2 for an additional 60-minute period (total 210 minutes).

Royal Navy Table 67



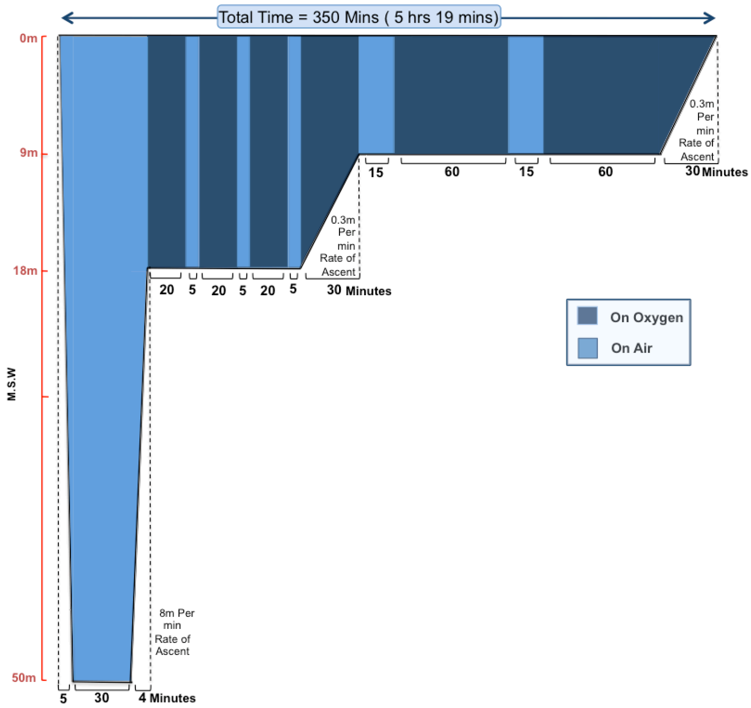
Royal Navy Table 63 Recompression Therapy (U.S.N. Table 6a) 3.6.4

This table was developed specifically for the treatment of arterial gas embolism. Given the difficulties in making such a diagnosis and the potential disadvantages associated with the initial compression to 50 m use of this table is reserved for those patients who present with rapid onset of severe symptoms following dives with minimal inert gas uptake and who show no significant improvement, or are continuing to deteriorate, when assessed following compression to 18 m breathing oxygen.
In practice this means that Table 63 will rarely be used except following massive rapid ascents or overt gas embolisms.

Proceed as Follows:

- Pressurise the chamber, without delay with air to 50m at the fastest rate that can be tolerated by the patient and attendant up to 30m per minute.
  - If a gas mixture of 32 O_2 :67 He is available, this should be breathed by the patient via BIBS.
- If the patient is free of symptoms and signs after 25 minutes, and 0_2 is available:
  - Decompression may be commenced using Table 63.
  - If 0_2 is not available Table 64 should be used, omitting the oxygen.
  - If there are persisting symptoms and signs after 30 minutes at 50 m, no matter how minor, Table 64 should be used.
- If the patient is deteriorating at 50 m, contact a Diving Medicine Specialist as a matter of urgency.
  - It may be necessary to compress the patient further and continue treatment using Table 65. This should not be contemplated however, unless:
    - A Diving Medicine Specialist is consulted.
    - The chamber is capable of supporting a prolonged treatment.
- Decompression from 50 m to 18 m should take 4 minutes after which Table 63 proceeds as for Table 62, except that the attendant must always breathe 0_2 during the final 60 minutes at 9 m and subsequent ascent (90 minutes in total).
- If the attendant has had a previous hyperbaric exposure within 24 hours oxygen should be breathed for both 60 minute periods at 9 m and during the ascent (total 150 minutes).

Royal Navy Table 63



Failure Of Recompression Treatment 3.6.5

Four major complications may effect the recompression treatment of a patient.

These Are:

- Worsening of the patient's condition during treatment.
- Recurrence of the patient's original symptoms or development of new symptoms during treatment.
- Recurrence of the patient's original symptoms or development of new symptoms after treatment.
- Failure of symptoms of decompression illness or gas embolism to resolve despite all efforts using standard treatment procedures.

When any of these complications occurs, the advice of diving medicine experts should be sought immediately, because alternative treatment procedures have been developed and used successfully when standard treatment procedures have failed.
These special procedures may involve the use of saturation diving decompression schedule; cases of this type occur more frequently when a significant period of time has elapsed between the onset of symptoms and the initial recompression.

DISORDERS OF DIVING 3.7

Adiabatic Compression 3.7.1

Adiabatic compression is the term used to explain Charles's Law relation to diving. Temperature increases with pressure. In a hyperbaric vessel (decompression chamber or bell), temperature will increase on compression (when the bell is blown down or the chamber pressurized).

It is important that pressurization speeds set down by your diving company are not exceeded.

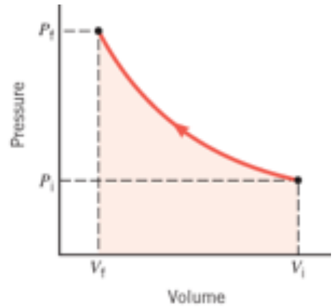
Oxy/Helium is about 6 times more conductive of heat than air, and if the humidity is high (over about 85%), then the body's ability to sweat and loose heat is reduced, resulting in an increase risk of heat exhaustion / stroke.

Normally the chamber environment should be maintained around 27 or 28°C and 75% humidity.

Prevention of Adiabatic Compression:

- Do not exceed pressurisation speeds.
- Monitor chamber temp during compression (check temp reader is calibrated).
- Do not overheat chamber prior to compression.
- Keep chambers in hot climates shaded.

Adiabatic Compression



Management of Adiabatic Compression:

- Conduct primary / secondary survey & record observations.
- Douse chamber exterior with cold water (cover with blankets and soak).
- Flush chamber with correct mixture.
- Decompress if emergency (chamber atmosphere will cool down).
- Use chamber heating system (if appropriate) on "cold cycle" to act as "heat sink".
- Cool occupants with cold water (shower, ice, sponge), and give cool fluids (weak salt water).
- Implement heat illness measures for chamber occupants.
- Seek medical advice from duty medic.

Aseptic Bone Necrosis 3.7.2

Aseptic bone necrosis is dead bone tissue in the absence of infection or disease process occurring in part of a bone, which is otherwise normal. This is thought to be caused by an absence of a blood supply to part of the bone due to condition such as trauma, iatrogenic (physician-induced) side effects of treatment using steroids or radiation, some blood disorders or alcoholism. Aseptic bone necrosis is often referred to as Avascular Necrosis.

Towards the end of the last century, aseptic bone necrosis was found to occur in men who worked in caissons; as a result this condition was originally known as Caisson Disease of Bone.

Dysbaric Osteo-necrosis (DON) 3.7.3

This is aseptic bone necrosis occurring in divers and compressed air workers. The earliest description of this condition was in 1888 and X-ray findings were first described in compressed air workers in 1911.

The condition was first described in divers in 1941. It is thought to be a chronic occlusion of bone blood vessels by bubbles or other mechanisms related to accumulation of gas in the tissues.

Definite lesions have been noted 17% or caisson air workers have definite lesions and 3% of commercial divers.

DON generally affects the; humerus, femur and tibia.

Dysbaric Osteo-necrosis

Presentation of Dysbaric Osteo-necrosis;

- Possibly symptomless.
- Sudden and persistent pain in a joint.
- Gradually increasing pain, stiffness and loss of movement of a joint;
  - Indicating the development of degenerative arthritis.

Management of Dysbaric Osteonecrosis

- If DON is discovered ceasing diving is recommended.
- Severe lesions will require orthopedic surgical intervention.

High Pressure Nervous Syndrome (HPNS) 3.7.4

High Pressure Nervous Syndrome (HPNS) is a derangement of central nervous system function that occurs during deep helium/oxygen dives, particularly saturation dives.

The cause is unknown. HPNS is first noted between 150m – 200m, and the severity appears to be both depth and compression rate dependent.

With slow compression, depths of 350m may be achieved with relative freedom from HPNS.

Beyond that, some HPNS may be present regardless of the compression rate.

Attempts to block the appearance of the syndrome have included the addition of nitrogen or hydrogen to the breathing mixture and the use of various drugs. No method appears to be entirely satisfactory.

HPNS

Presentation of HPNS:

- Nausea.
- Fine tremor – imbalance.
- Coarse tremor.
- Loss of manual dexterity - In-coordination.
- Jerky movements.
- Loss of alertness - Disorientation.
- Abdominal cramps and diarrhoea develop occasionally.
- In animal experiments convulsions have also been recorded.
- In severe cases; vertigo, extreme indifference to his surroundings, confusion.

In 1965 the Royal Navy Physiological Laboratory was conducting a series of deep dives in a compression chamber to depths of 200 – 350m. The condition appeared to improve after 90 mins at depth, and the subjects gradually returned to normal.

EXAMPLE: In a series of dives, the following symptoms were reported. Using a compression rate of 2.5m/min without rest stops:

- At 200m: Tremors appeared.
- At 240m: Changes in the brain activity was recorded by electro-encephalogram.
- At 320m: Development of muscular in-coordination.
- At 330m: Subjects beginning to experience loss of alertness.
- At 350m: Subjects develop extreme indifference, and decreased comprehension.

Some reports have recorded bouts of sleep occurring from which the subject is readily awakened. Difficulty in right-left orientation has also been reported.

The development and severity of High Pressure Nervous Syndrome appears to be related to the rate of compression at great depths being particularly more noticeable at faster rates.

Investigations into other possible contributory causes, such as the effects of oxygen, carbon dioxide, temperature, and fluid shift within the tissues due to gas pressure, have been found to have little, or no part in the incidence of HPNS.

It has been found that the inclusion of nitrogen, or other heavier narcotic gases has significantly reduced the cost of the mixture, alleviated the effects of voice distortion, and reduced the dangers of excess heat loss. For this reason it is common to use a "TRI-MIX" of oxygen, nitrogen and helium when diving deeper than 200m.

Prevention / Management of HPNS:

- Follow the general rule, "the deeper the dive, and the slower the rate of compression".
- Use appropriate gas mix.
- Include rest stops on compression.
- Monitor divers closely for signs of HPNS.
- Exclude – abort diver with severe symptoms.

Hydrostatic Nervous Syndrome 3.7.5

A similar condition to High Pressure Nervous Syndrome may occur when the subject has been exposed to extreme depths for long periods. It is **not** dependent on rate of compression.

Although the symptoms of this condition are similar to those of HPNS, the exact mechanism of this action is not fully understood. The main difference is in its occurrence after the depth has been stable for some time. The main form of treatment in both cases when symptoms are severe is to gradually decompress the individuals involved until the symptoms disappear.

Compression Arthralgia 3.7.6

Hyperbaric arthralgia is pain in the joints due to raised ambient pressure.

A diver suffering from hyperbaric arthralgia sometimes hears a creaking and cracking from his joints and feels as if his joint surfaces are dry (no "joint fluid"). Joints hurt especially on movement. The condition is aggravated by a too-rapid compression.

A compression rate of not more than 1m / min often avoids the painful effects of this condition although the cracking of the joints continues.

Tinnitus 3.7.7

Tinnitus or spontaneous noise or ringing in the ear can occur with middle ear disease that causes a conductive hearing loss, in terms of diving a perilymphic fistula or audio-vestibular DCI (very rare) may be the underlying cause. but it is usually associated with inner ear or brain disease.

HEARING LOSS Is Classified In To Three Categories:

- Conductive hearing loss, caused by;
  - Complete occlusion of the external auditory canal by wax.
  - Inflammation, swelling of the ear-drum or lining of the middle ear.
  - Fluids in the middle ear.
  - Changes in middle ear gas densities, pressure gradients across the ear drum.
  - Fixation of the ear bones, or loss of elasticity of the eardrum caused by scaring or large perforations.
- Neuro-sensory or nerve hearing loss, caused by nervous or vascular insufficiency in the inner ear;
  - Head injury.
  - Stroke.
  - Bubbles (DCI).
  - Round or oval window rupture.
  - Excessive noise exposure, or various other inner ear disease or conditions.
- Mixed or combined conductive and neuro-sensory hearing loss caused by simultaneous dysfunction of the middle and inner ear.

Management of Tinnitus:

- Seek ENT specialist review.
- Treat underlying cause of Tinnitus.

Vertigo 3.7.8

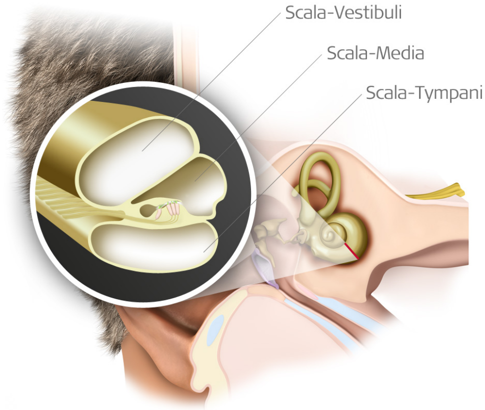
The occurrence of vertigo underwater is dangerous, being a potential cause of fatal underwater accidents. Normal balance under physiological conditions on dry land is maintained by the inter-action of gravity and a series of sensory organs. Joints and muscles, vision, and the vestibular organs all give complementary information to the brain about position in space, movements etc.

Underwater a profound change takes place. Buoyancy reduces the value of clues from joints and muscles. Darkness precludes visual clues and a great deal more reliance is placed upon sensations from the semi-circular canals and the vestibular apparatus generally.

Under calm conditions a diver gains extra clues from incidental observations such as bubble streaming, and buoyancy of objects with known behaviour at the depth involved, but under emergency or panic conditions this information too may not be available and sensation from the ear organs becomes a vital matter for survival.

DCI can cause gas release in the semi-circular canals or vestibule, causing physical disruption of the hair cells, which detect the relative movement of the labyrinthine fluids.

Vertigo



Presentation of Vertigo:

- False sensations of movement of the subject or of his surroundings, known as vertigo.
- Spinning sensation, such as is felt after getting off a roundabout,
- Swaying or falling sensation.
- Nystagmus – (a flickering movement of the eye).
- Severe nausea.

Management of Vertigo:

- Gain orientation as soon as symptoms of vertigo present.
- Report episodes & undergo review by dive doctor.
- Treat underlying cause.

Alternobaric Vertigo 3.7.9

Unequal or asymmetrical clearing of the middle ear during descent or ascent, and particularly during ascent, can cause vertigo. Regardless of the cause, vertigo and its accompanying spatial disorientation are hazardous if they occur during a dive.

Alternobaric Vertigo

Management of Alternobaric Vertigo

- Avoid diving if; there is difficulty clearing ears or if a Valsalva manoeuvre on the surface produces vertigo.
- If there is vertigo, ear blockage or ear fullness during compression, they should;
  - Stop any further descent.
  - Ascend until the ears can be cleared.

Omitted Decompression 3.7.10

In situations such as blow-up, loss of air supply, bodily injury or other emergencies, a diver may be required to surface prematurely, without taking the required decompression.

Surface decompression has been a recognised feature of commercial diving for many reasons for decades. It has earned the title 'bend and mend' as an overall policy.

Management of Omitted Decompression;

- Use appropriate tables / company procedures for surface decompression.
- Be suspicious. Observe diver for possible dysbaric condition (D.C.I. / A.G.E. / barotrauma).
  - If present apply appropriate treatment & compression table.
- If the diver shows no ill effects from omitted decompression, the diver should;
  - Be monitored for at least 4 hours.
  - Stay within the vicinity of a recompression chamber for 24-48hrs.
- Recompression may be considered as a precaution.
- In-water treatment for omitted, asymptomatic decompression should **not be performed**.

Surface Decompression

GAS TOXICITY 3.8

Gas toxicity is defined as ill health caused by absorbing airborne gas via the:

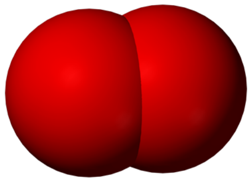
- Respiratory system.
- Skin.
- Mucous membrane.

The Factors That Influence The Casualty's Response To The Agent Are:

- The specific gas (some gases are far more toxic than others).
- Exposure time.
- Concentration / partial pressure of the gas.
- Workload (the higher the workload, the higher the respiratory rate, the higher the absorption of gas).
- General fitness.

Pulmonary Oxygen Toxicity 3.8.1

If O_2 is breathed at a high partial pressure for long periods it becomes toxic, particularly to the lungs. If a very high partial pressure of O_2 is breathed, even for short periods of time, it may rapidly become toxic to the brain (C.N.S. Oxygen Toxicity).



For practical purposes, pulmonary oxygen toxicity will not arise from normal air 'bounce' diving to less than 50 metres.

This is because decompression considerations will limit exposure to O_2 to within safe limits. Diving near the time/depth limits, particularly when such dives are performed repetitively, may provoke pulmonary O_2 toxicity in sensitive individuals.

Patients being treated with fully extended recompression Tables 62 and 63 or Tables 64 and 65 may also experience pulmonary O_2 toxicity, particularly where repeated treatments are applied.

Unit Pulmonary Toxic Dose

Where prolonged exposure to hyperbaric oxygen is necessary, such as during recompression therapy, an estimate of the reduction in vital capacity (VC) can be calculated from the following equation: Where kp is a factor derived from the pO_2 using the table below, and "t" the duration of exposure (in minutes).

The "Kp" Table For UPTD Calculation Is: **UPTD = kp X t**

The appropriate kp value is multiplied by the period of time (in minutes) spent at each oxygen partial pressure. These values are then summed to generate the total UPTD value for the exposure. Standard USN Table 6 or RN 62 Treatment Table without extensions are equivalent to 625 UPTD's.

Below is a table, which presents approximate values for expected decrement in vital capacity as a result of various UPTD exposures. It should be recognised that individuals may vary considerably in their response to high partial pressures of oxygen and the UPTD value is useful only as a guide. Generally, a dose of 1425 UPTD is considered to be the upper limit of acceptable exposure.

UPTD Units	% Decrease in VC
615	2 %
825	4 %
1035	6 %
1230	8 %
1425	10 %
1815	15 %
2190	20 %

pO_2(BA)	kp	pO_2(BA)	kp	pO_2(BA)	kp
0.5	0.00	1.3	1.48	2.1	2.64
0.6	0.26	1.4	1.63	2.2	2.77
0.7	0.47	1.5	1.78	2.3	2.91
0.8	0.65	1.6	1.93	2.4	3.04
0.9	0.83	1.7	2.07	2.5	3.17
1.0	1.00	1.8	2.21	2.6	3.31
1.1	1.16	1.9	2.36	2.7	3.44
1.2	1.32	2.0	2.49	2.8	3.57

Presentation of Pulmonary Oxygen Toxicity

- Tickling sensation in the throat, which is worse on inspiration.
- Irritating cough.
- A sensation of substernal burning.
- Coughing becomes uncontrollable.
- Shortness of breath eventually prevents even mild exertion.
- Acute Respiratory Distress Syndrome will present in severe cases.

Management of Pulmonary Oxygen Toxicity

- Reduce the concentration of O_2 in the breathing mixture, (preferably to 0.2 BAR. *IP0_2).*
- If substernal burning is present in patients who are responding well to treatment; discontinue oxygen.
- If significant neurological deficit remains and improvement is continuing (or if deterioration occurs when oxygen breathing is interrupted), oxygen breathing should be continued as long as considered beneficial or until pain limits inspiration.
- If oxygen breathing must be continued beyond the period of substernal burning, or if the 4 hour air breaks on long air tables cannot be used because of deterioration upon the discontinuance of oxygen, the oxygen breathing periods should be changed to 20 min on oxygen, followed by 10 min breathing chamber air.

C.N.S. Oxygen Toxicity 3.8.2

There is no fixed O_2 exposure at which toxicity becomes apparent. Instead, susceptibility varies both between individuals and within the same person from day to day. As a consequence, there is no cerebral equivalent of the UPTD.

The onset of C.N.S. Oxygen Toxicity is unlikely in resting individuals at depths of 15m or shallower, and very unlikely at 10m or shallower no matter what the level of activity.

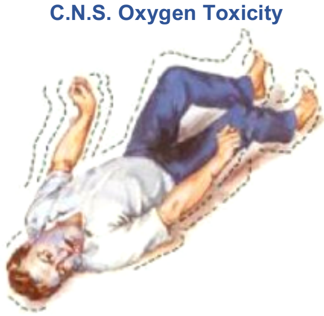
However, patients with severe cerebral decompression illness may be abnormally sensitive to oxygen.

Presentation of C.N.S. Oxygen Toxicity

The classic presentation of CNS Oxygen Toxicity is: V.E.N.T.I.D.C.:

- **V**ision (Tunnel vision) which may include any abnormality, such as tunnel vision (a contraction of the normal field of vision, as if looking through a tube) .
- **E**ars (Ringing/Tinnitus), which may include any abnormality of hearing.
- **N**ausea may be intermittent.
- **T**witching appears first in the lips or other facial muscles but may affect any muscle. (This is the most frequent and clearest warning of oxygen poisoning).
- **I**rritability, which includes any change in behaviour, such as anxiety, confusion, and unusual fatigue.
- **D**izziness, an apparent increase in breathing resistance, noticeable clumsiness or lack of co-ordination.
- **C**onvulsions such as generalized clonic tonic seizure.

C.N.S. Oxygen Toxicity



Management of C.N.S. Oxygen Toxicity:

- Reduce the concentration of O_2 in the breathing mixture, (preferably to 0.2 BAR. *IP0_2)*
- Conduct primary / secondary survey & record observations.
- Implement Seizure Management.
- Stop decompression. (Refer to company SOP's).
- Contact duty medic / supervisor.
- Prepare to evacuate (as per company S.O.P's).

Convulsions While In Water Diving:

- The diver's depth should be kept as constant as possible until at least the tonic phase of the convulsion ends.
- He should then be returned to the surface / bell.
- Implement airway / breathing management.
- If a diver surfaces because of an oxygen convulsion or must be surfaced to prevent drowning.
  - Observe for pulmonary barotrauma / A.G.E. / D.C.I.
- On reaching safety, remove the breathing apparatus and place the casualty in fresh air to recover.
- Treat for possible near drowning.

***Note**. The symptoms of c.n.s. O_2 toxicity may be made transiently worse when the inspired P0_2 falls. This is the so-called 'Off Phenomenon'. Consequently the onset of symptoms or signs may be delayed by up to 5 minutes after leaving the water, coming off O_2, or during a decompression stop where the partial pressure of O_2 is reduced.*

Hypoxia 3.8.3

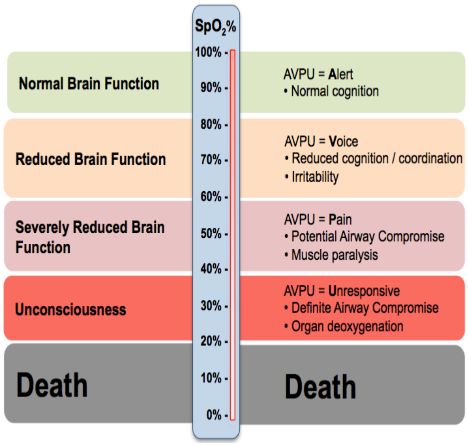
The term 'hypoxia' means 'low oxygen in the blood' (When 0_2, is less than 0.16bar) The term 'Anoxia' means 'an absence oxygen in the blood'.

The Causes Of Hypoxia / Anoxia Are Varied:

- External (reduced / absent O_2 supply in breathing gas).
- Airway impairment.
- Breathing impairment.
- Circulation impairment.
- Respiratory control centre impairment.

Presentation of Hypoxia

- See Hypoxia in Immediate Care Section.
- Cyanosis (Blueing of fingers, earlobes).
- Hyperventilation.
- Increased heart rate.
- Poor co-ordination.
- Sudden collapse.



Presentation of Anoxia

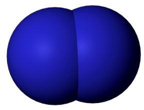
- Profound cyanosis (Blueing of fingers, earlobes).
- Death.

Management of Hypoxia / Anoxia;

- See Hypoxia in First Aid Section.
- Give high flow O_2 and monitor effects.
- Be prepared to resuscitate.

Nitrogen Narcosis 3.8.4

Narcosis while diving (also known as narced, inert gas narcosis or "the raptures of the deep"), is a reversible alteration in consciousness that occurs while diving at depth.

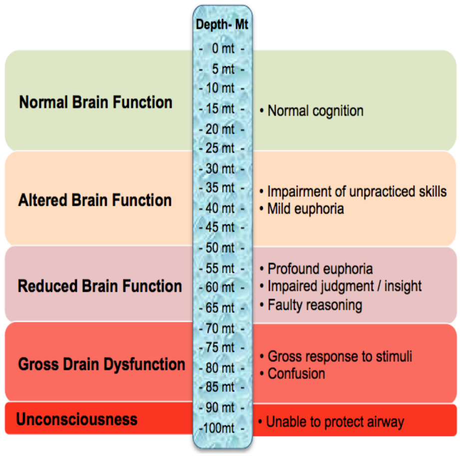


The Greek word *ναρκωσις* (narcosis) is derived from narke, "temporary decline or loss of senses and movement, numbness".

Narcosis produces a state similar to alcohol intoxication or nitrous oxide inhalation, and can occur during shallow dives, but usually does not become noticeable until greater depths, beyond 30 metres.

Presentation of Nitrogen Narcosis

- Responses significantly slow down.
- Loosing short-term memory.
- Lack of insight / faulty reasoning.
- Calculation errors.
- Idea fixations.
- Increased anxiety, anger or euphoria.
- Narrowing of a divers mental focus.

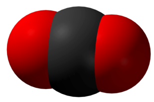


Management of Nitrogen Narcosis

- Decrease depth.
- Change mix (Nitrox?).

Hypercapnia (CO_2 Poisoning) 3.8.5

Also known as hypercarbia, is a condition where there is too much carbon dioxide (CO_2) in the blood.
Carbon dioxide is a gaseous product of the body's metabolism and is normally expelled through the lungs. Acceptable levels of CO_2 (As set by H.S.E.) is 5000 ppm or 0.5% in a breathing mix for 8hrs maximum.



Causes of Hypercapnia;

- Increased workload.
- Pre existing medical condition.
- Failure of CO_2 absorption (closed / semi closed).
  - Channelling.
  - Soda lime canister exhausted.
- Large dead space.
- CO_2 in gas mix.

Presentation of Hypercapnia

- Increase in respiration & pulse rate.

- Headache.
- Sweating.
- Dizziness.
- Nausea.
- Anxiety.
- Unconsciousness.

	CO_2	
Atmospheric CO_2	0.036% 360 ppm	No symptoms
Acceptable CO_2 Level (H.S.E.)	0.5% 5000 ppm	No symptoms
Mild CO_2 Toxicity	1% 10,000 ppm	• Drowsiness
Moderate CO_2 Toxicity	3% 30,000 ppm	• High pulse – Resps – B/P • Narcosis
Severe CO_2 Toxicity	5% 50,000 ppm	• Dizziness/ confusion/ Headache • Difficulty breathing
Critical CO_2 Toxicity	8% 80,000 ppm	• Dimmed Vision • Tremor / Sweating • Unconsciousness
Terminal CO_2 Toxicity	10% 100,000 ppm	Death

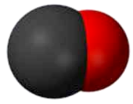
Management of Hypercapnia

- Manage unconsciousness / reduced consciousness as per Immediate Care.
- Ventilate environment / breathing mix.
- Change soda lime.
- Flush chamber.
- Equalize chamber with entry lock.

Carbon Monoxide Poisoning 3.8.6

Carbon monoxide poisoning occurs after enough inhalation of carbon monoxide (CO).

CO is a colourless, odourless, tasteless, and initially non-irritating toxic gas.



CO is a product of incomplete combustion of organic matter due to insufficient oxygen supply to enable complete oxidation to carbon dioxide (CO_2). It is often produced in domestic or industrial settings by older motor vehicles and other gasoline-powered compressors, heaters, and cooking equipment.

Exposures at 100 ppm or greater can be dangerous to human health. Generally caused in diving by a badly sited compressor intake or from oil breakdown in an overheating compressor.

CO has affinity to Haemoglobin 200 times greater than O_2

	CO	
Atmospheric CO	0% 0 ppm	No symptoms
Acceptable CO Level (H.S.E.)	0.005% 50 ppm	No symptoms
Mild CO Toxicity	0.02% 200 ppm	• Dizzy, Slight headache (2-3 hrs)
Severe CO Toxicity	0.04% 400 ppm	• Frontal headache (1-2 hrs) • Widespread Headache (2-3 hrs)
Critical CO Toxicity	0.08% 800 ppm	• Nausea, convulsions (45 mins) • Unconsciousness, Death (2 hrs)
Critical CO Toxicity	0.64% 6400 ppm	• Convulsions, Unconsciousness • Death (20 mins)
Terminal CO Toxicity	1.28% 12800 ppm	• Death (1-3 mins)

Presentation of Carbon Monoxide Poisoning

- Breathlessness on exertion.
- Lassitude.
- Dizziness / headache.
- Tinnitus.
- Confusion Loss of consciousness.
- Cherry red complexion (unreliable, rare and fatal).

Management of Carbon Monoxide Poisoning

- Change gas supply.
- Jump standby to assist divers ascent.
- Recompression (As per company SOP usually RNT 60 / 61).
- Administrating pure O_2 by BIBS (flushes out CO).
- Instigate reduced consciousness management.

Hydrogen Sulfide Poisoning 3.8.7

H_2S is an extremely hazardous, toxic compound. It is a colourless, flammable gas that can be identified in relatively low concentrations, by a characteristic *rotten egg* odor. The gas occurs naturally in coal pits, sulfur springs, gas wells, and as a product of decaying sulfur-containing organic matter, particularly under low oxygen conditions. It is therefore commonly encountered in places such as sewers, sewage treatment plants (H_2S is often called *sewer gas*), mines, and the holds of fishing ships.

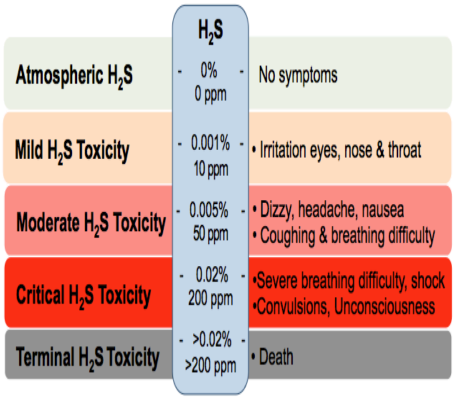
H_2S occurs naturally in the mud around the well-head of a drill rig. The gas is heavier than air and initially leaves a sulfurous (rotten egg) odour before permanently destroying the sense of smell and therefore becoming tasteless and odourless. Due to the fact the gas is heavier than air / $HE0_2$ it forces the air or gas mix above it leaving any unsuspecting diver to asphyxiate due to lack of oxygen.

When a diver is working on this site they can accumulate this mud on their equipment, bringing it back to the bell/chamber/deck upon their return. This allows the gas to escape into its surrounding environment.

Presentation of Hydrogen Sulphide Poisoning

- Initial smell of rotten eggs.

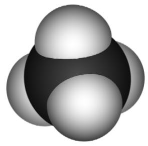
- Headaches.
- Loss of smell.
- Cough / Haemoptysis.
- Vertigo.
- Confusion.
- Nausea and vomiting.
- Asphyxiation.
- Possible loss of consciousness.
- Seizure.
- Death.



Management of Hydrogen Sulfide Poisoning

- If presence of H_2S is suspected then evacuate to a high point until the area is confirmed clear.
- Administer pure O_2 (flushes out H_2S).
- Instigate reduced consciousness management.

Hydrocarbon Poisoning 3.8.8



Within the commercial gas /oil industry there is often an associated risk of hydrocarbon vapour contamination.

There is likelihood for contamination of the bell atmosphere from vapourised contaminants carried on dive suits and umbilical's.

Potentially fatal, levels of hydrocarbons can accumulate in the enclosed environment of a diving bell. Hydrocarbon vapour has a profoundly sedative quality, so even if fatal levels are not reached immediately, divers may be incapacitated before they can initiate environmental flushing measures.

Presentation of Hydrocarbon Toxicity

Bell Vapour Analysis

Hydrocarbon vapours in the bell and can reach anaesthetic levels within minutes.

- Divers can suffer the effects within a few breaths.
- Even before unconsciousness, the ability to react normally becomes impaired:
  - 52% of the anaesthetic level of cyclo-hexane causes convulsions.
  - 44% of the anaesthetic level of benzene causes uncontrolled jerking of limbs.
  - 33% of the anaesthetic level of toluene leads to hyperactivity.
  - 13% of the anaesthetic level of xylene causes tremors, which could impair actions.

Management of Hydrocarbon Poisoning

- Ensure hydrocarbon analysis equipment is functioning & divers are trained in its use.
- Immidiatly don BIBS & flush compartment on contamination.
- Closley observe & manage casualtys who have sucomed to the effects of hydrocarbon exposure.
- Decontaminate bell (as per company SOP's).

Section 4

Legislation

DIVING REGULATIONS AND OTHER REQUIREMENTS 4.1

Requirements can be divided into two sections:
- Legal and statutory obligations
- Codes of practice, recommendations, accepted safe practices

Legal and Statutory Obligations – UK 4.1.1

Legislation

A. Health and Safety at Work etc., Act 1974 (Application outside Great Britain) Order 1995 SI 263

B. Diving at Work Regulations (DWR) 1997 SI 2776, [which replaced the Diving Operations at Work (Amendment) Regulations 1990 (SI 966), which in turn had replaced the Diving Operations at Work Regulations 1981 (SI 399)]

C. Merchant Shipping (Diving Safety) Regulation 2005.

D. The Offshore Installations (Inspectors and Casualties) Regulations 1973 SI 1842.

E. The Offshore Installations (Operational Safety, Health and Welfare and Life saving Appliances) (Revocations) Regulations 1989 SI 1672.

Diving At Work Regulations 1997 ACOP

Duties Of Supervisor

The supervisor shall, in respect of the diving operation for which he has been appointed as supervisor ensure that it is carried out, so far as is reasonably practicable without risk to the health and safety of all those taking part in that operation and of other persons who may be affected thereby in accordance with the requirements and prohibitions imposed on him by or under any relevant statutory provisions. In accordance, where this would not conflict with the diving project plan.

Prior to the commencement of the operation, ensure that each person taking part is aware of the contents of the diving project plan which relate to that operation; and enter in the diving operation record the particulars required by regulation 6(4) during the course of the operation.

The supervisor shall not dive during the diving operation, which he is supervising unless the diving project plan which relates to that operation specifically provides for the supervisor to so dive.

Power Of Supervisor To Give Directions

A supervisor may, whilst supervising the diving operation in respect of which he is appointed, give such reasonable directions to any person taking part in that operation or who may affect the safety of that operation as are necessary to enable him to comply with regulation 10.

Summary

The Diving at Work Regulations (DWR) 1997 (SI 2776) replaced the Diving Operations at Work (Amendment) Regulations 1990 (SI 996). These had revoked the Offshore Installations (Diving Operations) Regulations 1960 (SI 1229 and the Diving Operations Special Regulations 1960 SI 688).

The Regulations give broad outlines intended to cover all 'diving at work'. More detailed requirements are contained in the five Approved Codes of Practice (ACOP), which accompany the Regulations.

The principal Regulations apply to diving operations conducted in Great Britain in circumstances covered by the Health and Safety at Work etc., Act 1974 (Application outside Great Britain) Order 1995 (SI 263).

Approved Codes of Practice

The DWR are accompanied by five Approved Codes of Practice (ACOP).
These cover the various 'diving at work' activities, namely:

a) Commercial diving project offshore.
b) Commercial diving projects inland / inshore.
c) Media diving project.
d) Recreational diving projects.
e) Scientific and archaeological diving projects.

All offshore diving comes under (a), which also covers:

- Closed bell (saturation) diving.
- Diving from DP vessels.
- All commercial dives below 50 msw.

The ACOP gives detailed expression to the 'bare bones' of the DWR, and was written with the assistance of IMCA. In the case of inshore diving this assistance was given by the ADC (Association of Diving Contractors).

The Diving Contractor

No person shall act as a diving Contractor unless they are registered with the HSE. No person at work shall dive in a diving project and no employer shall employ any person in such a project unless there is one person and one person only who is the diving Contractor for that project.

The diving Contractor is the person who employs the diver or divers engaged in the diving project, or who dives in diving project as a self-employed diver.

If more than one person falls under this category then one person must be appointed in writing to act as the diving Contractor.

Duties of the Diving Contractor

The diving Contractor shall ensure that, so far as is reasonably practicable, that the diving project is planned, managed and conducted in a manner which protects the health and safety of all persons taking part in the project.

The Diving Contractor Shall:

- Ensure that a diving project plan is prepared and updated as necessary during the project.
- Appoint a person to supervise any diving operation, make a written record of the appointment, provide the person with that written record, and ensure that he is supplied with a copy of the diving project plan.
- Ensure that there are sufficient people with sufficient competence to carry out both the diving project and any foreseeable emergency action connected with the project.
- Ensure that suitable and sufficient plant is available to carry out both the diving project and any foreseeable emergency action connected with the project.
- Ensure that the said plant is maintained in safe working condition.
- Ensure, so far as is reasonably practicable, that any persons taking part in the diving project complies with requirements and prohibitions imposed on him.
- Ensure that a record, containing certain specific information, is kept of each diving operation.
- Retain the record for at least two years.

The Diving Project Plan

The DWR introduced the idea of a 'diving project' comprising one or more 'diving operations'. The Regulations require all diving projects to have a diving project plan. This shall be based upon an assessment of the risks to the health and safety of any person taking part in the diving project.

It will consist of a record of the outcome of the planning carried out in accordance with the requirement to ensure that the project is planned, managed, and conducted in a manner which protects the health and safety of all persons taking part in the project.

The plan shall also identify which approved codes of practice apply to the project, and shall identify each diving operation that makes up the project. Each such operation shall be such that it can be safely supervised by one person.

The Diving Supervisor

Only one supervisor shall be appointed to supervise a diving operation at any one time.
No person shall be appointed, or shall act, as a supervisor unless he is competent and, where appropriate, suitably qualified to perform the functions of supervisor in respect of the diving operation, which he is appointed to supervise.

Duties of the Diving Supervisor

It is the duty of the Diving Supervisor to ensure that each diving operation for which he is appointed is carried out, so far as is reasonably practicable,:

- Without risk to the health and safety of all those taking part in that operation and other persons who may be affected,

- In accordance with the requirements an prohibitions imposed on him by or under any relevant statutory provisions,
- In accordance with the diving project plan (where this does not conflict with either of above).

The Supervisor shall not dive during the diving operation, which he is supervising unless:

- He is guiding persons engaged in recreational diving using SCUBA,
- The dive is for archaeological, educational or scientific purposes using SCUBA
- He can do so without risk to the health and safety of those taking part in that operation, and
- The diving project plan specifically provides for the supervisor to dive.

Approved Codes of Practice

The DWR are accompanied by five Approved Codes of Practice (ACOP). These cover the various 'diving at work' activities.

Namely:

- Commercial diving project offshore.
- Commercial diving projects inland/inshore.
- Media diving project.
- Recreational diving projects.
- Scientific and archaeological diving projects.

All offshore diving comes under (a), which also covers:

- Closed bell (saturation) diving.
- Diving from DP (Dynamic Positioning) vessels.
- All commercial dives below 50msw.

The ACOP gives detailed expression to the 'bare bones' of the DWR, and was written with the assistance of IMCA. In the case of inshore diving this assistance was given by the ADC (Association of Diving Contractors).

Other Obligations Apart From Statutory Instruments (UK) 4.1.2

Standards And Classification Societies Required By Law

Some British and Norwegian standards apply to equipment used in diving operations by reference in the statutes. Where not specifically mentioned they would be required as an interpretation of any rule that maintains a system or individual item of equipment should be suitable for its intended use.

This rule would also apply to classification societies for the initial construction of plant and equipment and for major test and certification. (Lloyds Register of Shipping (LRS), American Bureau of Shipping (ABS), Det Norske Veritas (DNV) etc.)

Obligations To Follow Procedures And Recommendations

Most Clients stipulate in their contract with diving Contractors that all the relevant legislation, plus recommendations from HSE and others, will be followed, including the Contractor's own procedure manual.

Client Specifications

Some Clients have their own specifications for diving equipment and Contractor's procedures. These are normally in excess of any statutory requirements or Contractor's normal specifications or procedures. They are a contractual obligation and must be adhered to.

Recommendations And Guidelines

Bodies as the International Marine Contractors Association (IMCA), the Diving Medical Advisory Committee (DMAC), and the International Maritime Organisation (IMO), intermittently publish guidance notes and recommendations for use by their members and others.

Such publications are normally followed rigorously by the member Contractors.

HSE and NPD recommendations are followed except in exceptional circumstances.

Guidelines for such items as DP vessels usually have a large input from the industry. As such they are normally acceptable to diving Contractors before publication. In any event, under normal circumstances all guidelines and recommendations are followed. Not to, in the event of an accident or incident, would be in contravention of legislation in that the equipment or procedures were not safe or suitable.

In practice, 'agency' agreements exist between the various Departments of State having formal responsibility for the various Acts and Regulations. These result in the division of responsibilities summarised at the start of this section. UK Government Diving Inspectors have the right to visit and inspect, within reason, any site, installation or vessel from which diving operations are being carried out. Within the terms of the relevant statutory instruments, they may examine all plant and equipment and hold discussions with all personnel concerned with the operation. It is clearly necessary for them to develop a rapport with key personnel in order to assist in the improvement of safety standards without inhibiting the efficiency of the diving operation. Good communications between the Inspectors and relevant personnel, depending on the nature of particular problems and circumstances, is clearly vitally.

Diving Supervisor

The Diving Contractor should appoint Diving Supervisors to be in immediate control of each diving operation. Where two or more Diving Supervisors are appointed in respect of an operation, the Diving Contractor must specify which part of the diving operation each is to supervise. However, if it is permitted by the Diving Contractor in their specific written appointments, two Supervisors may arrange the time at which one may take over dive responsibility from the other.

A Diving Supervisor should be a competent person with adequate knowledge of the diving techniques to be used in the diving operation, and must be appointed in writing.

Ideally a Supervisor should have had experience of the particular techniques employed in the diving operations, which he is appointed to supervise or alternatively have a sound knowledge of the principals of the techniques to be used.

The Diving Supervisor Should Ensure:

- As far as is reasonably practicable, the diving operation that they are being asked to supervise complies with the requirements of the ACOP.
- The proposed dive site and the water and weather conditions are suitable.
- The risk assessment is still current for the circumstances prevailing on the day and during the dive,
- They understand their own areas of responsibility and who is responsible for any relevant areas.
- The personnel that they are to supervise are appropriately qualified and competent to carry out the work required of them.
- The diving project plan and arrangements for dealing with any foreseeable emergencies are clearly understood by all those engaged in the diving operation.
- The plant that they propose to use is adequate, safe, properly certified and maintained.
- The possible hazards from complex or potentially hazardous plant have been evaluated and are understood by all relevant parties and that, if required, training is given.
- All relevant people are aware that a diving operation is to start or continue.
- They have adequate means of communicating with any such personnel under their supervision. So long as they have such communication they do not need to be able to operate physically every control under their responsibility. For example, a supervisor should be able to supervise adequately the raising and lowering of a diving bell if their is a direct audio link with the winch operator, even though the winch may be located where the supervisor cannot see it or have ready access to it.
- Proper records of the diving operation are maintained.
- They are able to see divers in the bell or compression chamber during saturation operations.
- They maintain the diving operation record throughout the diving operation for which they are responsible.

The Diving Supervisor is responsible for the health and safety of divers and other personnel under his control. This responsibility includes divers under pressure and ranges from the treatment of decompression sickness (using well established techniques) to the treatment of medical problems. He must seek advice from a suitable, experienced Doctor if a diver in his team needs special medical attention.

Whilst the Doctor will advise on the treatment to be followed, the Diving Supervisor has ultimate responsibility for accepting or rejecting it under exceptional circumstances, having assessed all the circumstances of the case.

The Doctor acts in an advisory role; the Supervisor retains overall responsibility for the compression aspects of any treatment prescribed until he formally hands over responsibility of the Diver undergoing treatment to another person, for example at an onshore hyperbaric treatment facility. (This applies to Doctors at a diving site or at an onshore medical facility).

The Diving Supervisor, therefore, has very considerable responsibility for the diving operation. Whilst the Owner, OIM, Master, Harbour Master, Client's Representative and others may require him to terminate a dive, he is the only person who can authorise the actual commencement of a dive and control its detailed conduct thereafter.

Diver

The diver has a general duty of care for his own safety as well as for other members of the diving team. The diver may under certain rare circumstances, where he is his own employer, also be the Diving Contractor when he would have additional responsibilities.

Before taking part in any diving operation,

A Diver Must:

- Have a valid certificate of training or competence.
- Have a valid medical certificate.
- Be competent to carry out safely the work that he is called upon to perform.
- Inform his Diving Supervisor if he judges himself to be unfit, or if there is any other reason why he should not dive or remain underwater or pressure.
- Maintain a diver's log-book containing required specific information. He should sign every entry and ensure that it is countersigned by the Diving Supervisor. (At medical examinations he should present his log book to his Doctor. He should retain the book for at least two years from the date of the last entry).
- Carry out work in accordance with the instructions of the Diving Supervisor.

Regulatory requirements relating to minimum standards for divers vary from one country to another but arrangements have been made for the mutual recognition for bell and air diving between the UK and Norway. In the UK, diving regulations establish minimum qualifications for divers. These are defined in the regulations, and minimum training standards have been established with the approval of the Health and Safety Executive (HSE). In the UK, all new training certificates must be issued either by or on behalf of the HSE. An appeal procedure exists if the HSE refuses to issue a Certificate of Training or revokes a certificate that has been issued.

Initially there were four grades of diver in the UK, in ascending order of qualification they were:

Part IV Air Diver with self-contained equipment (where no surface compression chamber is required on site).

Part III Air Diver (where no surface compression chamber is required on site).

Part I Basic Air Diver.

Part II Mixed gas or bell diver.

These grades have been revised down to three new grades.

These are:

SCUBA Diver.

Surface Supply Diver (with a **'Top Up'** required for working offshore).

Closed Bell Diver.

Associated with these grades are 'competencies' which include various work tasks that may be required of him.

Certification to a particular grade does not imply that the Diver may carry out all work associated with his grade. In this respect, the training standards are minimum standards only. An additional responsibility is placed on the diver and all others concerned with the diving operation (particularly the Diving Contractor and Diving Supervisor) to ensure that he receives the additional training or familiarisation to ensure that he is competent to carry out safely the work, which he is required to perform. This additional training may involve tools, equipment, techniques and other matters.

Standby Diver

A standby diver should be in immediate readiness to provide any necessary assistance to the diver, whenever the diver is in the water. There should be one standby diver for every two divers in the water.

He should be dressed to enter the water, but does not have to wear a mask or helmet. However the equipment should be immediately to hand.

For surface supplied diving the standby diver should remain on the surface.

Fir closed bell diving the standby diver, or bellman, should remain inside the bell. Another diver should be on the surface with equipment suitable for intervention within the surface diving range. This diver does not have to be dressed for diving provided that the equipment is readily available, and may undertake duties within the dive team while the bell is under water.

Diving Technicians

Diving Technicians include equipment technicians and others who support the diving team, the diving operation and the necessary plant and equipment. Job titles and responsibilities vary considerably from Diving Contractor to Diving Contractor and from contract to contract depending on the nature of the work and the type of plant and equipment needed to support the diving operations.

Duties include the maintenance of plant and equipment, the operation of winches, gantries, handling equipment, lifting tackle and cranes, the cleaning of equipment and the mobilisation, control and demobilisation of the equipment the diver(s) may need to carry out their work underwater.

Whatever the qualifications, experience and responsibilities of these important personnel, they all have a duty of care for their own safety and for the safety of other members of the diving team. Functionally they all report to the Diving Supervisor.

NORWEGIAN REGULATIONS 4.2

On the 1st of January 2011, new regulations relating to Health, Environment and Safety (HES) entered into force. At the same time the "Acts, Regulations and Provisions for the Petroleum Activity" regulations 11th June 1990 No. 471 relating to Manned Underwater Operations (MUO) (The two NPD white-books) were repealed. On the 1st January 2004 The Petroleum Safety Authority (PSA) took over responsibility for safety, Emergency preparedness and the working environment in the Petroleum Sector from NPD

The new regulations relating to the Health, Safety and Environment in the Petroleum Activities on Offshore and Onshore facilities that are subject to the Petroleum Safety Authority (PSA), entered into force 1st Jan 2011.

Joint Regulations Offshore and Onshore

The Framework Regulations and the Management Regulations are Joint Regulations and are thus applicable both offshore & onshore, at certain facilities. The Purpose of joint regulations in the field of HSE is to secure a coherent and coordinated regulation of activities in the best possible way. This also applies to the regulatory supervision of the activities

The Regulations are the Framework Regulations, the Management Regulations, the Technical and Operations Regulations, the Facilities Regulations and the Activities Regulations. In support of the regulations, guidelines are issued. The regulations are in pursuance of, amongst others, the Petroleum Act and the Working Environment (WEA).

The structure and the content of these regulations, the extensive use of common and functional requirements, means the regulations must be read in context with each other and the acts.

Therefore, **the only way** of reading the regulations properly are electronic versions (they are not published on paper) and using the cross references to the other regulations

http://www.ptil.no/regulations/category87.

Listed in Appendix 6 are selected sections from the five regulations.

OTHER COUNTRIES 4.3

Denmark 4.3.1

Danish Diving Act 1979 and various notices which are, in effect, additions to the Act.

NB: Some parts of this Act apply only to standard dress, harbour diving.

Normally Clients in Denmark will insist on UK diving regulations being followed **as well** as the Danish Diving Act.

To work offshore, divers must have British or Norwegian Certificates.

To work in Danish inland waters and harbours, etc., a Danish Diving Certificate is required. British and Norwegian Certificates are not acceptable.

The enforcement of diving rules in Denmark is carried out by the Governments Ships Inspection Service.

Holland 4.3.2

Up till 2002 there were two separate diving regulations: one for offshore diving under the Mining legislation, and one for all other diving under the Working conditions legislation.

As of January 1st 2003 all diving comes under the Working conditions legislation.
Enforcement in the oil & gas industry remains the task of the State supervision of Mines, all other diving at work is under supervision of the Labour Inspectorate.

In Dutch this legislation is called : Arbeidsomstandighedenwetgeving or for short **Arbowet**.
The Arbo legislation is concerned with all kinds of working conditions. In it you'll find rules about diving, about working with asbestos, safety at the building site, noise, working in offices, etc.
Much of it is based on EU regulations.

The Arbowet Consists Of The Following Four Levels, Going From Very General To Great Detail.

- Arbowet = Arbo Law
- Arbobesluit = Arbo Act
- Arboregeling = Arbo Regulation
- Arbo beleidsregel = Arbo Guidance

The first three have strength of law. With regards to Arbo beleidsregel, you do not have to comply with, but you'll have to prove, based on you risk analysis, that what you do do gives the same level of safety as the guidance does.

Key principles

The Key Principles Of The Arbo Legislation Are:

- Working conditions must be as safe and healthy as possible;
- Employers and employees have a shared responsibility for the working conditions;
- A risk inventory and evaluation is compulsory at various stages before, during and after the job.

Whether you are considered to be an employer or employee depends not on whether money changes hands but on rather complicated jurisprudence. Deciding factor is whether there is an authoritative relationship, i.e. does the one have authority over the other.

In case of diving special provision is made so that relevant Arbo regulations and working time regulations apply to all members of the diving team, whether employer, employee or self employed.

Stricter Rules

At the same time that the two regulations were merged, some of the rules have become stricter.

1. Employers must give 5 days notice before start of job to the proper authority, i.e. State Supervision of Mines or the Labour Inspectorate of all diving work

- In water deeper than 9 meters or
- Current is stronger than 0,5 meters per second, or
- With planned decompression, or
- With breathing gas other than air, or
- Over a period longer than a week, or
- In the oil & gas industry.

If it is impossible to give 5 days notice, than the notification must be given as soon as possible.
In case of diving in the oil & gas industry extra information about safety measures is required.
This replaces the diving permit issued by the State Supervision of Mines.

2. All divers must hold a medical certificate of fitness to dive, to be renewed at least every year, issued by a registered diving doctor, conducting the medical in accordance with the Arbo regulation.
3 The diving supervisor must hold a diving supervisor certificate, issued by the Minister of Social Affairs and Labour, or a certifying authority, so designated by same Minister (the Netherlands Diving Centre at this time is the only institution so designated) after successfully completing a diving supervisor training course.
There is a one-year grandfather scheme, ending 31st December 2003.
All Divers, Diving Supervisors and Diver Medics wishing to work in Dutch waters, must also hold Dutch certificates by 1st January 2004.
The certification scheme for divers and diver medics was already in place since 1995.

The Arbo Act mentions 3 diver-training certificates:

- Category A for SCUBA diving.
- Category B for Surface Supply diving.
- Category C for Mixed Gas/bell diving.

The Arbo Act mentions 3 diver medic certificates:

- Diver First Aid - for 2 man diving teams only.
- Medical Aspects of Diving A (MAD-A) for all air diving.
- Added Medical Aspects of Diving B (MAD-B) for mixed gas/bell diving.

4. A certifying authority, accredited by the Accreditation Board must certify all diving equipment. This will come into force on a date still to be established.

- In accordance with EU regulations, as of January 1st 2003, diving, diver medical and diving supervisor certificates issued by EU or EER member states that are assessed to be equivalent by the Minister of Social Affairs and Labour, or by a certifying authority, so designated by same Minister (the Netherlands Diving Centre at this time is the only institution so designated) will be equated with the equivalent Dutch certificates.
- In the case of EU or EER member states, certificates will be deemed to be equivalent, unless they are in essence substantially unequal.
- Certificates of all other countries will be assessed for full compliance with the relevant legislation. For EU and EER certificates there is a transitional period of one year, ending 31st December 2003.

5. Though in theory it is still allowed to dive with a team of two divers, under the new Arbo guidance this will in practice only be possible for diving work such as cleaning windows in the aquariums of the Zoo.

Ireland 4.3.3

The Safety and Industry (Diving Operation) Regulations 1981 SI 422. These regulations were based on, and similar to, the old UK regulations (The Diving Operations at Work Regulations, SI 399).

General

Some countries diving inspectors, e.g., Danish Ships Ministry, can issue notices from time to time, which form part of legal requirements in the country concerned.

Section 5
Air & Gas Handling

AIR REQUIREMENTS AODC / IMCA014 5.1

The AODC/IMCA 014 Guidance Note on Minimum Quantities of Gas Required Offshore states:

A. Sufficient compressed air must always be available for two emergency dives to the full intended diving depth as reserve. This air must either be stored in containers or else supplied by two totally independent dedicated sources.

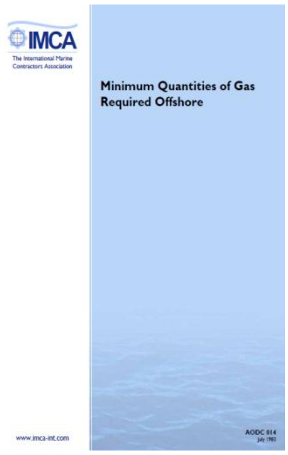
B. Sufficient compressed air must be available to pressurise both locks of the deck decompression chamber to the maximum possible treatment depth plus sufficient air for three complete surface decompression cycles. This air must either be stored in containers or else supplied by two totally independent dedicated sources.

NB:

1) Two totally independent sources could be two separate compressors one of which is connected to the rig or vessel emergency electric power or separate power source (e.g. diesel) or one compressor plus compressed air storage containers.

2) Rig air should not normally be considered as a dedicated air supply for diving as it is principally provided for other purposes and may not be available to the quality, or in the quantity or at the pressures required.

3) 90m^3 (3,200 cu ft) of breathing oxygen must be available for emergency treatment procedures.



GAS SAFETY 5.2

Safety Rules relating to gas handling and mixing include:-

- Oxygen shall be marked for "diving" only and comply with the purity standards.
- Pre-mix shall be for diving purposes and comply with the purity standards.
- Shore base must obtain a purity and analysis certificate from the supplier.

Poor gas handling has caused a number of fatalities both by explosion and by supply of the wrong gas to the diver.

High Pressure Gas 5.2.1

High-pressure gas is **dangerous**. A loose or broken fitting can blow off and cause severe injury or death. A free hose end can whip with sufficient force that it can also cause serious injury or death.

- Always use the correct hoses and fittings.
- Check the condition of all hoses and fittings before use. In particular, check hose end fittings for fatigue cracks.
- Tie hose ends to the quad to prevent whipping in the event of a fitting failing.
- Route all hoses safely and correctly, making sure that both ends are marked clearly with the percentage and destination.
- Make sure that any single bottles are secured in the upright position. If a bottle fell and broke its pillar valve it would be propelled with sufficient force to penetrate a steel bulkhead.

- Never close or open a valve without checking with the Supervisor, LST or Gasman.
- Open all valves slowly, at arms length, and look away from the valve.
- If you are venting gas, wear ear defenders or cover your ears. There is a risk of long-term damage to your hearing.
- Never play games with HP gas. A jet of gas can blind.
- Never connect a supply without analysing the gas first. The information on the tube or quad may be wrong and the wrong gas can kill.

Low Pressure Gas 5.2.2

Low-pressure gas can kill and injure as easily as high-pressure gas and should be treated with the same respect and according to the same procedures.

Particular care should be taken when changing filters or operating medical locks. A clamp can fly open with sufficient force to kill if it is released under only a few bar of pressure.

The diver in the chamber should also be aware of the risks of suction.

Oxygen 5.2.3

Oxygen, especially high-pressure oxygen, carries an additional risk of explosion. It is highly reactive. The heat of compression when oxygen is allowed to flow rapidly into a pipe can raise the temperature high enough to cause ignition of the metal.

Combustion occurs with the speed of an explosion and there have been numerous accidents involving serious burns and fatalities.

Principles of Safe Oxygen Handling Include:

- Never smoke when you are handling oxygen, or go near anybody who is smoking or near any naked flame for at least fifteen minutes after handling pure oxygen. Oxygen can accumulate in your clothing and your clothing will ignite easily.
- Ensure that all fittings are oxygen clean. This means completely free of oil, grease and dirt. Fittings are submerged in a biox solution until clean then rinsed in a soap and water solution. The fittings are then dried before use.
- Keep flexible hose to a minimum and use only hoses, which are kept specifically for oxygen and are oxygen clean. The hoses should be marked to stop confusion, i.e. colour coded.
- Previously it was forbidden to use any stainless steel tubing or fittings. Certain grades of stainless steel corrode in HP oxygen. Now reference is made to IMCA D012, which allows the use of certain grades.
- Use recommended O_2 compatible lubricants on O_2 valves and fittings.
- DO NOT USE PTFE thread tape on O_2 fittings. Compatible sealants can be used, e.g. Loktite Hydraulic Sealant 542. (However the part in DVIS 3, which mentions the production of Phosgene gas is a falsehood).
- Never use quarter turn valves. Opening them can generate sufficient heat of compression to cause ignition on pure oxygen. (Quarter turn valves may be in the line as emergency shut off valves).
- Ensure all oxygen transfer pumps are well maintained and only used for the transfer of oxygen. NEVER USE THEM FOR GAS OR AIR.

Oxygen Stowage

- All oxygen must be reduced to 40 bar at the quad.
- Pure oxygen and oxygen mix (over 25% O_2), shall be kept in the suppliers bank only.
- All oxygen and oxygen rich mixes shall be stowed in an open area, well ventilated, light and weather protected.
- All oxygen and oxygen rich mixes should be stowed well away from the diving system.
- The stowage area must be clearly marked : "O_2 STOWAGE - NO SMOKING".
- A fire hydrant must be within 10 m of the stowage area.
- If transfer of oxygen is taking place, a sign must be displayed: "O_2 UNDER TRANSFER".

Protective Clothing

- If possible, protective clothing should be worn when transferring oxygen.
- Nylon overalls should not be worn, as static electricity can build up on nylon.
  - This can lead to a spark discharge, which, in turn, could ignite any oxygen present.

CONNECTING A GAS SUPPLY 5.3

As the supervisor you have to be informed and kept up to date on the on all matters, when you ask someone to connect a new gas supply they should do the following:

- Analyse and note the starting pressure of the new quad or tube, which is to be connected. Tell you when they are disconnecting the old supply. They should note the final pressure of the quad or tube and check the positions of all the valves in the line they must vent the line and take all the precautions for handling HP gas, even if there are only a few bar left in the line. Vent the supply at the panel to clear out any old gas in the line before you take a sample for analysis.(if required).
- Connect the new supply.
- Open the valves to the panel.
- Analyse and note the pressure of the new supply at the panel.
- If the pressure does not agree with the pressure at the quad, a valve could still be closed or half closed, or connected to the wrong supply.
- They will inform the Supervisor that the new supply is connected and give the pressure and analysis.
- If the gas is being supplied to the diver there should be an in line analyser with audio- visual hi-lo alarms. The alarms must be activated.

Colour Coding Of Gas Supply 5.3.1

A colour coding system is used to identify pressurised gases.

An air diver may well be working on a vessel, which is carrying helium oxygen mixtures, pure oxygen and other gases for welding or burning operations.

A wrongly connected gas supply can kill and **every diver** should know the colour coding system.

It is unlikely that the air quads, which are generally separate from the mixed gas system, will contain anything other than air, but if there is the least doubt the supply should be analysed. All gas must be analysed before going on line. O_2 and CO_2 analysers should always be available, plus sometimes a helium analyser and/or gas chromatograph for special operations, e.g. hyperbaric welding.

Remember that colour coding only tells you what **should** be in the quad, it does not always tell you what **is** in the quad.

The Colour Coding of Gases			
Gas	**Bottle or Quad Body**	**Bottle or Quad Top**	
Nitrox mixtures (inc. Air)	Grey	Black and white quarters	
Diving Oxygen	Black	White	
Industrial Oxygen	Black	Black	
Helium	Brown	Brown	
Heliox mixtures	Brown	Brown & white quarters	
Tri-mix mixtures	Brown	Black, white & brown thirds	

Gas Register

A log-book is kept for all gases, including air. All entries are to be signed by the Supervisor. Upon delivery, the following should be entered in the register:-

- Date
- Quad number/gas contents
- Analysis - i.e. 5% O_2/95% He
- Quad pressure
- On-line date
- Finish pressure
- Date returned

In addition to a gas register, a daily gas-log must be kept showing the date, vessel, different percentage of gases, total volume, amount of gas used, gas arrived, gas departed, and gas on line.

All daily gas sheets should be signed by the supervisors.

Prior to using any gas it must be analysed before going "on line". Diver's on line breathing gas must be continually analysed in dive control.

GAS DELIVERY EQUIPMENT 5.4

Gas Hoses 5.4.1

Hoses are also referred to as *'whips'* and may be of heavy wire braided construction or made of far lighter synthetic materials like Synflex.

Swivel fittings are usually used on hose ends to allow tightening without twisting the hose.

They may be fixed onto wire-braided hose with simple hand tools but Synflex hose fittings need a special swaging tool.

Pressurised hoses should always be tied off. At the ends, attach the rope to the hose and not the end fitting. The hose should always be clearly visible with regular warning notices attached.

Hoses should always be run with sufficient slack to allow for take up when the hose is under pressure. They should be routed to avoid working areas and heat sources and twisting and small radius curves should be avoided.

Principles of Safe Whip Handling:

- Hoses used for oxygen transfer should be made of the non-conductive material, of proper working pressure, and have an ID of ½" (Normally Orange in colour to indicate that they are only to be used with gases >25% Oxygen).
- Oxygen whips must never be used for transferring mix gas (<25% O_2) or air.
- Oxygen whips should be stored away from other gas transfer hoses, ideally locked away to stop inadvertent use as non O_2 hoses.
- All lines are to be marked clearly as to their function at both ends (particularly long whips).
- All hoses must be kept clean and free from grease and oil.
- All end fittings should be protected with end caps when not in use.
- All hoses should be kept to a safe minimum length and protected on deck.
- Hoses are to be securely "whip checked" at both ends to reduce the risk of injury if a fitting was to fail.

Gas Fittings 5.4.2

A large range of fittings are designed to fulfil a variety of functions and it is essential that all the fittings used in the system are compatible with the pressure being used and with each other.

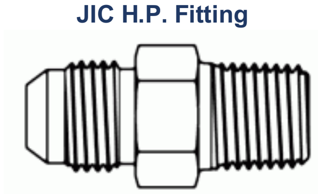
After repeated use, especially if they have been over tightened, hose and fittings may develop fatigue cracks.

They should always be checked before use and changed if necessary.

JIC **(Joint International Council)**

- These fittings are designed for use with HP hose.
- The seal is provided by the conical seating and no additional sealant is required.
- Do not over tighten these fittings as the sealing flange may split.

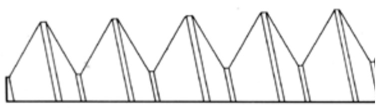
JIC H.P. Fitting



NPT **(National Pipe Taper)**

- These fittings have a tapered thread and a sealant is required.
- Remarkably large variety of different fittings.
- It is vitally important that the correct fittings are used in both connections.
- Beneath is a chart giving the various different American / international fittings.
- Even though the fittings may look similar, one may be American & the other International.
- It is tempting to simply use 'more' sealant tape. But this is unlikely to secure the fitting.

NPT H.P. Fitting



ISO 262 Metric Screw Thread

- 60^{O} Thread Angle
- Pitch Measured In Millimetres
- Truncation & Root Crest Are Flat & Of Different Widths
- Diameter Measured In Millimetres

ISO 2281/1 Parallel Pipe Thread

- 55^{O} Thread Angle
- Pitch Measured In Inches
- Truncation & Root Crest Are Round
- Diameter Measured In Inches

ISO 7/1 Tapered Thread

- 55^{O} Thread Angle
- Pitch Measured In Millimeters
- Truncation of Root & Crest Are Round
- Taper Angle 1° 47'

American Standard NTP Tapered Thread

- 60^{O} Thread Angle
- Pitch Measured In Inches
- Truncation of Root & Crest Are Flat
- Taper Angle 1° 47'

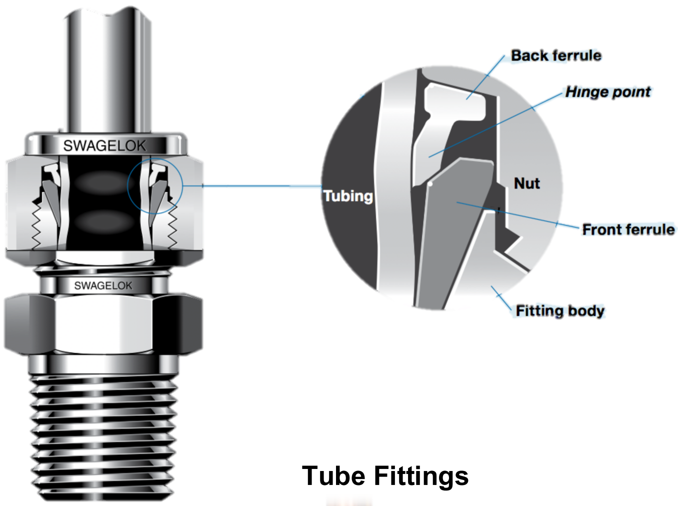
American Standard Screw Thread

- 60^{O} Thread Angle
- Pitch Measured In Inches
- Truncation & Root Crest Are Flat
- Diameter Measured In Inches

Swagelock

- These fittings are designed for use with HP stainless steel tubing.
- The seal is provided by a patented toothing and no additional sealant is required.
- Care is needed when tightening these fittings as the sealing mechanism needs to be accurately engaged.

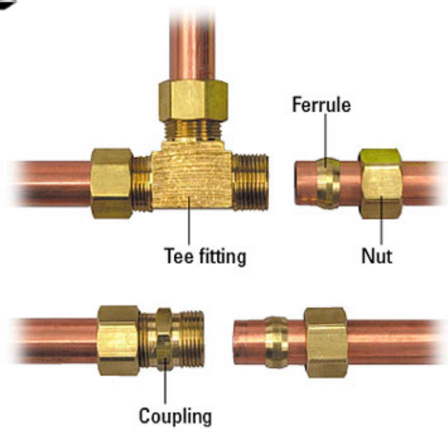
Swagelock H.P. Fittings



Tube Fittings

- Tube fittings are used to connect LP copper tubing.
- The seal is provided by a copper olive (ferrule), which slides over the tube and is compressed as the fitting is tightened.
- Sealants are not needed.

Tube Fittings



Teflon Tape

Teflon tape, also called thread tape or PTFE tape, is commonly use to increase the sealant ability of certain gas fittings.

- It is wound round the threads before fitting.
- Two wraps will suffice keeping the tape two threads clear from the end of the fitting.
- Put the tape on so that it does not unwind as the fitting is tightened.
- Excessive amounts may be carried into the pipe work, causing blockages in valves or reducers.
- **Never** use on JIC fittings or Swagelock fittings.
- Use only on thread to thread sealing fittings.
- Only use O_2 compatible Teflon tape on O_2 circuits.
- All fittings are to be rates for the proper pressures and made of correct material.
- Ensure all fittings are clean and free from grease and oil.

P.T.F.E. Tape

Quads 5.4.3

A quad is a bank of nine, twelve or sixteen large bottles, connected by a manifold.
Each bottle has separate isolation valves and is connected via the manifold to the two king valves.

Each bottle normally has a floodable volume of about 50litre. The widely used sixteen bottle quad has a total floodable volume of 800 litre or 0.8m^3. At a working pressure of 200bar it would contain 160m^3.

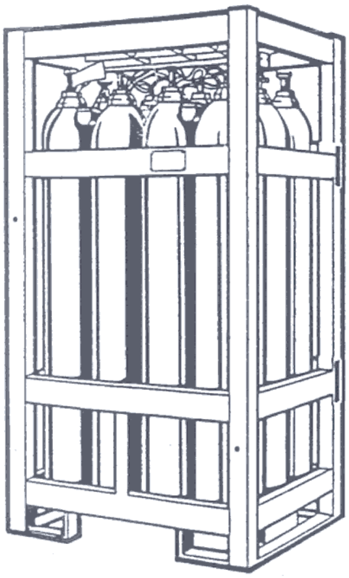
A superquad, which is used in mixed diving more than air diving, consists of sixty-four bottles.

Quads must have a visible hydrostatic test certificate - to be renewed every five years and should be in a good overall condition, always check the valves, pipe work, paint etc.

Quads must never be pressurised above the maximum working pressure.

Gas should not be mixed into any quads, which have contained air and should not be mixed into the suppliers bank.

All quads must clearly indicate the percentage of its constituent gases and must be colour coded accordingly.

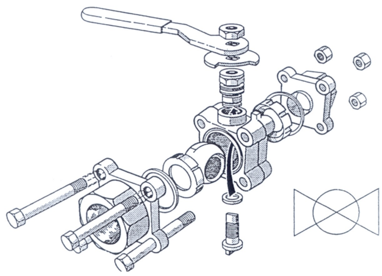


Length:	1.08m (3ft 6in)
Width:	0.82m (2ft 8in)
Height:	1.96m (6ft 5in)
Capacity:	**Helium:** 109 m^3 (3852 scf) **Oxygen:** 105 m^3 (3720 scf)
Working pressure:	**Helium:** 2845 psig **Oxygen:** 2500 psig
Weight:	1.10 tonnes
Volume/weight ratio:	**Helium:** 99.1 m^3/tonne **Oxygen:** 95.5 m^3/tonne
Deck space occupied:	0.85 square metres (9 square feet)
Hold volume occupied:	1.73 cubic metres (60 cubic feet)
Size and type of outlet:	Oxygen / Air $^5/_8$" BSP Female Helium / Heliox 21.8 mm 14 TPI Male
Identification colours:	**Brown:** helium **Brown / white:** helium/oxygen **Grey / black / white:** diving air **Black / white:** oxygen
Finish:	Corrosion-resistant valves and trim, shot blasted frame coated with marine-duty paints

Valves 5.4.4

Quarter Turn Valves

Quarter Turn Valve



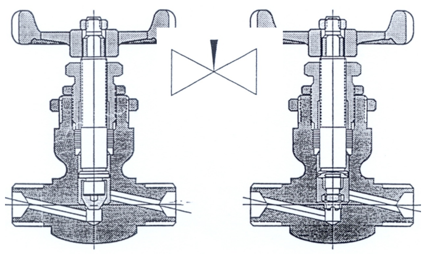
These are used where only a coarse flow control is required or may be used as Emergency Shut-off valves. They can be opened and closed quickly and the position of the handle indicates immediately whether the valve is open or closed.

If the handle is in line with the pipe the valve is open, if it is across the line of the pipe it is closed, although great care should be taken if the valve design allows the handle to be fitted in the wrong position.

Quarter turn valves should not be used on oxygen lines, since static discharge and friction associated with operating the valve may cause ignition in pure oxygen.

Needle Valves

Needle Valve



These provide a fine flow control but give no indication of whether the valve is open or closed.

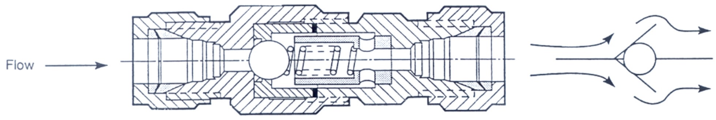
If a needle valve is fully open it is normal practice to turn it back for a quarter turn.

The valve is then free to turn in either direction and is clearly open.

Non-Return Valves

As the name implies they allow flow in only one direction and are widely used on helmets, control panels and chambers.

Non-Return Valve

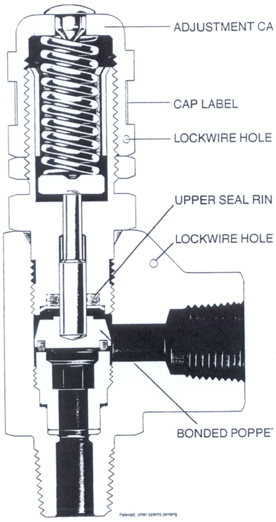


Relief Valves

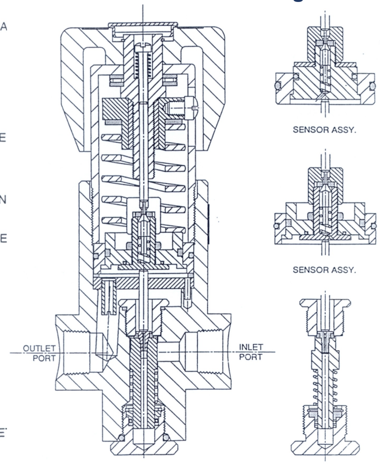
These are used on circuits, which are regulated to a specified pressure by O_2 circuits.

The relief valves are present to open above a chosen pressure. Thus if the regulator fails and allows higher pressures to pass, the relief valve protects the circuit by venting off the excess gas.

Relief Valve



Hand Loaded Pressure Regulator



Reducers or Regulators

These valves limit the pressure of the gas passing through the valve. They may be pre-set, as in the first stage of a scuba demand valve, or adjustable, as on a control panel.

The outlet pressure may also be influenced by a pilotage line. This is a pressure line coming from the chamber into the reducer. It ensures that if a pressure of 10bar is set on the reducer it will delivery air at 10bar over chamber pressure.

OXYGEN PIPE CLEANING 5.5

There are three times when the cleaning procedure for oxygen needs to be follows:-

- During the initial assembly/construction of the diving systems.
- During any major refit or modifications to existing equipment.
- Whenever outside contamination of the system is suspected.

The purpose of this cleaning is to ensure that all contaminants are removed.

Examples Of The Contaminants To Be Removed Are:-

- Hydrocarbon oils and greases.
- Thread lubricants.
- Paints and varnishes.
- Fluxes.
- Filings, burns and powdered metal oxides.
- Any other foreign substances that may be in the line.

The following previously used substances are NOT to be used, as their fumes and residues are extremely toxic.

- Trichlorethane, 'Genclene'.
- Carbon tetrachloride.
- Choroethane.

Use of these materials requires that great care be taken to ensure that all traces are removed, usually by detergent cleaning, fresh-water flushing, and then drying by purging the lines with an oil-free dry gas such as nitrogen. The effectiveness of this secondary cleaning is always suspect, especially where the piping could absorb some of the original cleaning material.

The diving industry recognises biox as a suitable agent for O_2 cleaning, however, experience gained during the American Space Programme showed that the use of detergents can achieve the same high degree of cleanliness as the previously used chemicals.

Oxygen Pipe Cleaning Procedure 5.5.1

Prepare The Cleaning Solution:-

- Add 6 grams (0.21 ounces) 'Diflex' powder to 2 litres (2.1 quarts) of hot, clean, fresh water.
- Stir until all of the 'Diflex' granules have dissolved.
- **NB:** The solution is alkaline and must be handled with care.

Cleaning Pipework

- Fill pipe with warm solution.
- Allow solution to remain in pipe for at least 20 minutes.
- Empty a small portion of the solution from the pipe and agitate for at least 2 minutes.
- After soaking and agitation, drain the pipe with care.
- Flush the pipe with running fresh water for at least 3 minutes, (rotating to ensure that all of the solution is flushed out).

Cleaning Fittings

- Place the fittings in warm solution.
- After 10 minutes, scrub the fitting with a bristle brush whilst in the solution.
- Allow the fitting to remain in the solution for a further 10 minutes.
- Rinse the fitting for at least 3 minutes in running fresh water, ensuring that all portions are thoroughly rinsed.

Drying

- Pipes and fittings should be blown dry using a dry, oil-free gas. (This should be regulated to 1 bar or less to avoid the possibility of gas embolism due to a high pressure gas stream impinging on the skin).
- **NB:** Ensure eye protection is worn.

Storage

Fittings

- Unless they are to be used immediately, fittings should be placed in gas tight clean polythene bags on completion of the cleaning process.

Pipes and Hoses

- Unless they are to be immediately used, the pipes, etc. should have both ends sealed on completion of the cleaning process. This can be done using cleaned plugs or by placing the ends in gas tight clean polythene bags and taping the bag shut around the pipe, well away from the end.
- Under no circumstances should tape, (silver, masking, electrical, etc.) be used to seal the end of the pipe.

Tools And Clothing Used During Cleaning Process:-

Tools

- All tools should be subjected to the cleaning procedures for fittings before they are used on cleaned parts.

Clothing

- Clean overalls or laboratory coats should be worn while cleaning and also during the re-assembly of cleaned valves, regulators, etc. Protective gloves (household washing-up type are suitable) must be worn during the cleaning, rinsing and drying stages.
- A plastic or rubber apron should be worn during the cleaning and rinsing stages.
- Safety glasses should be worn at all times during the process.
- During re-assembly, clean, lint-free gloves should be worn.

First Aid

- If, during the cleaning process, any chemical comes into contact with the body, liberally rinse the affected areas with fresh water.
- If in the eyes, a slightly acidic proprietary eye-wash can be used, and following a thorough rinsing medical attention should be sought.
- Due to the loss of skin oils through frequent or prolonged exposure, skin cracking and soreness may develop; treat with lanolin-based hand cream after cleaning work is completed.

"Safe" Lubricants

For Direct Exposure to 100% Oxygen

- Krytox 240 AC grease. Manufactured by EI DuPont Nemours & Company Inc., Petroleum Chemical Division, Wilmington, Delaware 19898, USA.

- Fomblin, fluids and greases. Manufactured by Mont-Edison (UK) Ltd., 11a West Halkin Street, London, SW1X 8LF, UK.

For Exposure to Elevated Percentages of Oxygen

- The following compounds can be used where the oxygen percentage may be elevated, (30% oxygen maximum) and there are no un-oxidised aluminium surfaces, the temperature will not exceed 100°C and there is no likelihood of exposure to a stream of oxygen.
- Acceptable compounds:
  - MS4.
  - Other similar silicon-based lubricants.

GAS COMPRESSION 5.6

The helium-oxygen breathing gases used in deep diving operations can be purchased in a premixed condition or as pure gases.

Even if the company's usual practice is to use premixed gases, the LST or Gasman needs to know the various ways and techniques of mixing gases, as on occasion a special mix or further supply may be required.

There are several methods of mixing gases, based on weight, volume and partial pressure. This can be done in individual cylinders, 'quads', or the diving chambers.

When Mixing Gas, The Following Points Must Be Kept In Mind:-

- Cylinders or quads should never be brought to atmospheric pressure as this would allow moisture to enter. The only exception is when a vacuum pump is going to be employed to evacuate the cylinders or quads.
- Analyse the contents prior to mixing.
- Ensure that all hoses are cleaned of lubricants or contaminants.
- Always add oxygen at the lowest possible pressure.
- Only a specially designed oxygen pump should be used for pure oxygen.
- The use of high-pressure oxygen is restricted by regulations, therefore the pipe runs (copper, monel or brass) or hoses must be as short as possible and used only for oxygen.
- Always use needle valves on oxygen lines and open them slowly.
- Check the maximum storage pressure of the cylinders or quads to be used and ensure that the pressure necessary to create the desired mixture does not exceed the rating of the storage vessel.

Compressors 5.6.2

Compressors may be required to supply high-pressure gas or air for filling SCUBA bottles and quads or low-pressure air for supply direct to the diver.

In general, the gas or air is compressed in stages to the required pressure. The gas or air will be cooled between stages and traps will remove moisture and oil particles.

A chemical filter will remove any trace gases such as carbon monoxide together with any remaining oil or water.

The compressor may be driven by a diesel or petrol engine or an electric motor.

The compressor is rated according to the free volume of air it will take in per minute and the maximum pressure at which it will delivery the air.

For example, a rating of 5 cubic feet per minute at 200 ats means that it will take 16 minutes to fill an 80 cubic foot bottle to 200 ats.

H.P. Compressors

The schematic diagram shows a typical HP compressor. It is a three-stage compressor with air-cooling between stages. Larger compressors like the Williams & James 175 may have water-cooling.

Relief valves in the second and third stages prevent over pressurisation of the system, and pressure regulators ensure that the compressor works at maximum efficiency. The compressor may be operated manually or have various types of automatic control systems.

Pressure stop systems will switch the compressor off at a set pressure, usually 200 bar.

Automatic systems will switch the compressor on when the pressure is below a certain level and off when the pressure is above a certain level. Extreme care should be taken when changing filters or carrying out maintenance on auto start compressors. The power supply should be disconnected.

Precise operating procedures will vary from compressor to compressor, but in general:-

Before Starting:-

- Check oil levels in the compressor and in the engine driving the compressor.
- Check water levels in the cooling system, if applicable or check circulating water is running.
- Drain the oil and water traps.

Starting:-

- Open all the drains. The compressor should never be started under load.
- Check that all outlet valves are in the correct positions.
- Start the engine.
- Check oil pressures and switch off if they do not reach correct levels within about 30 seconds.
- Close the drain valves.
- When the pressure is higher than the pressure in the bottle or quad, open the valves slowly. (Never put back pressure on a compressor).

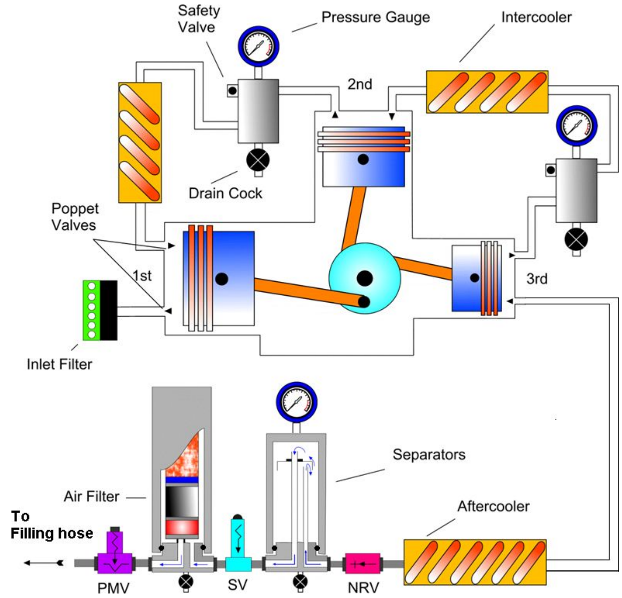
Running:-

- Check pressures.
- Check oil pressures.
- Operate drain valves.
- Check filters.

Shutting Down:-

- Switch off.
- Close bottle or quad.
- Vent air from compressor. Taking care to protect your ears.

H.P. Compressor

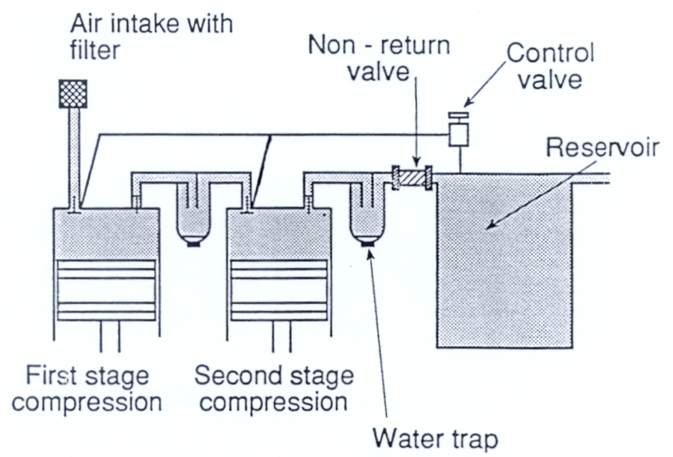


L.P. Compressors

The schematic diagram shows a typical LP compressor. LP compressors operate according to the same basic principles as HP compressors but are generally two stage. The same general operating procedures should be followed.

The compressor pumps into a reservoir and a regulating valve opens when the working pressure is reached. The compressor will then idle until pressure starts to drop in the reservoir.

L.P. Compressor



Filter Systems

Air supplied for diving must conform to British Standard 4001. The maximum level of impurities allows are shown in the section on Gas Purity.

Carbon monoxide may be introduced into the air supply by placing the compressor intake close to an engine exhaust or be produced in the compressor itself by partial burning of lubricating oil.

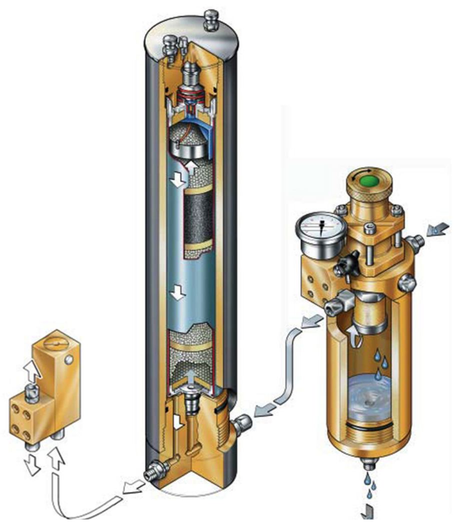
Correct placing of the air intake and correct maintenance of the compressor can avoid both these problems, but the effects of carbon monoxide poisoning are so serious that it is usual to pass the air supply through a chemical filter as an additional precaution.

The same filter will remove any oil and water vapour and dust particles.

The diagram shows an air filter and the functions of each part.

Intake filters are designed to stop grit or dust being drawn into the compressor.

Compressor Filtratio



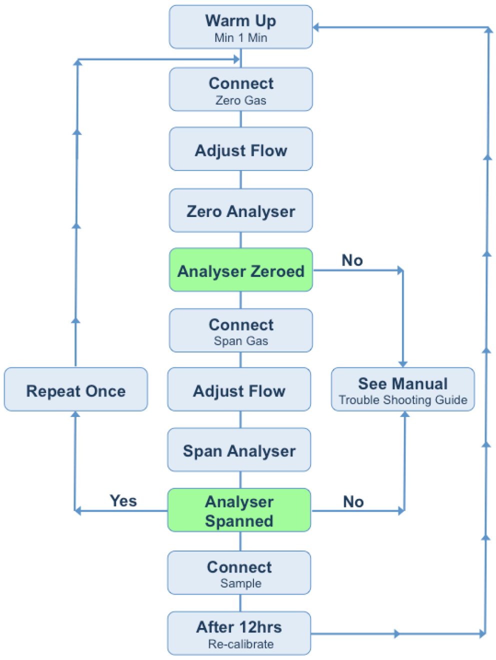
GAS ANALYSIS 5.7

The LST is principally concerned with the measurement of oxygen and carbon dioxide levels in both bell and chamber atmospheres and also in the gas supplied to both. He or she may use one of a large range of main electrical or battery analysers or possibly a colorimetric tube.

All analysers read partial pressure, and while those designed for use under pressure will give a direct readout in partial pressure, those on the surface give a readout in either percentage or parts per million. Thus a surface readout must be multiplied by the absolute pressure to give a partial pressure at the relevant depth.

The only exception to this rule is with colorimetric tubes, on which the scale is in concentration (% or ppm) but used frequently under pressure.

Calibration Flowchart



Analyzers

Analyzers vary considerably in complexity and ease of use. Some require a long warm up time before stabilization, others are ready for use after switching on, some require internal calibration, some do not etc.. The full information regarding the setting up of analysis equipment will be found in the manufacturers manual, but after initial stabilization of the instrument the principle of calibration is common to all analyzers, namely the setting of a low point or zero and of a high point or span. The sample gas will give a readout between these points at a level corresponding to its content.

It is very important in instruments with meter readouts that the mechanical zero is set before switch on. Misalignment of the mechanical zero can considerably alter the accuracy of the analyzer.

Setting Zero

Not all analyzers require zero calibration as the zero position is present at the point where there is no signal output from the sensor, but for most a flow of zero gas, normally pure helium, is required.

Check in-line filters. The makers manual will state what filters are required and also the most suitable flow rates. Pass the zero gas through the analyzer at the recommended rate, allow a stabilising period and then adjust the readout to zero. On some digital analyzers there is no negative position, set the zero at a point where the readout is flashing between 0.0 and 0.1, i.e. just at the positive side of zero.

Setting the Span

Always tcalibrate on the range that you will be working with, as you do sometimes have differences between the ranges.

Flow a calibration gas of known concentration through the analyzer at the prescribed flow rate. Using the span control either set the value directly or to the value displayed on the graph which accompanies some instruments.

With some oxygen analysers, especially microfuel cell analyzers, the sensors can be exposed to air and calibrated to 20.9%. Ensure that there is a reasonable ventilation system in operation as the oxygen content in air can vary in confined areas.

If the zero and span adjustments are large it is advisable to redo the zero and span calibration, but after the initial warm up and setting up is complete, it is usual to zero and span once only.

Analyzing

It is important that the gas samples to be analyzed arrive at the analyzer through the same filters and at the same flow rates as the gases used for calibration.

Re calibration periods vary greatly between analyzers, some recommend, in their handbooks, four hours while others speak in terms of weeks.

UK regulations state that re calibration must be carried out on a 12 hourly basis (Norway 24 hours), hence each shift must carry out a re calibration. This is good practice any way. It ensures that each shift has verified the calibration and has checked the alarm points. However the tendency to continually adjust the analyzers, which are maybe only a few millibars out, is not recommended.

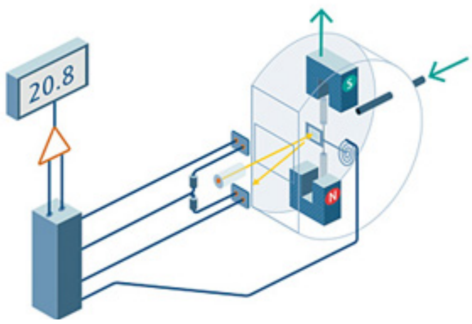
Oxygen Analysis 5.7.1

There are two main systems used to analyse oxygen levels, they are: Paramagnetism and Polarography.

Paramagnetism

The Servomex analyser works on the principle that oxygen is a paramagnetic gas.

Para Magnetism



Two hollow quartz spheres, each filled with an inert gas, are positioned at either end of the rod forming a "dumb-bell", which is suspended in a non-uniform magnetic field. The spheres, being slightly diamagnetic, take up a position away from the most intense part of the magnetic field.

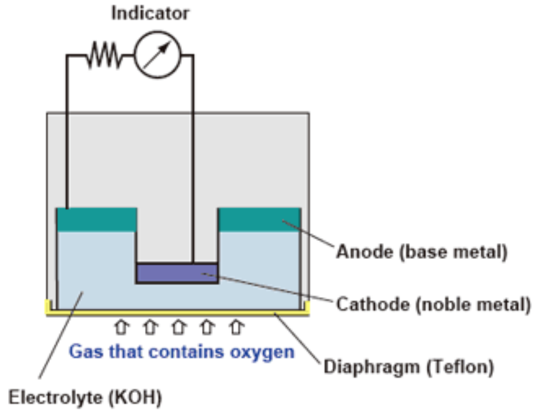
The zero position of the "dumb-bell" is sensed by a split photo cell receiving light reflected by a mirror on the suspension. The measuring system is therefore null balanced.

When the surrounding gas contains oxygen, the dumb-bell spheres are pushed further out of the field by the relatively strong paramagnetism of the oxygen. Thus the movement of the mirror on the suspension alters the pathways of the light beam and thus its position at the photocell. The output of the photocell is amplified and fed back to a coil wound onto the suspension, which returns the dumb-bell to its null position. This feed back current value is proportional to the amount of oxygen in the sample, giving a readout on the instrument as an oxygen percentage.

Polarography

The majority of O_2 analysers currently used offshore use the principle of polarography with the micro-fuel cell as the sensor component.

Oxygen Polarography



The sensor operates as an electrical cell whose output is affected by available oxygen. The diagram shows the main components, notably a lead anode, a gold cathode, a conducting electrolyte, normally potassium chloride (KCl) and a Teflon diffusion barrier.

The gold cathode serves as a reaction site for the reduction of oxygen molecules into hydroxyl ions. These hydroxyl ions react with the lead anode forming lead oxide and releasing electrons. The electron flow between anode and cathode is through an external load resistor, producing an output voltage. The output voltage is therefore a function of the number of oxygen molecules reduced at the gold cathode. Only a span calibration is required as the zero position is built into the sensor as no output voltage.

As in all chemical reactions, temperature fluctuations alter the speed of reaction. To overcome this, each sensor has a thermistor in the circuit, either on the cell itself or close by in the cell holder.

A thermistor is a resistor with a negative co-efficient, which will ensure that the signal to the readout is kept constant when temperature fluctuations occur.

The cells available have a limited life span, which is determined by the amount of lead in the anode and the amount of oxygen being monitored.

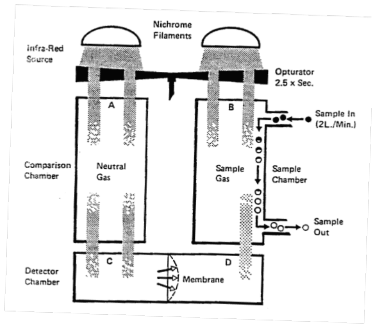
The sensor is influenced very little by other gases.

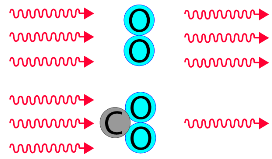
A problem may arise if water condenses on the membrane affecting its permeability to O_2. Thus it operates at < 99% RH

Carbon Dioxide Analysis 5.7.2

Most CO_2 analysers work on the principle of infra-red light absorption. Carbon dioxide absorbs infra-red radiation in amounts proportional to its concentration.

Infra-Red CO_2 Absorption Analyser





Two identical beams of infra-red radiation pass along parallel optical paths, the sample cell and the reference or comparison cell, to a sensing element - the detector. The comparison cell is filled with an inert gas containing no carbon dioxide so that the light beam on that pathway arrives at the detector unchanged. Any carbon dioxide in the sample cell absorbs a corresponding amount of infra-red radiation, thus disturbing the balance between the pathways.

The detector cell is a dual chamber cell filled with the gas that is measured, i.e. in this case CO_2. The CO_2 at the detector absorbs the incoming radiation resulting in a temperature and thus pressure increase. The amount of pressure/temperature increase is proportional to the amount of radiation arriving. This in turn depends on the amount of CO_2 in sample. The reference / comparison side will be constant but the sample side will fluctuate depending on CO_2 content. The pressure inequality between the chambers of the detector cell is converted and amplified to give an output signal to the readout.

Air Purity Analysis 5.7.3

In the UK sector, BS EN 12021 gives the standard for care and maintenance of equipment used in compressed air diving. Part of this document gives information on the purity standard required of breathing air. The maximum levels of contaminants, as stipulated in BS EN 12021.

In addition, the air must be free of all dust or metallic particles, be odourless and should not contain any toxic or irritating substances.

To avoid the contamination of compressed air for breathing purposes. onboard compressors and cylinders should be operated and maintained in accordance with manufacturers handbook and instructions. Ensure that suitable filtration is used and properly maintained, e.g. particle filters, charcoal, etc. Consider the position of the air intake and of wind direction while running the

compressor to avoid contamination of breathing gas by engine exhaust fumes.

It is a requirement that all compressors should submit a three monthly sample for analysis. Should this analysis not conform to the standard, then the compressor may not be used for pumping breathing gas until the necessary improvements or maintenance has been undertaken and a new sample has been analysed satisfactorily.

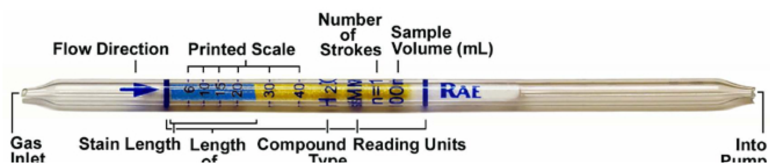
Air Purity Levels	
Carbon Monoxide	3 parts per million
Carbon Dioxide	500 parts per million
Oil	0.5 mg per m^3
Water	35 mg per m^3

Colorimetric Tubes

Colorimetric tubes, e.g. Dräger, MSA, Gastec, are commonly used offshore, notably for the measurement of carbon dioxide in bells and chambers but also for the identification and quantification of other trace gases. The tubes give a readout due to colour change brought about by the reaction between gas tested and the chemical indicator. The tubes are calibrated to be used on the surface so special care must be taken when they are used under pressure.

Over 100 different detection tubes are available.

Colorimetric Tubes



Some hints on the use of colorimetric tubes:

- Check pump gas tightness by inserting unopened tube and compressing bellows. (If the bellows open then there is a gas leak).
- Open inlet end of tube first, then outlet end.
- Insert tube into pump with arrow pointing to pump.
- N = number of pumps, i.e. N = 5 = 5 pumps.
- Take reading from end of discoloration.

- Do not use the same tube twice.
- Ensure that the tube is in-date.
- Always allow bellows to fully expand after each pump.

Note: Tubes normally give a reading in percent or parts per million (ppm).

To Convert This Reading To A Partial Pressure:

At Depth	Readout in % x 10	=	partial pressure in mbar
	Readout in ppm	=	partial pressure in µbar
On Surface	Readout in % x Abs Pressure x 10	=	partial pressure in mbar
	Readout in ppm x Abs Pressure	=	partial pressure inµbar

Humidity has no influence on readings.

TRAUMA TRAINING

Section 6
Dive Safety

SAFETY OF AIR DIVING VESSELS 6.1

The Department of Energy has issued "Air Range Diving Support Vessel Guidance ref number OTH 336 Guidelines for Air Dive Vessels".

The document is aimed at clients and contractors chartering dive vessels and is only set out in very broad terms. There are, however, some points that may be useful and Supervisors should be aware of this document. The following are requirements that Supervisors should consider when air diving from vessels.

Sighting of Equipment

Equipment must be sited so as to provide the maximum accessibility and protection within the constraints of the vessel layout.

The DDC must be situated as near as possible to the diver deployment position and on the same deck level. When using surface decompression techniques the DDC position must allow the diver to be recompressed within the stipulated surface interval without any undue exertion, e.g. climbing or running. Access to a DDC must allow an unconscious diver to be transported by stretcher from the dive position to the DDC.

Deck Mounted Compressor

These must be sited so as to ensure good access for maintenance and protection from the elements.

Compressor intakes should also be sited so as to minimise contamination from funnel and other machinery exhausts. This normally means that intakes should be flexible and placed "up wind" of any fumes or exhaust discharges.

Supervisors must be aware of differing wind directions and the possible re-positioning of the vessel. The relationship between the wind direction, funnel exhausts and compressor intakes should be checked frequently by the supervisor or competent person.

Gas Quads

The weight and bulk combined with the contents of gas quads make them potentially dangerous if they are allowed any free movement in a seaway. Quads should therefore be adequately secured and prevented from moving by sea fastenings or other approved means.

Quads should also be sited so as to minimise any flexible hose run distances. Hose runs should be protected from accidental damage.

Access to the Water

Adequate arrangements should be made to ensure that divers may enter and leave the water safely at all times. These arrangements should take full account of the difficulties that may occur at the air/water interface, particularly under bad weather conditions. Movement through the interface is one of the most critical periods of a surface oriented or bell dive.

In surface oriented diving, the diver leaves conditions of relative weightlessness in the water (where all movements are made deliberately) to be suddenly subjected to violent movements by the water. At the same time he has to support his own weight and that of his equipment, whilst climbing aboard the support vessel or dive platform.

Under no circumstances should they be expected to climb up long vertical ladders, either with or without his equipment. However if ladders are used, they should be angled into the water and protrude about 2 metres (6 feet) into it so that the diver can get a foothold.

Any winch used to lower divers into the water or raise them from it should be constructed so that a brake is applied automatically except when the controls are in the operating position, i.e. it must operate "fail safe". It should not be fitted with a pawl and ratchet gear in which the pawl has to be disengaged before lowering.

Any cage or basket should be able to carry at least two divers in uncramped conditions. It should be designed to prevent divers falling from it, it should have inboard handholds and it should not tip or spin. It should protect the divers from falling objects.

Mooring of Vessel 6.1.1

Vessels Moored to Platforms

It is common practice when diving operations are being conducted over the stern, for vessels to be moored by forward anchors and to have nylon or cordage hawsers from the stern bits to a fixed point on a platform.

This can be a very efficient and safe method of mooring a vessel for diving operations.

There are, however, some safety aspects that supervisors should be aware of:

- The bow anchor(s) may drag causing the vessel to list to leeward. This could pull a diver's umbilical and either drag him from the job or injure him. Down lines and work lines may also be over-tensioned and could part.
- One or both stern lines could part causing violent movement of the vessel stern away from the platform with the result that down and working lines can part and the diver can be pulled from the job and possibly injured.

• The Supervisor must therefore ensure that the stern lines to be used are of sufficient strength and in reasonable condition. Two mooring lines must always be secured when diving operations are in progress. If one line parts or is removed for any reason then diving must cease. Diving must not take place if only one mooring line is secured.

• Vessels Moored by Anchors

• If work is being carried out at a distance from a platform or mooring line facilities do not exist, then the most usual method of ensuring that a vessel remains in a fixed position is by use of a four-point moor.

• Mooring with less than four anchors can allow the vessel to move with the tide and wind and possibly hazard any diving operation. For these reasons Supervisors should proceed with caution if the vessel has less than four anchors deployed.

• Dragging of anchors whilst diving is taking place will have virtually the same result when 4 point moored as dragging anchors while moored to a platform.

• Supervisors must therefore ensure that all bridge watch, keeping personnel are aware of the dangers of the vessel altering location due to dragging anchors whilst diving operations are in progress. If possible, ships staff should take anchor bearings and the Diving Supervisor informed immediately when any alteration occurs.

• Securing of Propellers, Intakes, etc

• Before diving operations take place, it must be ensured by the Diving Supervisor that all machinery, propellers, intakes, thrusters, etc., that may harm or possibly affect a diver are immobilised or switched off. Further provision must be made to ensure that none of the above can be accidentally or inadvertently switched on.

• Bridge watch keepers must be informed when divers enter or leave the water and must be aware of the need for the immobilisation of machinery and propellers, etc.

• If the diving operation is being carried out on a platform or other structure, then any intakes or devices on the platform that may harm a diver must also be immobilised.

• Platform Superintendent and OIMs

• If the diving vessel is working on or within 500 metres of a platform or structure then permission from the OIM must be obtained for divers to enter the water before operations commence. This would, in some cases, be obtained by the clients representative but the Supervisor should ensure that in all events it has been obtained before diving takes place.

TRAUMA TRAINING

Section 7
Air Diving

OFFSHORE SURFACE DIVING TECHNIQUES 7.1

There are several options to the Offshore Supervisor with regards to achieving the contractors goals on underwater projects.

S.C.U.B.A. 7.1.1

SCUBA has inherent limitations and difficulties, such as limited breathing gas supplies and is unsuitable for activities covered by the Diving at Work regulations 1999. Approved Code of Practice "Commercial Diving Projects Offshore".

Surface Supplied Diving 7.1.2

Introduction

Surface supplied diving operations may be conducted from a number of different worksites or positions. Prior to any surface supplied diving operation, The Diving at Work Regulations 1997 (DWR) and its supporting Approved Code of Practice (ACOP), Commercial Diving Projects Offshore, requires that each diving project must have a Diving Project Plan (DPP).

Awareness During Air Diving Operations

- Maximum depth for air diving is 50 msw.
- Maximum pO_2 in water 1.5 bar.
- Length of divers umbilical.
- Bailout Bottle contents and size.

Wet Bells 7.1.3

Wet Bells come in varying degrees of sophistication and size; from modified baskets with a Perspex dome.

However, as a general rule wet bells cannot be pressurised above the ambient pressure.

The Wet Bell

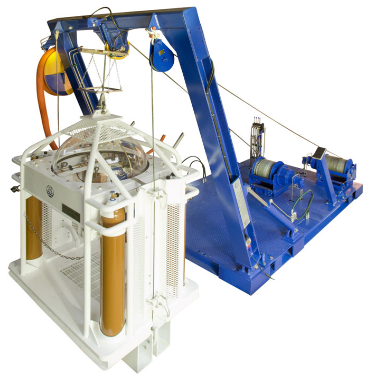
Whichever type or make of bell is used, two distinct varieties are available:

- **Type 1** Bells in which the diver and standby divers umbilicals terminate at the surface in a conventional dive panel.
- **Type 2** Bells in which the divers umbilicals terminate at a dedicated bell panel in the bell.

Procedures

Wet Bells may be used from any fixed platform or structure, semi-submersible vessel, DSV or support ship that is capable of supporting the Launch & Recovery System (L.A.R.S.).

The L.A.R.S.



In general, they may be used to replace all surface oriented diving techniques and the use of baskets.

Except in exceptional circumstances wet bells provide enhanced diver safety over baskets or surface oriented techniques.

In areas or on operations where the ACOP applies, Wet Bells may not be used at depths greater than 165 ft (50 metres).

IMCA International Code of Practice Offshore diving, wet bells can only be used to 75 msw. Divers must breathe Heliox and the bottom time is limited to 30 min.

Specifications, Requirements and Testing Construction

A Wet Bell must be constructed so as to comply with all existing legislation and recommendations. It must also be capable of containing, in safety and comfort, the required divers and equipment. In general, as it is not a pressure vessel, the construction requirements are the same as for a basket used for man riding.

Testing

Testing and certification is as for a man-riding basket. Various components of the handling system will require brake and load tests. MPI and inspections of critical welds will also be required.

Specifications and Equipment

Diving baskets and open bottom bells used in support of surface supplied diving should be able to carry at least two fully equipped divers in an un-cramped position. It should be designed to prevent the divers from falling out and to prevent spinning and tipping. The basket should be fitted with suitable overhead protection and handholds.

Auditing of Air Dive System

Auditing and assurance plays a crucial part of ensuring the safety and integrity of any diving system as well as ensuring efficient diving operations. Therefore it is essential that all diving systems are audited by a competent auditor, periodically or post mobilisation.

Auditing Of Air Diving Systems Is Covered By:

IMCA D 023 Diving Equipment Systems Inspection and Guidance Note – DESIGN for Surface oriented (Air) Diving Systems

Requirements

These must reflect the dive location and any guidelines or recommendations appertaining to the location.

Specific procedures must be produced for an individual vessel if diving from a wet bell is carried out while in a DP mode.

The basic requirements for this are contained in IMCA 10 “Diving Operations from vessels operating in Dynamically positioned mode.

Emergencies

Wet Bell emergencies will be varied. Procedures to cater for emergencies must be produced that are applicable to the individual work site/location and individual bell.

The procedures must cover, but not be limited to:

- Loss of gas supply to one or both divers.
- Loss of communications, lighting, hot water.
- Unconsciousness in one or both divers.
- Loss of main or guide wire winch power.
- Emergencies caused by outside agencies, e.g. supply boat or other vessel, objects falling over the side in the vicinity of the diving operation, fire, explosion or other emergency aboard the support vessel or rig.

Nitrox 7.1.4

A Brief History

What is Nitrox? Its real name is ‘Enriched Air’

It’s a mixture of compressed air and oxygen to make a breathing mixture higher than 21%.

It was introduced into the diving world in between the 1920-30’s by Draeger of Germany, who made an independent nitrox backpack for a standard diving suit.

In the 1950s the United States Navy (USN) documented enriched oxygen gas procedures for military use of what we today call nitrox, in the USN Diving Manual.

Since the early 1990’s, nitrox has been widely used in the commercial diving Industries.

Commercial Diving project Offshore – Diving at Work Regs 1997 ACOP:

The recommended maximum partial pressure for oxygen is 1.5bar atmosphere for surface- supplied diving equipment.

This should never be exceeded.

The accidents that have happened are because:-

- The wrong gas at the wrong depth.
- Failing to analyse the gas before use.

What is Nitrox

Nitrox is a mixture of air and oxygen. It is used to archive a percentage of oxygen higher than normal breathing air.

The air that we breathe has 21% oxygen and 79% nitrogen.

By adding the correct amount of oxygen to a cylinder, then a pre determined amount of air to fill the cylinder up, we can easily make the end gas mixture any percentage that we require.

Using an empty diving bottle/cylinder filling it with 32 bar of oxygen and then topping up with air to 230 bar will give you an oxygen percentage of 32% oxygen and 68% of nitrogen in it. A 32% / 68% Nitrox or enriched air is the only percentage we can blend by applying this simple formula. All other mixes will require reference to mixing tables that determine the percentage of oxygen that must be added to get the desired mix if partial pressure blending is being used.

Nitrox And Diving

Nitrox has certainly made air diving safer.

To calculate bottom times and pressure groups, Nitrox can be used three ways for diving:-

1. We have equivalent air depths.
2. We can dive on air tables but using nitrox.
3. We dive using nitrox on nitrox tables.

By using nitrox on air decompression tables, we are making the dive safer.

When using Nitrox diving techniques ensure that you follow your company procedures! This ensures that the correct (EAD) Equivalent Air Depth tables are being used and understood!!

Gas Analysis

Before we can even start diving, we have to make sure we have the correct gas mixture.

This has to be done at the quads, cylinders or low-pressure receiver if coming direct of a nitrox compressor.

If you have a quad all cylinders have to be checked!!

There are various different analysers on the market from hand held to panel mounted.

Potential Hazards

When diving on nitrox there is still the possibilities of getting Decompression Illness, the biggest problem is going beyond your depth as the Partial Pressure increases there is always the chance of oxygen toxicity poisoning.

This is the high percentage of oxygen effect the brain and results in a convulsion

While the diver is having a convulsion he must not be brought to the surface as they are not breathing, the chance of a Pneumothorax is high.

When the convulsion has finished bring the diver to the surface and place on oxygen (it's an impossibility to convulse on 100% oxygen at 1 bar) if need be start basic life support.

Signs & Symptoms

- **V**ision
- **E**ars
- **N**ausea
- **T**witching
- **I**rritability
- **D**izziness

Prior to Diving Operations

- You must always follow your companies guidelines.
- You must always analyses the divers breathing mixture & continuously monitor online Air to the diver.

- Your bail out must be the same as your breathing gas.
- You must never exceed a PO_2 of 1.5 bar.
- Your equipment must be oxygen clean.
- You must always know you maximum operating depth.
- You must always work out you equivalent air depth.
- All ways have the cylinder labelled with the correct mix and colour code.

Surface Decompression Procedures 7.1.5

During surface oriented diving operations when decompression is being carried out in the water, the diver (apart from being supported by his lifeline) should always be on a shot-rope, diving stage or wet bell. In order to carry out decompression safely, his maximum depth of dive and his depth at each stage of the decompression procedure must be known accurately. Decompression stops must be carried out with the diver at rest.

As an alternative to carrying out decompression in the water when air diving, the technique of surface decompression may be used.

The following conditions should be satisfied:

1. A compression chamber must be available with a working pressure equivalent to at least the maximum depth of dive.
2. The diver must be able to leave the last in-water stop, return to surface, enter the chamber and be re-pressurised without hindrance all within a period specified in the decompression schedule being used.
3. Sufficient trained personnel must be available to assist the diver from the water and into the surface compression chamber, and to control the chamber and the prescribed decompression schedule.
4. All personnel involved in the diving operation must be informed that surface decompression procedures will be used and be fully briefed as to their duties before the diver makes his initial Ascent.
5. All equipment, plant and gas supplies must be checked and found adequate for this type of decompression before diving takes place.
6. The divers ascent must be closely monitored and controlled. Both divers and supervisors must be aware of the importance of the correct ascent rate during surface decompression procedures.

During surface decompression the following procedure is to be followed and the chamber operator.

The Supervisor must ensure that:

- A stopwatch is used to time the decompression.
- All times are accurately recorded on the surface decompression chamber log.
- The divers undergoing decompression are on BIBS.
- The BIBS have an effective seal.
- The divers do not remove the mask to talk, eat or drink during the oxygen breathing cycles.
- The divers should adopt a lying position and do not adopt a cramped sitting position.
- The door dogs are unlatched when the chamber is under pressure.

AIR DECOMPRESSION CHAMBERS 7.2

Check Lists

It is the responsibility of the Supervisor to ensure that a detailed list of pre-dive checks is produced. Chambers will vary in their valve and fitting configurations so the following is a guide only.

Internal checks

Before The Dive, Ensure That:

- The internal lights are operational.
- The communications, both electrical and sound powered, if fitted, are operational.
- The scrubbers, if fitted, are operational.
- The number and operation of the BIBS is correct.

- That the BIBS are clean and disinfected.
- All O-rings in the doors, manways and medical locks are fitted correctly and are lubricated with silicone.
- The bilge is clean and dry.(At the start of the day).
- The valve checks have been completed.
- The viewports are clear of obstruction.

External Checks

Before The Dive, Ensure That:

- The valve checks have been completed.
- The supply hoses are in good condition.
- The main air supply is connected with the compressor running.
- The secondary HP air is on line and regulated.
- The oxygen supply quad is on line with the pressure regulated at the quad.
- There is sufficient oxygen to undertake a full DCI treatment table and the normal decompression.
- T stopwatch is at the control panel.
- The surface decompression chamber log is at the control panel.

Chamber Operations

- Take all precautions against fire.
- Provide fire extinguishers.
- Use fire retardant paint and materials in the chamber.
- Ventilate the chamber according to specified rates and gas mixtures.
- Ensure proper decompression of all personnel entering the chamber.
- Ensure that the chamber and its auxiliary equipment are in proper operating condition at all times.
- Ensure that all personnel are properly trained in the operation of the equipment and are able to do any job required in a possible treatment.
- Prepare the chamber for immediate re-use following use or a treatment.
- **Never** use oil on any oxygen fitting or equipment in oxygen service.
- **Never** allow gas supply tanks to be depleted or reach low capacity.
- **Never** allow damage to door seals and dogs. Use minimum force in "dogging down".
- **Never** leave doors dogged after pressurisation.
- **Never** allow open flames, matches, cigarette lighters to be carried into the chamber.
- **Never** permit electrical appliances to be used in the chamber.
- **Never** permit products into the chamber, which may contaminate or off-gas into the chamber atmosphere.

Items Forbidden in Air Decompression Chambers

The Following Items Are Not Permitted In The Decompression Chamber When Under Pressure:

- Matches / Lighter.
- Cigarettes / cigars.
- Aerosols.
- Petroleum based grease and fluids.
- All oils.
- Explosives.
- Glass, mercury or alcohol thermometers.
- Impact adhesives.
- Chemical / solvent cleaners.
- Alcohol.
- Batteries with unprotected leads.
- Drugs.
- Electrical equipment which may short circuit or cause an arc - no matter how small or insignificant.

- **Location**
- The deck chamber must be located so that the diver has easy access on leaving the water, and that the diver can be at the chamber decompression stop within the time stated in schedule used.

Chamber Emergencies 7.2.1

Although the chamber is considerably safer than the sea-bed it is still a potentially dangerous place. There have been several fatalities and numerous near misses in incidents, some of which were the result of surface error but others were caused by, or aggravated by, the divers' lack of knowledge of the inside of the chamber.

It is imperative that before blowdown the chamber is prepared and equipped to cope with any emergency and although it is difficult to control this readiness once the chamber is under pressure, it must be emphasised to the divers that any alteration of valve positions or unplugging of BIBS etc. may endanger their security. All divers entering the system must be aware of the internal layout and of emergency procedures.

Unbreathable Atmosphere 7.2.2

The atmosphere may become unbreathable due to either contamination by a toxic gas or by the reduction of the pO_2 to hypoxic levels.

If possible, evacuate the chamber and isolate it. In any case go onto BIBS, which should always be in a state of readiness. Keep the divers informed of your actions.

Do not underestimate the effects of toxic or hypoxic atmospheres. Divers must stay on BIBS until the atmosphere is breathable. There should be enough gas on board to keep all the divers in the chamber supplied on BIBS for a minimum of four hours (AODC recommendations). In practice there will probably be considerably more.

Once they are on BIBS and isolated then the subsequent actions will be determined by the seriousness of the situation. On no account must the divers be allowed to re-enter the contaminated chamber until it is absolutely certain that the environment is safe.

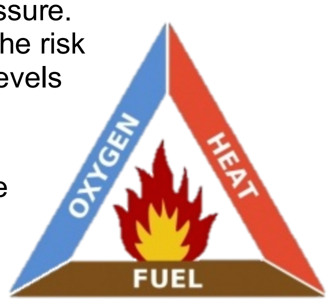
Fire 7.2.3

Before a fire can start there must be sufficient oxygen, a combustible material and a source of ignition.

Oxygen

In some cases the chamber atmosphere is unable to support combustion. As the depth is increased the oxygen concentration is reduced in order to maintain a constant oxygen partial pressure.
An oxygen concentration of 8% or less is not sufficient to support combustion and the risk of fire is negligible. Although there is some risk, fire remains unlikely until oxygen levels approach 20%.

Above 20% the risk increases considerably and at no time should the chamber atmosphere oxygen level be allowed to exceed 25%. The diagram below shows the three zones of combustion as a consequence of oxygen percentage and depth.



Fuel

Great care should be exercised in the selection of material to be used in or allowed into the chamber system. The chamber paint-work should be fire resistant as should all loose coverings, e.g. bedding and curtains. Large amounts of newspapers and books should not be allowed to accumulate within the chamber.

Heat

Heat or a source of ignition is restricted to the electrical supply or perhaps a static discharge. Consequently there is strict regulation on electrical supplies to chambers and to the design and security of all internal wiring and fittings.
In general, the fire risk in the chamber is very low, however the consequence of fire is extremely serious and precautions to minimise the risk must be taken. In addition all surface and dive personnel must be conversant with the procedures to be taken in the event of fire.

Fire Within a Chamber 7.2.4

A fire occurring due to high oxygen levels would be a flash fire, which almost constitutes an explosion. There have been a number of fatalities in air-filled chambers.

If a normal fire occurs, the divers should evacuate the chamber, close the door and go on to BIBS. The greatest danger may come from toxic fumes. They should then inform surface who will vent the burning chamber. As the pO_2 drops, the fire will go out.

If the cause is a smouldering electrical fire then obviously the initial action by the surface crew would be to shut off the electrical supply. The divers, on BIBS, may then extinguish the fire and then evacuate to another chamber to allow an assessment to be made as to the subsequent remedial action.

If it is impossible to evacuate the chamber, the divers should go on to BIBS and use the available fire-fighting equipment.

Hyperbaric Fire Extinguisher

Fire in Outside Chamber 7.2.5

In the event of this type of fire occurring, the following steps may be taken to regain control:-

- Life Support personnel to don breathing apparatus.
- Isolate all oxygen and electrical supplies but maintain chamber communication.
- Inform the Diving Superintendent and Dive Control of the situation.
- Inform divers in the chamber and, if necessary, put divers on BIBS.
- Attempt to extinguish the fire with locally sited appliances until help arrives.
- Keep an eye on the chamber depth.
- Keep chambers cool by hosing down with cold water paying particular attention to O_2 and gas lines.
- Prepare to transfer divers into the HRV or consider an Accelerated Emergency Decompression as discussed in DMAC 31.

Fire Safety 7.2.6

Fire, while a major hazard to the diver, is one of the hazards most amenable to minimisation or elimination. Three conditions must exist at the same time and in the same place for a fire to occur. These are combustible materials, oxygen and a source of ignition.

By eliminating or separating any one of those items from the other two it becomes impossible for a fire to occur. While it is often difficult to accomplish either of those tasks, it is up to the chamber/diving system designer to do as much as possible to keep the unit inherently safe. Beyond that the responsibility rests with the Supervisor and the divers themselves to ensure that all possible precautions are taken.

Precautions:-

"No Smoking"

Open flames or burning materials are never to be allowed inside the chamber. On all occasions, including when the chamber is open to the atmosphere, all matches, lighters, cigarettes, tobacco, pipes etc. should be left outside the chamber. By building this habit it is less likely that someone may inadvertently take such items into the chamber when it is about to be pressurised.

Constant Watch

At all times when the chamber environment is capable of supporting combustion, a constant watch over the chamber interior should be maintained. During periods when the divers are awake they should be alert to any signs of a developing fire and avoid creating conditions conducive to the start of or rapid growth of a fire. During those periods when the divers are asleep or concentrating on other activities, the Supervisor must maintain a closer watch on the chamber. Ideally, and now required under Norwegian regulations, he will have devices to assist him in this matter.

Training

The divers should know how to operate the extinguishing systems provided in each chamber as well as the types of fires they are suitable for dealing with. In addition they should practise the company's emergency procedures periodically to ensure a rapid and proper response to the situation. Similarly, the Life Support personnel involved in the operation of the chamber should know and practice the correct response to this type of situation.

Prevention

As mentioned in the general section, separation or elimination of one of the three elements necessary to a fire's existence will prevent it. It is possible to build and equip a system in which the only item that could burn is the diver, but such a system would be excessively expensive and rather lacking in creature comforts. Therefore this section shall concentrate on minimising the possibility and risk of fire.

Both prior to and following any dive, the diver or Supervisor checking the chambers should examine the condition of all internal wiring for wear and damage.

Any electrically driven motors should be checked for ease of operation and that nothing can interfere and cause the rotor to lock.

Rules

The following rules, if carefully followed, will do much to prevent a fire from occurring or limit the spread of the fire.

- Maintain the oxygen concentration/partial pressure as low as possible, preferably within the region of non-combustion. The oxygen percentage must never exceed 25%.
- Use an overboard dump system when oxygen or high pO_2 mixtures are breathed by mask.
- Eliminate ignition sources.
- Use combustible materials as sparingly as possible, excluding completely flammable liquids, powders and gases.
- If combustible materials must be used, the type, quantity and arrangement in the chamber must be carefully controlled.
- Fire-walls and other containment techniques should be used to isolate potential high-risk fire zones.

Detection

Because of the speed of fire development in oxygen-enriched atmospheres and the resultant extreme hazard to personnel, detection equipment capable of activating fire extinguishing systems or other emergency action should be used. The detection system should be capable of volume surveillance and be able to detect incipient combustion as well as flame.

Summarising briefly, the detectors rely on temperature rise, radiation emission, or combustion products of the flame process for activation, but certain of these detectors, such as the overheat or rate-of-temperature rise detectors are not acceptable for oxygen-enriched environments because of their slow response time and limited volume coverage. In addition, smoke detectors using low-level radiation are not suitable as increased density of the hyperbaric environment affects their operation.

Extinguishing

Fire can be extinguished by physical action, chemical action, or a combination of both. The table below provides a comparative summary of the types.

Fire Extinguishing Agents for Oxygen Enriched Atmospheres

Agent	Mode of Action	Personnel	Use In O_2-Fires	Mode of Action
Water	1,2,5	Excellent	Good	Quenching (cooling).
Foam	1,3.5	Good	Unknown	Inerting (oxygen dilution).
Dry powder (NaHCO$_3$, ABC)	3,4,5	Good	Unknown	Blanketing.
CO_2	1,2	Fair	Poor	Chemical inhibition
N_2	2	Poor (Anoxia)	Poor	Radiation shielding

* May decompose in heat to yield toxic products.

Water

At present, due to safety considerations, the best extinguishing agent for use in hyperbaric chambers is water. Water extinguishing operates primarily by cooling. It works best if it strikes the flame or wets the fire, but wetting most substances will retard or prevent their burning, even oxygen. Simultaneously with discharge of water, all electrical power within the chamber must be switched off to prevent shorting and electrical shocks to personnel within the chamber.

Foam

High-expansion foam has been shown to be an effective means of extinguishing fires that have been allowed to build up to their full intensity. However, little is yet known about the harm the foam or its pyrolysis products can do to the human body, especially under a high partial pressure.

Gas Dilution

Agents such as nitrogen and carbon dioxide depend primarily on the dilution of the oxygen content to a level, which will no longer support combustion. In the absence of a special breathing system to protect against carbon dioxide toxicity, carbon dioxide extinguishing cannot safely be employed in a hyperbaric chamber. In an attempt to replace carbon dioxide as a gaseous fire-quenching agent, both nitrogen and helium have been considered and tested.

Dry Powders

Although dry chemical agents should provide rapid suppression of flame and excellent radiation shielding when initially discharged, the permanency of the fire extinguishing is doubtful. It should be noted that dry chemicals are not suitable for vertical or overhead surface use, thereby limiting their use to spot suppression of fires in the lower half of the chamber.

Hyperbaric Fire Extinguisher

Material Prohibited in the Chamber 7.2.7

The following items comprise a reasonably comprehensive listing of items and materials that should not be allowed into the chamber. The letter(s) following each item indicates the general reason for prohibiting it, (the coding is shown below):-

Listings

- Adhesives (F)
- Aerosols (D,E,F)
- Aftershave (D,F)
- Alcohol (D,F,P)
- Batteries with unprotected leads (F)
- Chemical cleaner, e.g. trichloroethylene, 'Freon' (D)
- Cigarettes, cigars, tobacco of all kinds (F, M)
- Cleansing powder (C,F,P)
- Drugs (not on permitted drugs list) (P)
- Electrical equipment (F)
  - (Some electrical instruments run on battery (<6V) and are allowable.)
- Explosives (E)
- Glass thermometers (C,D,P)
- Lighters (F)
- Matches (F)
- Non-diving watches (L,M)
- Petroleum based lubricants, greases, fluids (F)
- Thermos flasks (L,P)
- Non-fireproof bedding (blankets, sheets, pillows, mattresses) (F)
- Excessive newspapers & books (F)

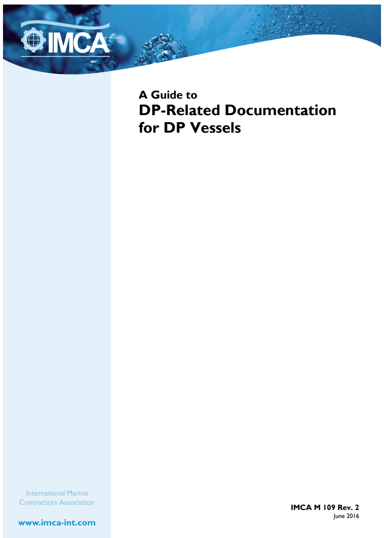
Code	Reason
C	Possibility of damaging the chamber.
D	Contamination of the environment.
E	Explosion risk.
F	Fire source or a combustible substance.
L	Could be damaged by pressure.
M	Will possibly cause a mess.
P	Affects ability of diver.

Section 8
Dynamic Positioning

DIVING FROM D.P. VESSELS 8.1

In May 2008 IMCA produced **IMCA DO10**. This covers the standard operating procedure for diving from a vessel that has a DP system.

There have been some serious injuries and a fatality with divers going into or to close the thrusters.


IMCA

A Guide to
DP-Related Documentation
for DP Vessels

International Marine Contractors Association
www.imca-int.com

IMCA M 109 Rev. 2
June 2016

Fixed Diving Supports 8.1.1

Obviously, diving from a fixed platform provides a very stable and safe base for diving operations. Unfortunately most fixed installations combine the disadvantages of not having much space available, having limited or intermittent requirements for diving services, and often having an oil inventory on board which represents a hazard to a diving operation.

Mobile But Anchored Diving Barges / Vessels 8.1.2

They do have their own disadvantages.

The problems with anchors and chains or cables are numerous. They require another vessel to help run them. They require calm weather for deployment and can only be laid in areas where there are no subsea structures, like other wellheads and pipelines, because of the risk of damage. During pipelay, vessels using anchors are very slow. They have to have anchor handling tugs standing by to re-position anchors as the vessel moves along laying pipe.

A system of positioning has been developed that relies on various types of sensors that enable the vessels thrusters to react to movement and to keep the vessel in a particular set position.

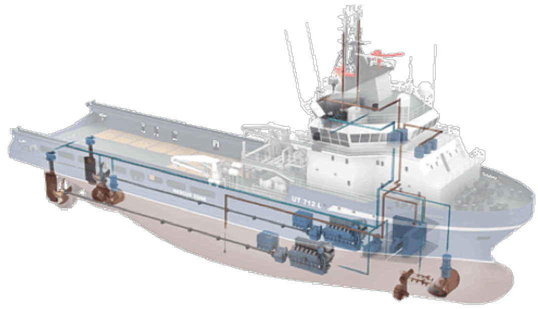
By necessity this is a complicated subject. Below is an outline of dynamic positioning and how it works.

DYNAMIC POSITIONING 8.2

Dynamic positioning can be simply defined as a vessel's ability to maintain heading and position by means of thrusters and propellers to counteract the effects of displacing forces such as wind, current and wave action. It is a system whereby deviations, caused by these displacing forces, from the set heading and position are measured and are counteracted by vectors and turning moments produced by thruster activity.

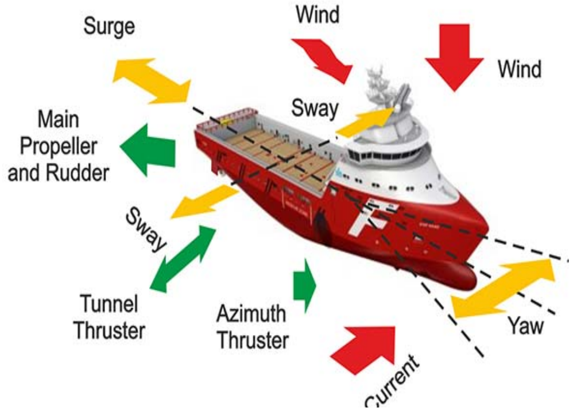
A vessel is said to have six types of freedom of movement.

D.P. Vessel



Three are linear and three are rotational:

- Linear along the longitudinal axis: **Surge**
- Rotational about the longitudinal axis: **Roll**
- Linear along the athwart-ships axis: **Sway**
- Rotational about the athwart-ships axis: **Pitch**
- Linear along the vertical axis: **Heave**
- Rotational about the vertical axis: **Yaw**



DP systems control 3 of the 6 types of freedom: -

Surge, Sway and Jaw.

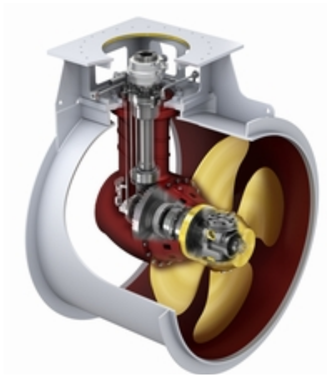
No attempt is made to control pitch, roll or heave although these must be measured and accounted for when controlling surge, sway and yaw.

Thrusters 8.2.1

The thrusters should be located and operated to minimise potential interference of the wash with other thrusters, sensor systems, diving system and divers.

The thrusters should be sited to achieve fore and aft, athwart ships and rotational thrust and so configured that the loss of any one thruster leaves sufficient thrust in each direction to ensure the vessel holds position and heading when operating within its forecast operational capability.

D.P. Thruster



In the event of pitch, azimuth or motor speed control malfunction, or when control error becomes unacceptable, the function controlled may remain the same as it was at the time of failure, or the pitch may be automatically set to zero or the thruster automatically stopped and de-selected.

Under no circumstances should thruster assume maximum thrust condition on failure.

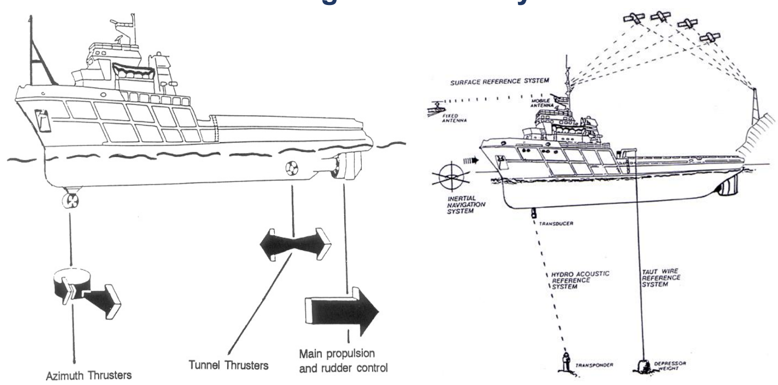
Means should be available whereby any thruster may be stopped from any DP control without using the DP computer to generate the command.

The D.P. Vessel 8.2.2

In order to give the thrusters the instructions that will permit to maintain the ship on location, precise information is needed regarding her exact position.

This information is collected and monitored by an array of devices known as the Position Reference Systems.

Positioning Reference System



Position Reference Systems 8.2.3

As one single set of reference signal from one single Position Reference system could be erroneous.

It is required that all times at least three independent Position Reference Systems be on- line, and at **least**

two should be of a different type.

Artemis

Microwave tracking between a FIXED and MOBILE STATION above sea-level.

The mobile station is on the moving vessel and the fix at some fixed reference point, e.g. a platform. Position fixing is achieved by accurate range and bearing measurements.

Disadvantages are:

- Requires an unobstructed line-of-sight. Interposing vessels or platforms can cause blanking of signal.
- Remote beacons are vulnerable to unauthorised manual interference.
- Minimum cut off distances of from 15-50 metres.
- Loss of signal due to vertical cut off.
- Interference from 3cm radar (Fishing boats).

HPR

Hydro-acoustic Position Reference (HPR) System consists of a transponder positioned on the seabed which transmits a reply pulse when interrogated by a request pulse from a transducer (hydrophone) mounted below the vessel. These come in a variety of configurations : Narrow beam, Wide beam, Fixed head, tracking head and HIPAP.

Disadvantages Are:

- A VRU (Vertical Reference Unit) is required.
- Sea-water is not a perfect transmission medium. Signals suffer from interference from underwater noise. Signals become blocked due to aeration (air bubbles). Signals get reflected from sea-bed and underwater obstructions such as platform structures.

Advantages Are:

- The beacon or transponder can be left in situ to provide means of relocation when vessel returns to site.
- High degree of accuracy, 1 to 2% of water depth.
- Independent of shore of fixed platform.

Vertical Taut Wire

Vertical & moon-pool taut wires are under constant tension and connected to a depressor weight on

the sea-bed. The horizontal displacement of the vessel from the sea-bed reference point is measured in two planes by inclinometers mounted on the davit head. Taut wire systems should provide position information accurate to within +/- 2% of water depth.

Disadvantages Are:

- Mechanical limitation of the maximum angle at which the taut wire can operate is in theory 30 degrees from the vertical. This gives a horizontal range of about 60% of water depth however in practice this is incorrect as the hull of the ship often places greater limitations
- Subject to fouling by down lines or divers.
- Standard winch equipment limits maximum operating depth to about 300 msw.

Advantages Are:

- Reliable and rugged.
- Simple to deploy and recover.
- The inclinometers measure the wire angle relative to gravity and therefore no pitch and roll compensation is required (no VRU).

Surface Taut Wire

Instead of utilising a weight placed on the seabed to keep the wire taut, the surface system is based on attaching the wire to a fixed point above the sea surface and then tensioning it. By retaining a constant tension, (via a voltage reading) the DP system will adjust accordingly to keep the vessel in position.

DGPS (Differential Global Positioning)

DGPS works by obtaining fixes from at least 4 satellites to obtain a position, however these satellites contain an in-built error. To reduce the error the vessel receives corrections from land based radio stations which by the virtue of knowing their position exactly and compared with the satellites are able to calculate the satellite errors.

These corrections are transmitted to the vessel either by HF radio or by a satellite.

Laser Radar Systems (Fan Beams)

This type is a high accuracy system with a working range of more than 2km (weather dependant). The system requires only simple reflector devices to be installed on a fixed installation such as a drilling rig. The system consists of a laser unit mounted on the vessel and controlled via a PC.

Disadvantages:

- The signal relies on an uninterrupted line of sight.
- Any vessel on rain, fog, etc. interrupting the signal will cause this system to foil.

Other Sensors

A number of other information such as wind speed/direction, heading, vertical reference system, pitch and roll are also fed into the DP computer as these factors do influence the position keeping capability of the DSV.

DP Vessels Management 8.2.4

Loss of position during a dive can have catastrophic consequences. Consequently DP systems are being classed as per their potential ability to loose position, or not, when a malfunction occurs.

Class One

Failure of a simple component can cause a loss of position. Class one is **not suitable** for diving activity.

Class Two

Single failure of any **active component** shall not cause loss of position. Class two is **suitable** for diving activity.

Class Three

Single point failure of any **active** or **passive component**, including fire and flooding in any compartment shall not cause loss of position. Class three is **suitable** for diving activity.

Note:

- **Active components** are items such as; pumps, thrusters, generators, etc.
- **Passive components** are items such as; pipes.

DP Performance Assurance

Obviously there are many interacting components at work on DP vessel at any one time. In order to identify the components whose failure may cause other failures ultimately leading to a loss of position, it is necessary to perform a special risk analysis.

Failure Mode and Effects Analysis (FMEA) 8.2.5

This analysis describes the system, sub systems and components and identifies the failure modes of each of these components and predicts the effects of these failures both at local level and at global level on the DP system and thus the vessels station keeping ability. The FMEA is verified by providing trials to establish the accuracy of the study. After the proving trials the FMEA is updated accordingly. Subsequent changes to any system are normally assessed in the same way and the FMEA revised accordingly.

A key objective of an FMEA is to ensure that there are no failures, which can result in unexpected loss of position, and if any are present that it is identified by alarm or other warning in order that the DP operator can take corrective action.

It is important in a fully redundancy system to ensure redundancy is maintained on all components, i.e. a pair of pumps which supply a critical system should be powered from separate switchboard, or in lower class vessel from separate cells within the same switchboard.

Industry Control

Beside the official regulatory and legislative bodies such as the HSE, the industry itself is organised so as to regulate itself through a system of self imposed guidance's and codes.

The main offshore industry Trade Association is currently the IMCA (International Marine Contractors Association).

The main divisions are:

- Diving, Marine, ROV and Survey.
  - The IMCA itself has absorbed the AODC (Association of Offshore Diving Contractors) from which it was born.
  - The Marine Division of IMCA has absorbed the previous DPVOA (Dynamic Positioning Vessel Owners Association).
  - Current guidance on DP diving support vessel is shared between the:
- Marine Division
  - Defining the mechanical and electric requirements.
- Diving Division
  - Whose guidance note **IMCA D010** "Diving Operation from Vessels Operating in Dynamically Positioned Mode" defines more the procedural aspects of diving from a DP vessel.

Interfaces between DP Vessel and Diving 8.2.6

Communications

Communications between Dive Control and the Bridge DP control are paramount. There must be privileged communication systems and they must be used extensively to update each other regarding the various phases of the diving operations, and the performance of the DP vessel, including deterioration of performance, levels of alert etc.

These systems must be provided with 100% redundancy, including being supplied from UPS (Uninterruptible Power Supply) and battery back up.

Display Of International Lights And Shapes

All vessels engaged in dredging or underwater operations, when restricted in ability to manoeuvre, should exhibit lights and shapes as follows:

- Three all-round lights in a vertical line. The highest and lowest of these lights should be red and the middle line should be white.
- Three shapes in a vertical line. The highest and lowest of these shapes should be balls and the middle one diamond. The shapes should be coloured black.

Minimum Number Of Independent Position Reference Systems Required For Diving

All DP systems for diving vessels are designed so that no single fault should cause a catastrophic failure. This principle immediately introduces the concept of 100% redundancy. This includes computers, generators, thrusters, position sensors and position reference systems.   It is recommended that **at least three** independent position reference systems be available.

These need not all work on different principles, but if similar systems are to be considered to be independent, they should not be subject to a common mode failure. When conducting DP diving operations at least two independent systems should be deployed and on-line. If the third system is not on-line then it should be available for immediate use as a back-up.

It should be noted however that in some cases four systems may be required. The choice of which reference system to use in priority will be dictated by the circumstances.

Bearing In Mind That:

- HPR can be affected by noise.

- DGPS signal will be lost if a platform blocks the line of sight.
- Taut wire may be caught and dragged by a large packaged lowered by crane such as a spool piece.
- Artemis, or fan beam also require a line of sight.

Shallow water diving will have its own set of requirement regarding DP reference systems.

Vessel Movement Limitations During A Dive

A diving support vessel under stable DP control may execute changes to a previously agreed position or heading without recalling the divers to the deployment device, provided all relevant personnel have been advised, and that the DP operator and the diving supervisor are both satisfied with the following criteria:

- The move can be executed safely.
- Umbilicals and other diving related work lines are clear and will remain so during the move.
- Divers understand the move and are not endangered by it.
- Divers can easily reach the deployment device.
- Three position references will be on-line throughout the move.
- The move is executed at low speed.
- Change of heading and position are not carried out simultaneously.
- Maximum single vessel movement: 5 degrees and 10 metre movement.
- The move can be stopped **at any time.**
- The move will not exceed the scope of any one of three position references
- The move will be stopped if one position reference has to be repositioned and this results in only two position reference systems being on-line.
- The DP operator will verify the move input before execution.
- Due account has been taken of the selected centre of rotation when heading is to be changed.

If the DP operator has any doubts about the safety of the move, he should instruct the diving supervisor to recall the divers to the deployment device and stop the move to reassess the safety of proceeding.

DP Alert System 8.2.7

The status of a DP Diving Operation will always correspond to one of the following:

- Everything is working fine as should be.
- Or deterioration of some parameter giving a cause for concern.
- Or degradation leading to loss of position.

In order to convey this situation, to the various diving departments a system of lights is provided in dive control, saturation control, air diving control, working area and, where applicable, the ROV or submersible control position, manually activated from, and repeated in, the DP control room.

- **Steady green light:** to indicate vessel under automatic DP control, normal operational status and confirming the Alert System functional.
- **Flashing yellow light:** to indicate degraded DP operating alert
- **Flashing red light:** to indicate DP emergency.

A distinctive alarm should sound in the saturation control room, air diving control area, ECR, the Master's cabin, Operations Superintendent's cabin (if applicable) and the senior Diving Supervisor's cabin in conjunction with the flashing red light. Provision of a means of cancelling the audio function of the signals from the receiving positions when they have been noted should be made.

Normal Operational Status (Green light)

The vessel can be defined as in "normal operation status" and all the following conditions apply:

- Vessel under DP control and DP system operating normally with appropriate backup systems available.
- Thruster outputs and total power consumption is equal to or less than the maximum thrust and power that would be available after the worst single failure.
- Vessel's indicated position and heading is within predetermined limits and the worst single failure would not result in safe working limits being exceeded.
- No risk of collision exists.

Degraded Operational Status (Yellow Alert)

The vessel can be defined as being in a degraded operational status when any of the following conditions applies:

- A failure in a sub-system, leaving the DP system in an operational state (possibly after reconfiguration) but with no suitable backup available, so that an additional fault could result in DP system breakdown and Emergency Status.
- Available power units are reduced to the extent that failure of one more could prevent the vessel holding position or heading in existing or forecast conditions.
- Available thrust units are reduced to the extent that failure of one more could prevent the vessel holding position or heading in the existing conditions.
- Vessel's position keeping performance is unstable.
- Vessel's indicated position deviates beyond pre-determined limits more than once over a period of 5 minutes.
- Risk of collision exists.
- Weather conditions are judged to be becoming unsuitable for DP diving.
- Any other condition or circumstances effecting the operation of the vessel which could reduce the status from "normal".

Emergency Status (Red Alert)

A vessel can be defined as in "Emergency Status" if either of the following conditions apply:

- System failure results in an inability to maintain positioning or heading control.
- Any external condition exists, including imminent collision.

▪ Responses to DP Alerts

- **Green** – normal operational status Full DP diving operations can be undertaken.
- **Yellow** – degraded operation status

(Where a yellow alert is signalled by a flashing light and an audio alarm, the audio component in dive control should be capable of cancellation)

The diving supervisor will instruct the divers to suspend operations and, where practical in terms of speed and safety, make safe any work or items of equipment that could offer a further hazard before moving to an agreed safe location.

After consulting with the DP Operator, the diving supervisor will decide on the next course of action. This may involve the divers returning to the deployment device and preparing to return to the surface, or returning to the worksite and resuming work.

If the DP Operator is unable to provide clear advice, the diving supervisor shall instruct the divers to return to the deployment device and/or prepare to return to the surface as appropriate.

The diver's safety is paramount. If there is any doubt about the appropriate course of action, the DP Operator and diving supervisor shall both act to provide the greatest protection for the divers.

- **Red** – emergency status

The diving supervisor must instruct the divers to return immediately to the deployment device and/or prepare to return to the surface closing the inner hatch and getting a seal in the case of a diving bell. After considering any potential hazards, e.g. fouling of adjacent anchor wires, jacket members, etc., the deployment device and/or the divers should be recovered as soon as possible.

The DP Operator must use all available means to limit vessel-position loss during the recovery of the divers.

DP and Divers' Umbilicals Safety

It is obvious that propellers and thrusters remotely operated through a computer responding automatically to the signals of a set of reference systems will start operating at any time, regardless if divers or their umbilicals happen to be in close vicinity.

If this happens, divers or their umbilicals can be blown down by the wash or current created and are likely to come in contact with these moving machinery, with obvious fatal consequences.

Umbilical Safety Principle

In order to avoid the possibility of accident as described above, the following principle has been defined and adopted by the industry:

"The length of any diver's excursion umbilical has to be shorter than the distance:

- Between the point of deployment or tending (surface dive station, basket, wet bell or bell)
- And the nearest thruster or propeller"

In practice the divers umbilical is kept 5 metres shorter and the standby diver or the bell man's umbilical 3 metres shorter than that distance.

The above principle is absolute and no derogation can be permitted nor granted by anyone.

However, if the circumstances permit, "the nearest thruster" could be deselected and locked out by the DP Operator, providing of course this does not affect the DP status. In such a case, the next "nearest thruster" becomes "the nearest one".

Safe Umbilical Length Calculation

This "safe length" can be calculated as follows:

a = depth of deployment device minus the draft of the vessel

b = horizontal distance between the wire of the deployment system and the nearest thruster

c = the maximum length of umbilical

Formulae : $a^2 + b^2 = c^2$

Example:

a = 35m

Draft = 5m

b = 20m

What will be the length of C?

$c = \sqrt{(a^2 + b^2)}$

$= \sqrt{35^2 + 20^2}$

= 40.31

less 5m for the diver and the 3m for bellman.

= 35m for the diver's umbilical.

= 37m for the bellman's umbilical.

Charts Of Safe Umbilical Lengths

In order to avoid the possibility of error in the above calculation, most companies provide charts of safe length of umbilicals for each of their DSV, and each of their diver deployment device, for every 5 or 10 metres of depth such as the one overleaf.

Extension Of Umbilical Reach

If the job requires a greater length of umbilical than the one that can be safely deployed, it is sometimes possible to use the "golden gate" principle.

This consists of deploying a structure such as a large ring or a dive basket some distance between the deployment device and the job. This can be done for example with the use of a crane.

The diver will then exit his deployment device, swim towards and through the "golden gate" and proceed to the worksite. In such a case, the safe length of umbilical that can be deployed will have to be calculated from the golden gate ie, the maximum length of umbilical that can be safely deployed will have to be equal to the distances between the golden gate and the nearest thruster minus 5 metres.

DP Diving Over Submerged Structures

This type of situation, such as when diving on a submerged wellhead can present two sorts of hazards:

- Lack of a visual reference at the surface, and,
- Possibility for the basket, wet bell or bell to collide with the submerged structure if the DP vessel suffers a malfunction.

The structure location should be recorded in the operational plot, and if necessary a couple of transponders could be installed by the divers in order to give the DP Operator a reliable electronic reference indication as to the vessel exact position.

If at all possible, it is advisable to keep the divers deployment device, basket, wet bell or bell at a level above the highest point of the submerged underwater structure.

Shallow Water DP Diving Operations

Shallow water operation will adversely affect a DP vessel in a number of ways. These have to be reviewed in detail as part of the Risk Assessment for the operation.

Vessel Draught

Beside the obvious risk of hitting the seabed, the less water there is under the keel or under the lowest thruster, the greater the problems:

- Thrusters will blow silt from the seabed that will affect the visibilty.
- Due to their closeness, the noise from the thrusters will interfere with:
  - HRP operation.
  - Divers communication.
- The close proximity of the thrusters may severely limit the length of umbilicals.
- There may be little room under the keel to deploy the bell, wet bell or basket out of the moon pool.

Vessel Capability

Similar sea states affect the DP vessel more over shallow water and require more power to maintain location.

Environmental Conditions

Shallow water renders diving operations more sensitive to weather than those in deeper water. Furthermore, shallow water regions are often associated with strong, rapidly changing currents that can affect both diving operations and vessel station keeping capability.

Position Reference Systems

Seabed based reference systems such as taut wire or HPR send a signal which is read by the DP system. The vessel is “allowed” a certain amount of position fluctuation, before the signal is lost. The shallower the water, the less leeway is allowed to the ship before she looses the signal.

So for shallow water operations non-seabed reference systems must be preferred, such as Artemis, Fan Beams or DGPS.

For shallow water diving operations there should be a minimum of three position reference system on line and a minimum of one must be a radio or surface position reference.

DP Malfunction 8.2.8

Despite all the care and attention that goes into designing, building, testing, risk assessing, maintaining and training DPO’s and into operating DP vessels, malfunctions can and do happen.

Malfunction Effects On The Ship

These can be broadly classified under three categories:

- **Slippage:** With all systems apparently functioning and no reported failure or malfunction, the vessel is “slipping” position, that is she may be drifting slowly of her own accord.
- **Drive Off:** At some point, the computer erroneously convinces itself that the ship is at a wrong location and musters all the power of the thrusters to return the ship to another location. This results in the vessel suddenly powering away in a given direction.

Drift Off: The vessel loses all or part of the power going to the thrusters and she drifts off under the influence of environmental forces, wind, waves, currents. In the worst possible case the malfunction may cause a total loss of power onboard, also known as "blackship".

DP Malfunction And The Divers:

Slippage: It is often the diver himself who reports that the vessel appears to be shifting position slowly.

Drift Off, or Drive Off:

The speed of the move is greater, (far greater in case of drive off) and the risks are:

- The deployment device (basket, wet bell or bell) colliding with underwater obstruction, in the worst case becoming trapped and disconnected from the mother ship as the lift wire breaks off
- The diver(s) themselves being dragged by their umbilical through and against obstructions, risking serious injuries.
- The divers umbilical themselves becoming snagged and parting.

DP Malfunctions. Diver's Mitigation

In order to minimise the consequences of a DP vessel malfunction, there are certain precautions that can be taken:

- In case of submerged installation, keeping the diver deployment device above the highest point of the under-water structure, or positioning the vessel downwind / down current from the under-water structure.
- In all cases, divers to keep their umbilical religiously tidy, as straight and as clear back to the deployment device as possible. The diver's obsession has to be: "if the vessel takes off now is my umbilical clear enough to allow me to be dragged clear of the obstructions unarmed?"

▪ **DP Malfunction / Diving Alongside A Platform**

▪ In case of "drive off" or "drift off" while the vessel is alongside a platform, there may be contact wit the platform:

- No contact, we are in the situation described above.
- Contact with the platform, paradoxically that may be a good thing as:
  - The platform will stop the unwanted move, and normally with limited damage as the DSV had no time to gather speed and momentum.
  - Similarly, while there may have been "contact" between the deployment device and the platform, it is highly unlikely that the main wire will have been ruptured.

DP Malfunction/ Diving Vessel Inside Or Near An "Anchor Pattern"

What is referred to as an "anchor pattern" is usually a floating object (ship, drilling rig, floatel, SBM or SPM buoy, FPSO etc). Kept in position by an array of anchors whose lines, chains or wires, will radiate from it. These anchor lines will be connected to the object at or close to the surface, and will extend toward the seabed, each according to its own curve or "catenary".

The exact **position** and catenary of each of these anchor lines may be indicated on purposely issued blue prints, but nothing at the surface will materialise them.

Anchor Pattern DP Malfunction – Effect On Divers

A DSV at work will normally have a diver deployment device (basket, wet bell, bell) suspended underneath by its wire.

If the DSV suffers a "drift off" or "drive off" malfunction and her path crosses that of a submerged anchor line, these two lines (anchor line and deployment device lift wire) will come into contact.

As the DSV moves on, the deployment device will be lifted until it comes in direct contact with the anchor wire.

At this stage, it is very likely that the lift wire (certainly incapable of stopping a drifting DSV) will part and the diver deployment device will fall to the seabed.

The potential fate of the divers at this stage would be very speculative, but there is no doubt that such a situation would be dire.

DP Malfunction In An Anchor Pattern – Divers Mitigation

- DP “slippages” are usually of no consequences to diver or DSV’s
- DP “drive off’s” could result in contact with near-by platforms, but are usually controlled by the DP operators switching over to manual control or “joy stick”.
- DP “drift offs” due to partial or total loss of power (blackship situation) while a diving deployment device is suspended from her would be of no serious consequence as long as the DSV path does not cross that of a submerged anchor line.

Safety Principle When DP Diving In Or Near An Anchor Pattern

The Risk Assessment that must be undertaken before such type of operation will have to take into account the possibility of the vessel losing power.

Accordingly, DP DSV should only deploy divers in or near an Anchor Pattern situation, providing the environmental forces of wind, sea state and current would combine to push her away from the path of any anchor line if she was to suffer a loss of power.

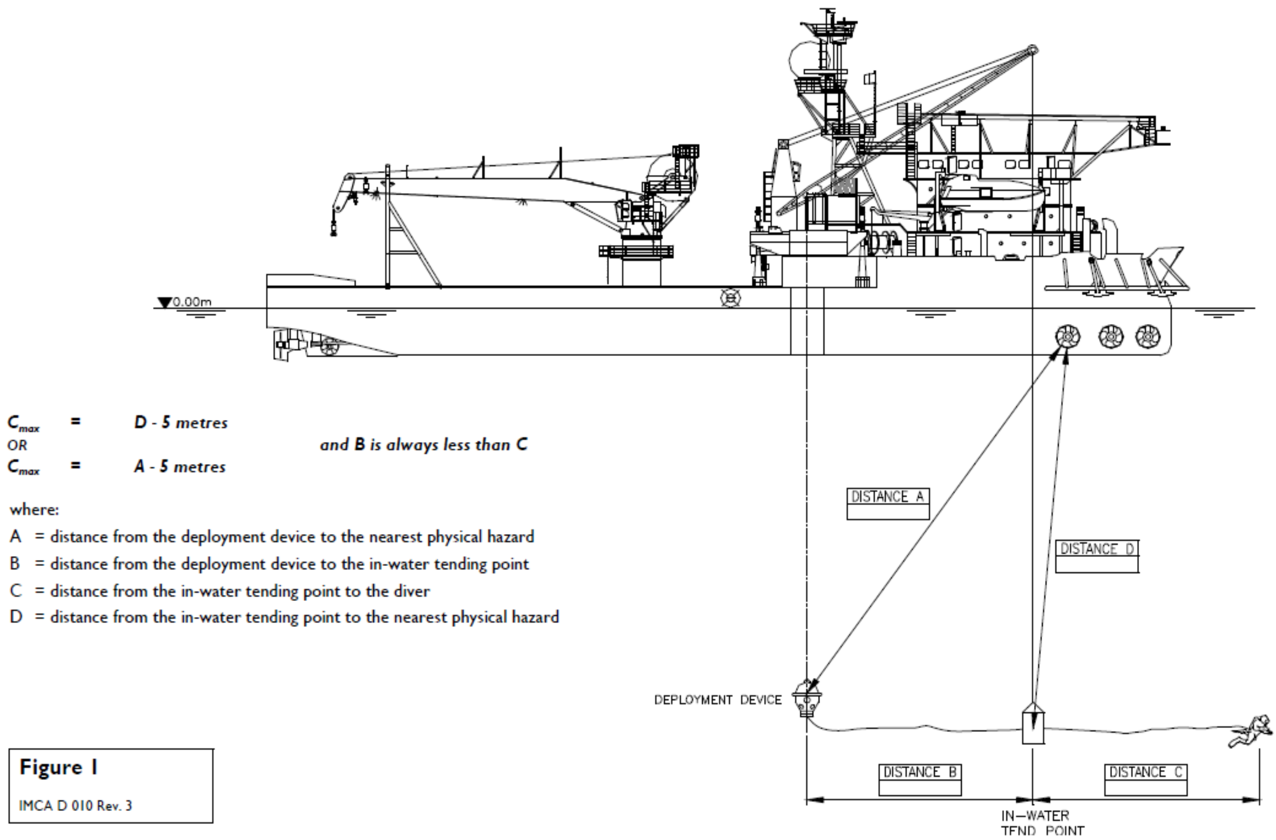


Figure I
IMCA D 010 Rev. 3

Section 9
Risk Assessment

HAZARD IDENTIFICATION AND RISK ASSESSMENT 9.1

The Procedure Scope

The document describes a formal process to be carried out for all work activities to ensure that our people, ships and equipment are as safe as is reasonably practicable.

This process of Risk Management involves:

- **IDENTIFYING THE HAZARDS**, which are the potential causes of harm, associated with the tasks about to be undertaken. (Hazards could include substances, parts of a machine, form of energy, method of work, work situation.)
- **ASSESSING THE RISKS** which can arise from hazards. (Risk is a measure of the probability that harm from a particular Hazard will occur.)
- **IDENTIFYING SUITABLE CONTROL MEASURES** to eliminate the hazard or control unacceptable hazard effects.
- **RECORDING** the results of the above 3 activities.
- **IMPLEMENTING CONTROL MEASURES** at the worksite.
- **ENSURING THAT RESIDUAL RISKS ARE AS LOW AS REASONABLY PRACTICABLE (ALARP)**.

This dictates that our work activities are conducted, supervised and managed correctly in accordance with approved practices. Improvements made when actually conducting the work shall be recorded and fed back to the benefit of future users.

Protocol of Risk Assessment Risk 9.1.2

Assessment Principles

- Risk Assessments are conducted with the aim of reducing risk to a level, which is as low as is reasonably practicable.
- Risk Assessments shall be performed prior to any work commencing by all project teams, departments, units and on all worksites where hazards have been identified or hazards are thought to exist.
- Risk Assessments should be managed to focus on key issues, shall be kept short and simple and MUST be recorded.
- People participating in the Risk Assessment shall be identified in the record.
- Risk Assessments must be conducted in a systematic fashion using the key steps identified in the detailed procedure (Section 3).

Responsibilities

Managers, who are responsible for a particular task or piece of equipment in terms of production, safety, cost and quality, are responsible for the technical quality of the Risk Assessments and for ensuring that adequate Risk Assessments have been conducted to ensure as far as reasonably practicable that the job/system/environment is safe for people and equipment.

Timing of Risk Assessments

All work is covered by risk assessments. Routine work covered by standard procedures and generic task plans will be assessed and a generic Risk Assessment or Critical Job Analysis completed. They may be referenced and reviewed prior to the work. However, when:

- Performing any non-routine activity.
- Performing a new task.
- When new people are involved.
- When third party people are involved.
- When major changes to the work/system are considered.

A specific Risk Assessment should be conducted suitably in advance of the work activity to allow the control measures to be correctly implemented. This may involve reviewing previous generic or specific Risk Assessments from the HIRA database.

Stages of Risk Assessment

A Preliminary Hazard Analysis (for project work) and three stages of Risk Assessment are carried out prior to work execution.

Preliminary Hazard Analyses are a series of assessment processes such as HAZOP, conducted at the outset or early stages of the Engineering phase or a series of assessments conducted throughout the developing engineering project work. The assessments are conducted in an office environment normally by managers and project people who have ownership of the tasks. The PHA's are used to agree the overall methodology to be used by assessing solutions and finding measures which provide the lowest risk. The methodology agreed will allow detailed Engineering to proceed to an approved level. (refer to the Engineering Instruction for details of the PHA).

Stage 1 is conducted in an office environment normally by managers and people who have ownership of the task/tasks/equipment including people competent in conducting Risk Assessments. The assessment is carried out towards the end of the project/equipment design or engineering phase but sufficiently well in advance of the work to allow adequate lead-time to provide equipment identified during the Stage 1 assessment, which will further reduce the risks.

The emphasis is on confirming the methodology as defined in the "Issued for Approval" Procedures but with the aim of refining control measures which provide the lowest risk. (The methodology of the work itself shall have been agreed and engineered from the outputs of the PHA). The target should be to ensure all aspects of the work have been assessed including contingency methods, hazards have been identified, and control measures defined before going to the worksite, such that all risks are made as low as reasonably practicable. The assessment should also consider recovery situations when the work does not go according to plan.

Stage 2 is normally carried out at the worksite by the people directly involved in the supervision of the activities utilising the documented results of the Stage 1 assessments. It is primarily instigated to confirm full understanding of the work and control measures to be implemented but may, in special circumstances, be used to further assess details of the work control and recovery measures. The emphasis is now on the details of the man / machine interface.

Stage 3 is usually called the **toolbox** talk and is a briefing given by the supervisors to the people directly under their control and who will be conducting the work activities. Again reference should be made to the previously recorded Stage 1 and Stage 2 assessment records and has the purpose of ensuring the people concerned fully understand the work, the control measures, any recovery or contingency measures and their responsibilities in executing them. Again people need to be aware of what has to be done in situations where the work starts to diverge from the plan and what their roles will be in recovering from it. It also serves as a final check that every hazard has been identified. Team members shall be given an opportunity to ask questions about these issues.

Toolbox talks shall be carried out as part of shift handovers or as part of specific pre job activity. The relevant Task Plan and, if appropriate, the relevant Permit to Work shall be part of the toolbox talks. The toolbox talk form (Ref. Appendix I) shall be used, and names of participants listed on the form.

There is a degree of flexibility in how Stage 2 and Stage 3 assessments are carried out at the worksite; for example, they may be combined if all people attend the shift briefing and have the opportunity to discuss / raise further areas of concern. What is important, is that everyone involved in the job is fully aware of his responsibilities, accepts the risks, the control measures to be implemented, and knows to stop the job or knows how to recover the situation or the contingency activities if things do not go exactly as planned. They must also be made aware that they should stop the job, if changes have not been agreed and risk assessed.

Techniques of Risk Assessment

The main technique used for work activities is:

- Hazard Identification and Risk Assessment (HIRA). This is the most common process applied to the Stage 1, Stage 2 and Stage 3 activities, and is covered in detail in this document. This is the main process, which shall be used for all Offshore project activities.

There are 3 other techniques, which may be used but are not described in detail within this document. These may be developed by appropriate divisions or departments as required.

- Hazard Operability study (HAZOP), which is generally used for system design to identify hazardous and operability problems. It may also be used to determine risks associated with operations during Preliminary Hazard Analyses to provide a measure for the suggested operational methods and can confirm the suitability of the methodology being designed.
- Critical Job Analysis (CJA), which involves a systematic identification of various job functions at the worksite, the job function discipline activities, the identification of hazards then associated with

those activities, and the safeguards.

• Failure Mode and Effect Analysis (FMEA) involves the evaluation of consequences of component failure within a system.

Involvement

The following table identifies who should participate in risk assessment processes.

Owners of Job / Attendees Type of Assessment	Line Manager	Project Manager	Offshore Manager	Supervisor	Senior Engineer	Engineer	Technician	HSE Advisor	Marine Rep	Task Supervisor	Task Executer	Customer Rep	Third Party Rep	Subcontractor Rep	Consultant Expert	Safety Delegate
Preliminary Hazard Analysis		◆	1	1	◆	◆		◆	●					●		
HIRA Stage 1 Construction Project		◆	◆	1	◆	◆		◆	1			◆	◆	◆	●	●
HIRA Stage 2 Construction Project			◆	◆					◆	◆	●	●				●
HIRA Stage 3 Construction Project			●	●						◆	◆					●
HIRA Stage 1 System Build		◆	●	●	◆	◆		◆	●						●	●
HIRA Stage 2 System Build			◆	●	◆	◆	◆		●	◆	◆					●
HIRA Stage 3 System Build			●	●						◆	◆					●
HAZOP Study		◆	●	●	◆	◆		◆	●						●	●
Critical Job Analysis	◆		◆	◆						◆	◆					●
FMEA			●	●	◆	◆	●								◆	●

◆ Denotes mandatory or designated nominee ● Denotes optional

Please note that the exact job titles may vary in different Regions and on different worksites. The titles are presented for guidance.

Detailed HIRA Procedure 9.1.3

The Hazard Identification and Risk Assessment (HIRA) procedure comprises 6 key steps which are described in the tables on the following 6 pages.

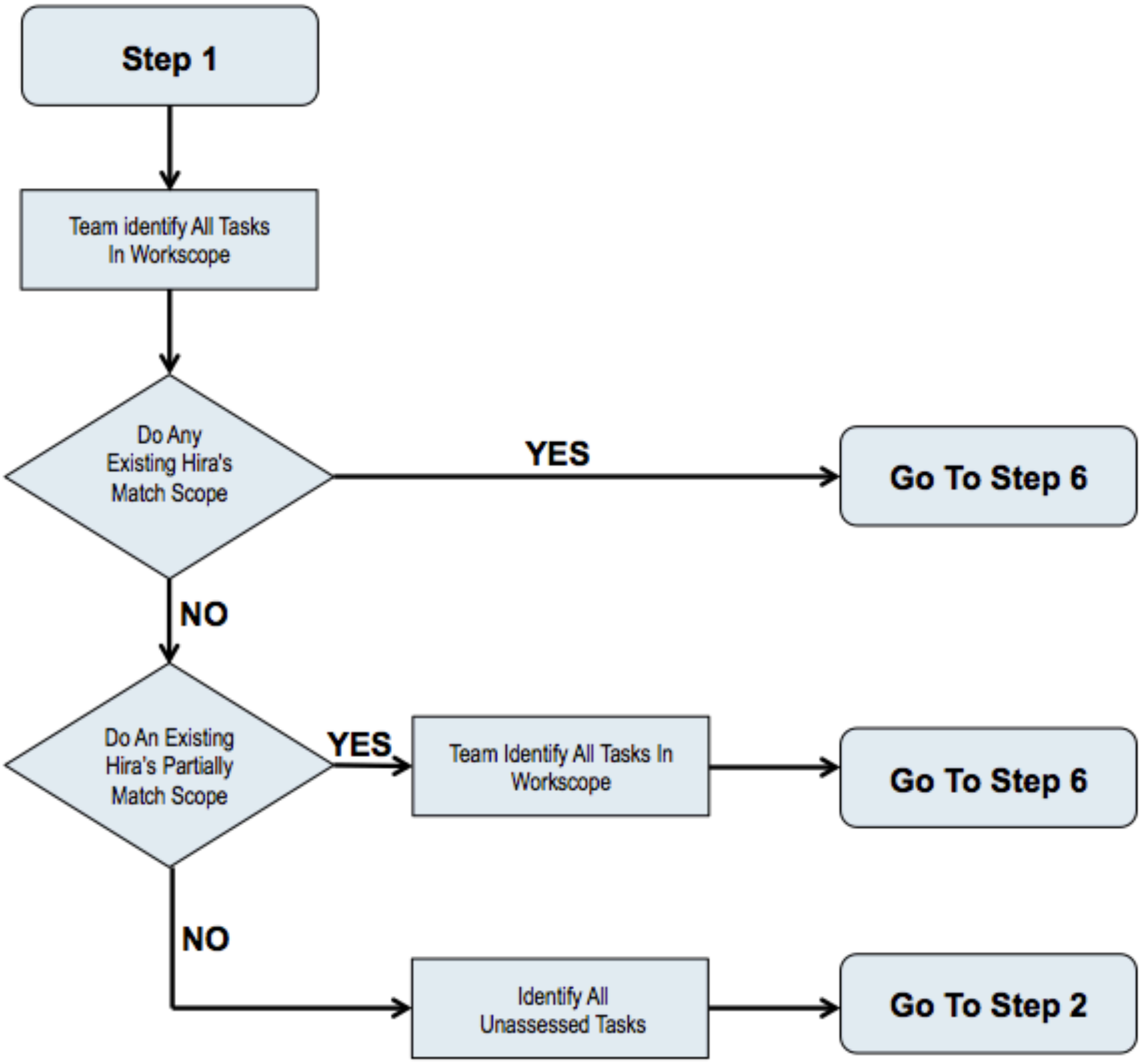
The Key Steps Are:

1. Task identification
2. Hazard identification
3. Identifying who/what might be harmed

4. Quantifying the risk
5. Applying control measures
6. Re-appraising the residual risk

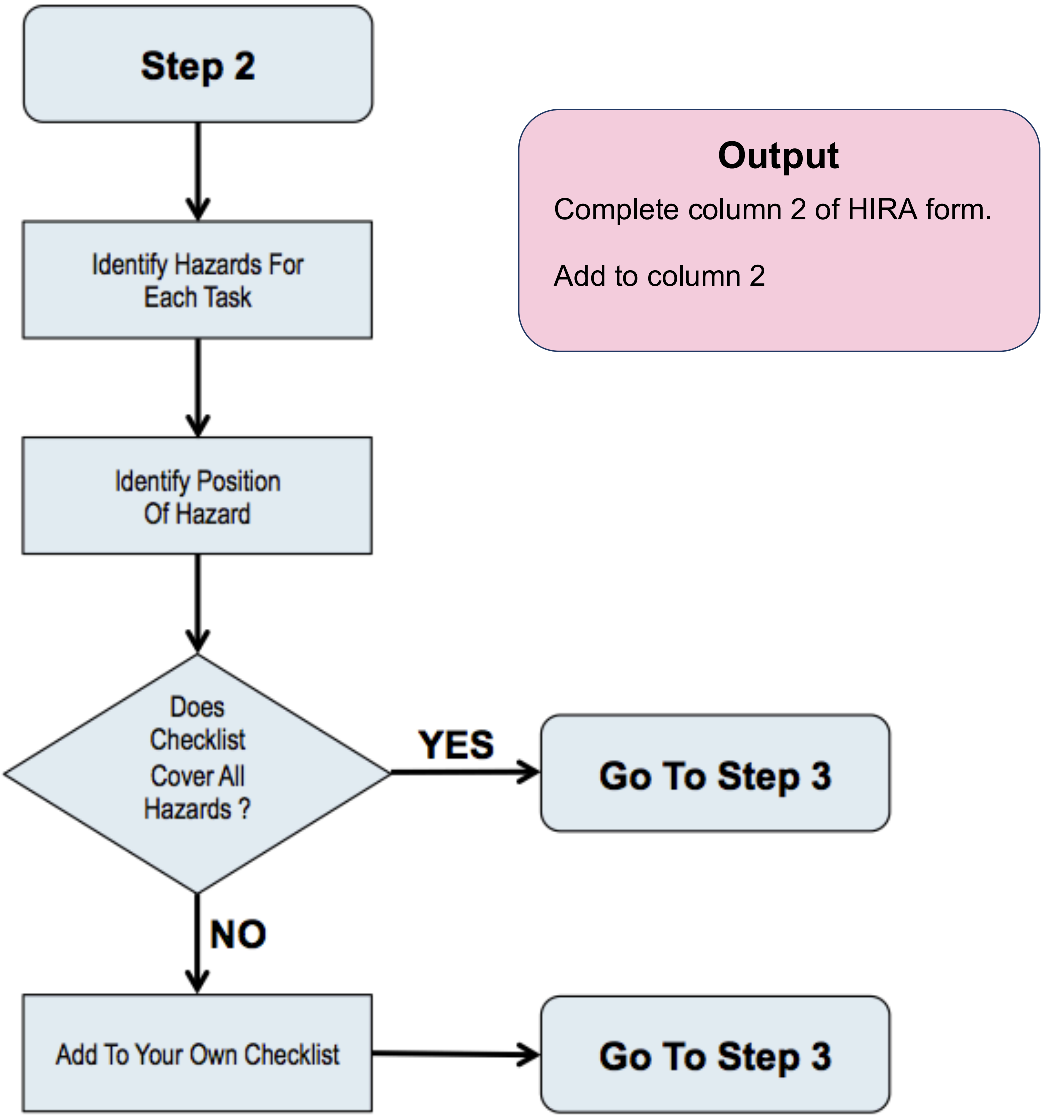
The tables show activities which you must do or questions you need to ask yourself in completing a Risk Assessment as well as giving details of references which you may use at each stage of the process. The output (or deliverable) at each stage of the process is described also.

Step 1: Task Identification



Note:
Arrows pointing to, for example "Go to step 6" refer to flowchart steps which are presented in the following pages.

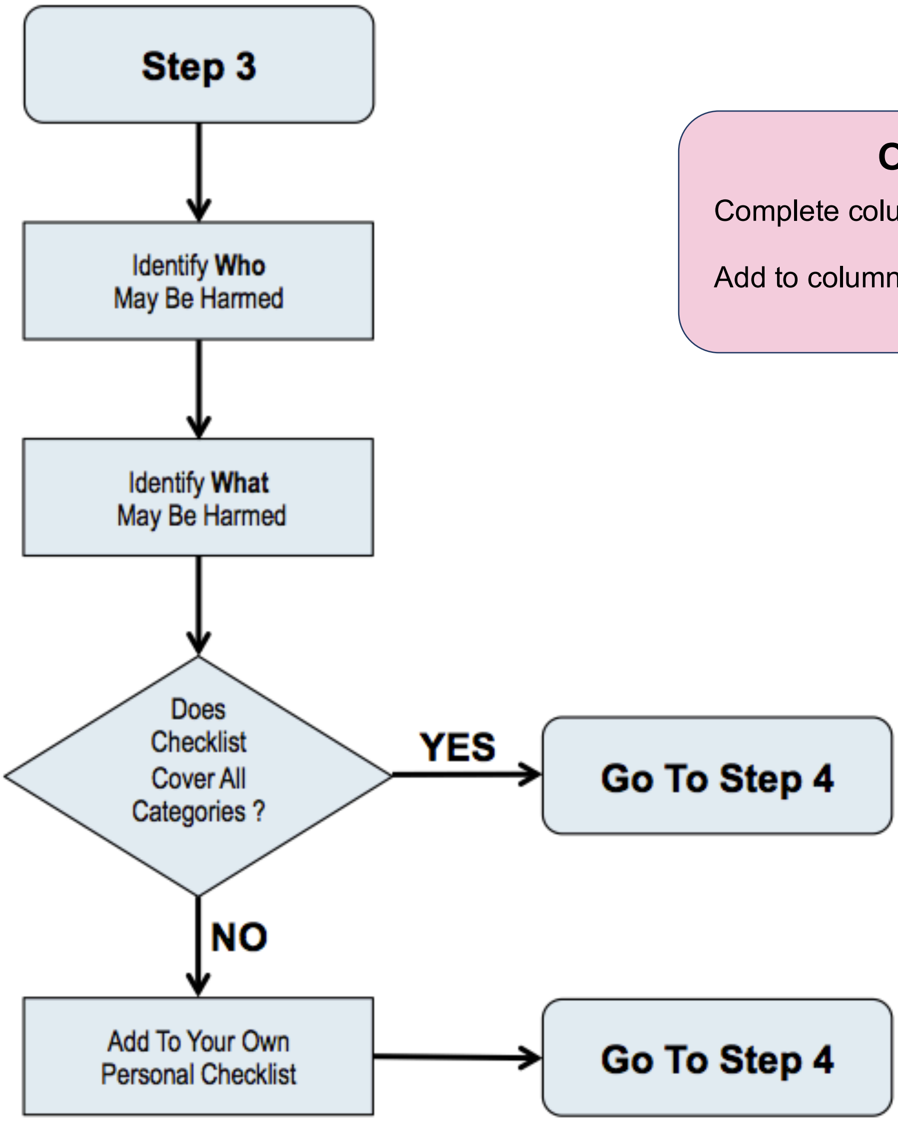
Step 2: Hazard Identification



The following list acts as a guide to identifying potential hazards:

- Slip / trip / fall Hazards
- Chemicals / Pollution / Contaminants
- Moving parts of machinery / vehicles
- Pressure / Vacuum
- Working at height / over side
- Dust
- Position and entrapment
- Lighting levels
- Low oxygen environment
- Restricted access / egress
- Single Point failures
- Weak structures
- Ship heave or roll
- Crane operations
- Vibration
- Sparks / material from welding / grinding
- Flammable materials
- Moving/Swinging objects
- Voltage
- Noise
- Fumes / Noxious Gases
- Manual handling
- Low / High temperature
- Radiation
- Hydrocarbons
- Posture
- Unstable objects
- Explosives
- Weather conditions
- Bacteria, virus, diseases
- Dangerous animals
- Tasks with repetitive strain injury potential

Step 3: Who / What Might Be Harmed



Output

Complete column 3 of HIRA form.

Add to column 3

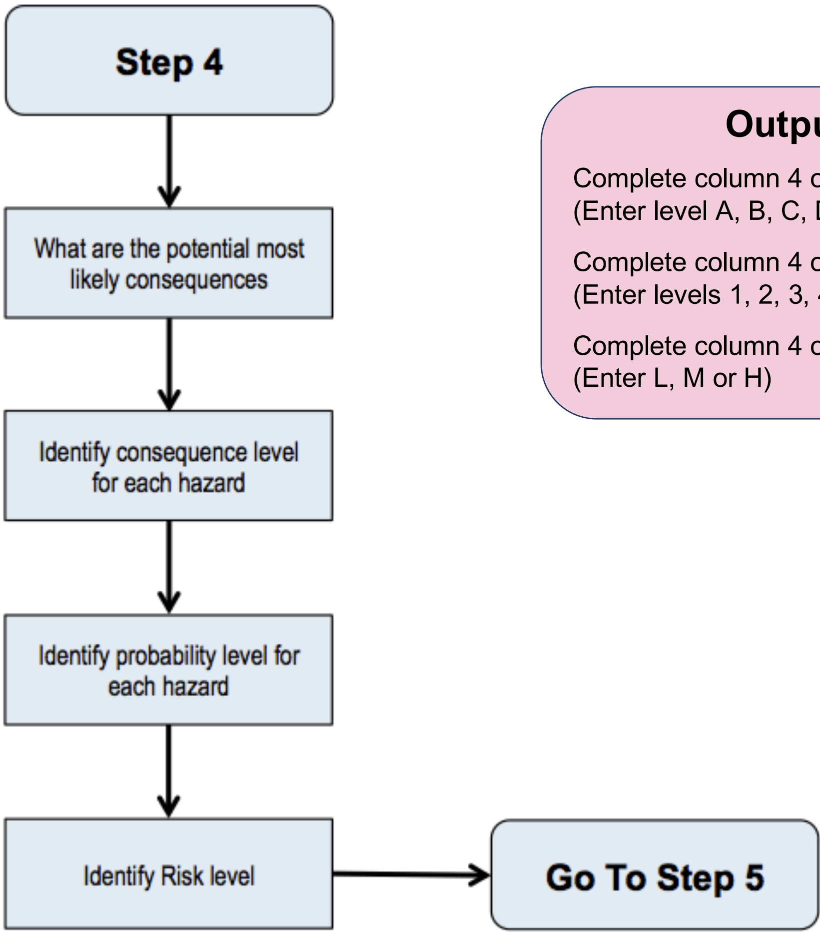
You need to ask yourself, who might be harmed by referring to the list below:

- Newly hired personnel
- Contractors
- Operators of equipment
- Marine and deck crew
- External parties
- Office staff
- People sharing your workplace
- Cleaners
- Personnel new to the site
- Divers

What might be harmed:

- Assets
- Material
- Equipment
- Environment

Step 4: Quantify the Risk



Output

Complete column 4 of HIRA form (Enter level A, B, C, D or E)

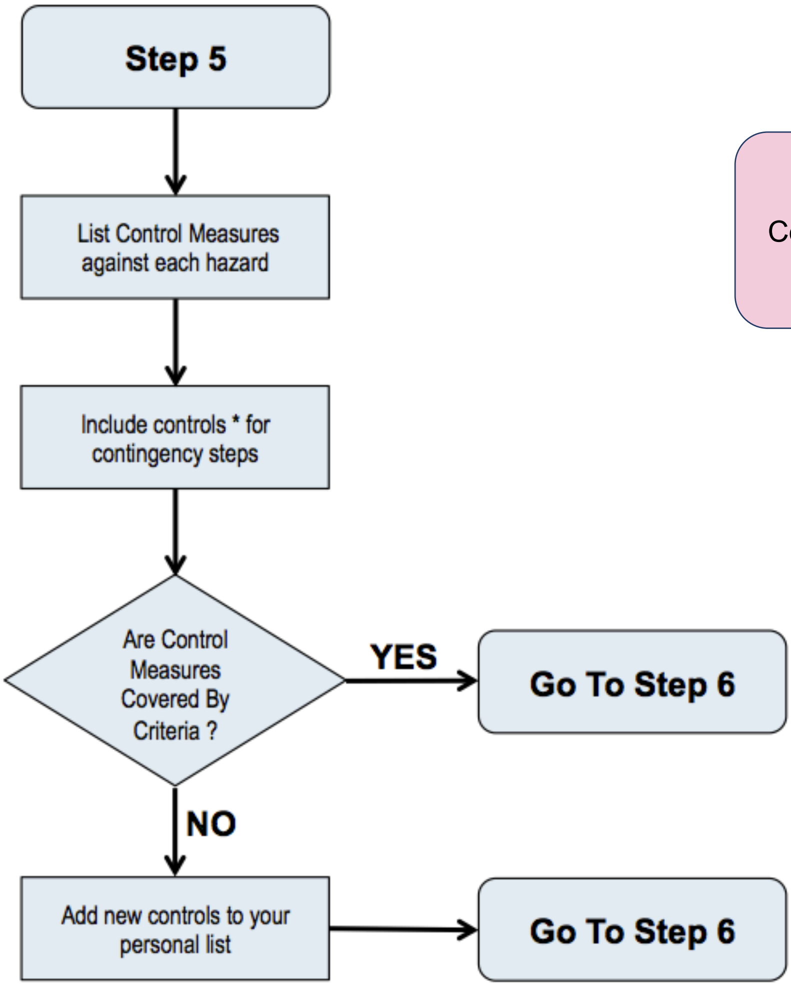
Complete column 4 of HIRA form (Enter levels 1, 2, 3, 4 or 5)

Complete column 4 of HIRA form (Enter L, M or H)

The matrix based on the IMCA International code of practice provides guidance in determining the risk rating from the probability level (or likelihood of occurrence) given as the columns 1-5 of the matrix and the risk severity level (or how serious the hazard effect could be) given as the rows A – E of the matrix.

HAZARD SEVERITY OUTCOME			PROBABILITY					
INJURY	SPILL / POLLUTION	DAMAGE	Very Unlikely 1	Unlikely 2	Possible 3	Likely 4	Very Likely 5	
Very Serious Death or multiple serious long term injuries	> 100 m3	US$ > 1 million	M	M	H	H	H	E
Serious Long term serious injury	0 ltr - 100 m3	US$ 50,000 – 1 million	L	M	M	H	H	D
Moderate Injury leading to & up to 10 days away from work (LTI)	10 - 100 ltr	US$ 10,000 - 50,000	L	L	M	M	H	C
Slight First aid required or medical treatment (NLTI)	1 – 10 ltr	US$ < 10,000	L	L	L	M	M	B
Negligible No specific treatment or loss of work	< 1 ltr	No Cost	L	L	L	L	M	A
For definition of risk severity and probability see Sections 5.2 and 5.3			L LOW RISK		M MEDIUM RISK		H UNACCEPTABLE RISK	

Step 5: Control Measures



Output

Complete column 5 of HIRA form.

Do the control measures include:

- Adequate information, instruction, training?
- Adequate systems or procedures?

Do the existing precautions:

- Meet the normal legal requirement?
- Represent good practice?
- Comply with a recognised industry standard?
- Reduce Risk as low as reasonably practicable?
- Have an acceptable low level of residual risk (i.e. L on matrix)

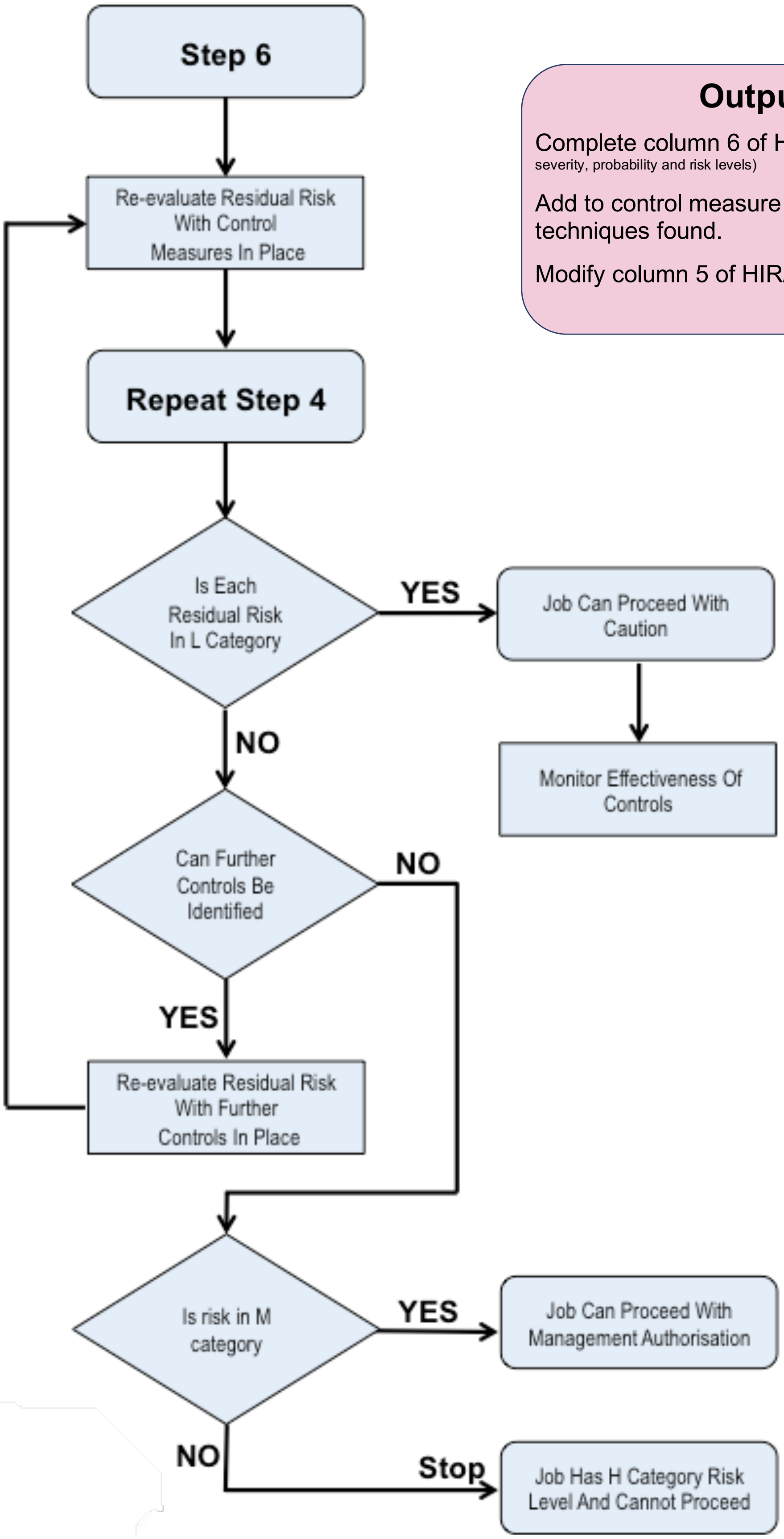
If so, then the Risks are adequately controlled, but you need to record the precautions you have in place. You may refer to procedures, company rules, Industry Codes of Practice or Guidelines. Priority must be given to those Risks, which affect large numbers of people and could result in serious Harm.

The principles below should be applied when taking further action, in the following order:

1. Remove the Risk completely.
2. Evaluate alternative methods/equipment.
3. Organise work activities to reduce exposure to the Hazard.
4. Prevent access to the Hazard (e.g. guarding).
5. Ensure PPE is available.
6. Provide equipment/facilities for remedial action (e.g. washing facilities for removal contamination).

Have you covered all contingencies – are you sure you have covered all the reasonable possible situations where a snag or failure could occur and from which you can safely recover from such a problem and complete the activity?

Step 6: Residual Risk



Output

Complete column 6 of HIRA form (Enter severity, probability and risk levels)

Add to control measure list if better techniques found.

Modify column 5 of HIRA form.

Reporting And Follow-Up 9.1.4

Offshore Project Records

All projects involved with offshore works shall present a Stage 1 assessment to the offshore team on HIRA record forms (Refer to Appendix I). The completion of the HIRA Record requires a person with detailed knowledge of the operation, such as the Senior Project Engineer, if it is to be done adequately.

Records of HAZOP for PHA, or CJA/ JSA for generic work and FMEA which is not related directly to offshore project operations may use forms developed on a Regional basis. As guidance, typical forms are presented in Appendix II.

On completion of a **Stage 1** Risk Assessment HIRA (or alternative, such as HAZOP or FMEA for non offshore project works), a formal report with the following contents, shall be issued:

- **Introduction** - Scope including an outline of the work tasks.
- **Assessment Records** - The completed HIRA (or HAZOP, FMEA) and supporting Risk assessment forms.
- **Recommendations** - HIRA Close out record forms may be used to summarise actions, dates and the people responsible to carry out actions well in advance of the Offshore works.
- **Appendix(ces)** (if required).

Once actions are completed, the final HIRA report can be prepared and approved by the relevant Project Manager. As far as practicable, all activities identified as H or M shall have control measures clearly defined and assessed on the **Stage 1** record prior to being submitted to the offshore team. The final HIRA records should be added to the HIRA database or copied to the Regional HSEQ Department to add to the list of available Risk Assessment reports.

Stage 2 Risk Assessments require the approved forms from the **Stage 1** Risk Assessment to be reviewed and enhanced if required with further appropriate worksite interface controls. These may be kept at the worksite or onboard the ship or barge to complement the catalogue of Risk Assessments previously undertaken for future reference.

When doing a **Stage 3** HIRA or toolbox talk, the completed form together with Task Plan and, when relevant, Permit To Work Form need to be kept on record during the life of the project. In the event of a serious or very serious undesired event, they need to be kept as a permanent record. As a minimum, the record of the talk and the attendees should be recorded in the daily operational log sheet, or deck logbook as appropriate.

Follow Up and Close Out

The person responsible for the production of the report or formal record shall clearly identify who is responsible for actions defining control measures and will set a time limit. The time limit shall not extend beyond 30 days, and sufficiently well in advance of the work activities. It is unacceptable to have issues in the **Stage 1** assessment without proper identification of the control method or residual risk items with a H (unacceptable Risk) classification being presented to the offshore worksite manager to resolve.

The originator of the report is responsible for including the latest revision of the forms into the revised Risk Assessment Report. He should then re-issue the revised report, or alternatively an attachment to the original report, which records the close out actions.

INFORMATION ON RISK ASSESSMENT AND OTHER TECHNIQUES 9.2

Risk Criteria

L Low Risk - No further immediate controls are required. Proceed with care.

M Medium Risk - Activity must be investigated with a view to reducing risk further. The Task can only proceed with appropriate management authorisation after consultation with specialist people.

H Unacceptable Risk - Task must not be undertaken. It requires Immediate action to avoid the hazard or substantially reduce the risk by further/better control measures.

Probability Guidelines

It is appreciated that probability of occurrence is fairly subjective and open to personal interpretation. In an attempt to achieve a level of consistency the following definitions are applied.

1. **Very unlikely**- a freak combination of factors would be required for an accident to result.
2. **Unlikely**- a rare combination of factors would be required for an accident to result.
3. **Possible**- could happen when additional factors are present but otherwise is unlikely to occur.
4. **Likely**- not certain to happen but an additional factor may result in an accident.
5. **Very likely**- almost inevitable that an incident would result.

Severity Guidelines

- **Negligible-**
  - Negligible injury or health implications.
  - No absense from work.
  - Negligible loss of function or damage to equipment resulting in no costs.
  - Negligible damage to the environment.
- **Slight**
  - Minor injury requiring first aid or medical treatment.
  - Damage to equipment requiring minor repair.
  - Some pollution impact to the environment.
- **Moderate**
  - Injury leading to a lost time case but with no long-term disablement.
  - Localised damage to equipment requiring significant repair and loss of function.
  - Moderate pollution incurring some restitution costs.
- **Serious**
  - Involves a single severe injury where long term disability results.
  - Damage to equipment resulting in major loss of operational capability.
  - Severe pollution with short-term implications incurring significant restitution costs.
- **Very Serious**
  - A fatality or multiple severe injuries.
  - Major long-term implication for operational capability.
  - Extensive pollution with long-term implication and very high restitution costs.

Hazard and Operability Analysis (HAZOP) 9.2.2

HAZOP is a structured qualitative technique for identification of a Hazard and/or operability problems relating to a specific design or process.

These are generally carried out at the equipment or system design stage, when major changes in systems are planned (Stage 1), or to check suggested operational methods (PHA).

This technique involves a team of key people who have an expert knowledge of the specific design or process, which should include the operators of the system or ship.

A chairerson, who competent in the HAZOP technique, but not necessarily on the design or process, provides a guidance.

The team interrogate deviations in the design or the process, a section at a time, using a systematic approach consisting of guide words applied to operating parameters.

Typical Guide-Words Could Be:

- Certification.
- Training.
- Familiarisation.
- Contamination.
- Responsibility.
- Physical factors (noise, light etc.).
- Weather conditions.
- Contingency solutions.

Combines, Or Associated With:

- No.
- More.

- Less.
- Too much/too large.
- To little/too small.

The findings of the HAZOP study shall be fully recorded, with follow-up actions specified as appropriate.

The guide words listed under the hazard identification section (3.2) may be used.

Critical Job Analysis/Job Safety Analysis

The aim of the Critical Job Analysis/ Job Safety Analysis is to clearly identify the Hazards which people will be exposed to on a daily basis at the specific worksite as they carry out their duties.

The Hazards will be rated in such a manner to identify those which are considered the most serious. People shall exercise additional caution and vigilance when conducting activities which have potentially highly rated Hazards.

It is the responsibility of the Line Manager(s) to ensure that CJA's/ JSA's exist for all relevant job functions directly under their area of influence.

For example, the Ship Operations Manager and Offshore Manager would be responsible for CJAs/JSAs for people with safety critical roles on board a construction ship.

CJA/ JSA Identification

The first step in CJA/JSA involves a systematic identification of the various job functions/disciplines that exist at the worksite. Typically this would involve identifying the job title and functional description of each individual.

The next step requires that the normal discipline associated activities are clearly identified and listed under the job title.

Having identified the activities undertaken by each Functional Description/discipline the next step is to identify the Hazards associated with these activities, and rate them in accordance with the Acceptance Criteria as described in Section 3.4 of this document.

The recommendations taken or proposed to reduce the Risk should be entered into the comments column on the CJA form.

The identification of activities and their Risk Assessment must be carried out as a joint exercise between a discipline supervisor and one or more person employed to carry out the job function/discipline being evaluated.

Failure Mode and Effect Analysis

The FMEA is basically a qualitative analysis technique, and is normally executed in the system design phase.

This technique questions the potential failure of individual components of a system, and evaluates the consequences so as to:

- Identify all possible Single Point Failures.
- Identify the Risk and cost of loss associated with such failures.
- Identify the means whereby Single Point Failures can be eliminated, or provided with redundancy.
- Identify contingency systems to compensate where Single Point Failures cannot be eliminated or provided with redundancy.

Section 10
Leadership

LEADERSHIP 10.1

Leadership is a function of knowing yourself, having a vision that is well communicated, building trust among colleagues, and taking effective action to realize your own leadership potential."

Aim and Explanation

The job of a supervisor in the diving industry is to manage a safe commercial diving operation. Supervisors do this with a combination of knowledge and skills.

Which Are:

- Their experience and knowledge of diving.
- Their appreciation and initiation of safe working practice.
- Their assessment and efficient use of the diving system and plant available to be used.
- Their use and knowledge of diving regulations, company regulations and procedures, company diving tables.
- The study of the plans and procedures of the job to be carried out.
- Their skills of man management.

The first five items are covered by industry experience, company seminars and training manuals. The **aim** of this document is to offer guidelines on the last skill listed, that of **man management**, which involves the diving supervisor in the **art of leadership**. We will occasionally touch on the other items listed in their context as they relate to man management, but it is not the intention of this document to examine them in any depth.

For supervisors, leadership is the art of utilising their crew to perform commercial diving tasks, willingly and enthusiastically, using efficiently the combined talents and skills of the whole team, in a safe and orderly manner.

Misconceptions

First look at three misleading statements which you may have come across :

- "He's a born or natural leader"
- "I'm not here to make friends, just to get a job done"
- "Never ask anyone to do a job you wouldn't do yourself"

They each have an element of truth but are at the same time misleading.

Firstly, about **"natural or born leaders".** Leadership is a skill like any other that can be taught and learnt. As with any skill, people's ability will vary, some have natural attributes that complement their ability to lead. You will have come across a top hand welder who seems to have a multi-articulated arm with the co-ordination to weld in any direction around the back of a pipe from a view in a mirror held in his other hand. If you told him he was a natural welder he would be justifiably put out as he will have spent a lot of time and hard work to learn and develop his skills of fabrication and welding, which luckily for him are complemented by a natural talent of co-ordination. For the one of him you have met another hundred competent welders who also do an excellent steady job.

So it is with supervisors, some have natural talents on which they have built their leadership qualities. The majority of supervisors in our industry will have had to acquire, learn and discover their skills of man management via hard-learnt lessons from recognised mistakes. A fortunate few will have had formal training. Your ability for leadership will be in realising that it can be taught and applying yourselves to an art that grows and develops with each experience and job. You never stop learning about man management.

The second statement, **"I am not here to make friends..."** is that of a second rate manager who can't gain the respect of the team he is supposedly in charge of. Invariably you will make friends, or may already have long standing friendships with men in one of the positions under your management. What is important is your ability to respect and treat fairly all the men in your team developing their confidence in your ability to run a safe and efficient operation. A cautionary rule to temper your approach is that if you are prepared to hire a friend you must also be prepared to fire him.

The third statement, **"never ask anyone to do a job you couldn't do yourself"**, goes much against what man management is about and that is utilising the talents and skills of the men in your team to their maximum potential, in the correct jobs suited to their abilities. Your job is to assess, direct and delegate, not compete with the men in your team who will encompass all the multiplicity of skills employed on a modern offshore operation. It is more to the point that you should know and understand what you are requiring men to do.

Selection and Improvement

So what is it we have to learn and develop that starts the separation of the managers from the managed. As with the example of the welder, there are natural abilities to build on, some men are fortunate to have more than others: in part two we shall go onto examine the skills that are required. You will find that you already possess many of these qualities and skills, some may need developing like neglected muscles you haven't used and finally, a few may need to be learnt.

The start of the separation is that you want to be the supervisor. This can be for various reasons, it may be because of external pressure, for instance you are no longer able to dive for medical or fitness reasons and the only route for you to continue working is to go into supervision. It could be the mature decision that you have had enough of diving due to age, or no desire to continue in the water. One of the main reasons with a lot of men is that they have an inborn drive to take charge, whatever they do and will go into supervision because they always believe that they can do it better.

Whichever route you come into supervision, for some, once in the job it will come as a shock, especially those used to working with good supervisors. A professional will make his job look easy and watching them at work, the unaware can be deceived into thinking it is easy. They will soon discover that the reality of diving supervision is somewhat different and you are in an industry that isn't going to spend a lot of time teaching you to manage correctly.

In the Armed Forces the whole system is set up at every level in the art of leading, managing and instructing men so they spend a good proportion of their time selecting, developing and training their managers. You will not have that time, money or facilities lavished on you in the commercial industry that you work in.

The IMCA Diving Supervisor's scheme is an assessment of the theory required by supervisors, but there is no facility or time period set aside to train you in the skills of managing an offshore worksite. The onus is on you and the supervisors already doing the job offshore, to train you on site. Most of it will be done by your observation and practise when acting as an understudy. For the trainee supervisor or LST this will be based on the shift supervisor.

For the shift supervisor, who should already be a competent manager, it will be from observation of the superintendent in charge of the worksite.

Whatever level you are at, two of the governing factors on your leadership potential is your own character and personality.

All supervisors will have varying approaches, moulded by their character and personality and the successful manager incorporates most or all of the qualities we will go on to examine, how he employs them will be relatively unique to him. You have no doubt met every successful type of supervisor, from the loud extrovert to the quiet introvert. To learn from them, you have to look at the techniques they use to achieve their aim and especially those that have the respect of their men and whose teams perform tasks with enthusiasm. To try and copy their character is the wrong approach as you have your own on which you will develop your management style by observing their methods.

Summary

Once you have decided to be a supervisor or as a supervisor realise that you could improve, you must observe those whom you judge to be successful supervisors, study their technique, dismiss that which you consider they do wrong and note and learn from their good points.

Compare that to your methods, recognise the mistakes or misuse of techniques in your approach and adapt to improve your overall performance.

Leadership Skills 10.1.2

This section will introduce a guide to a selection of skills, listed below, which cover most of what you require to be competent manager.

Different problems will see you utilising varying percentages from these skills as your own approach and the situation dictates:

- Fairness
- A sense of responsibility
- Moral Courage
- Decisiveness
- Being Mentally Alert
- Being Observant
- Being Communicative
- Logic
- Being Opinionated
- Self Confidence
- Having a Sense of Humour
- Being Patient / Tolerant
- Being Competitive & Commercial
- Being Safety Minded, i.e. having Imagination and Foresight
- Thoroughness
- Having a Sense of Curiosity
- Being Adaptable
- Loyalty

At first glance it may appear they are the attributes of a saint not a supervisor but as the text develops you will see that for an able manager they are quite ordinary and that they can be learned and developed**.**

Fairness

Fairness has already been touched on in the context of treating all members of your team according to their position and skills in that team and not by personal relationships. A hard principle to follow as it's a natural human reaction to favour friends and while every manager will to some extent transgress in this area it is as well to be able to control it and as far as possible treat all members equally as far as their abilities warrant it.

Without a doubt at some time you will be perceived to be acting unfairly as you also have to be highly selective in a commercial operation, which will require you at times to bypass less able men and give employment to those who get the job done. In this you are being fair up the chain to the management that trusted you with the supervisory position.

Responsibility and Moral Courage

When you accept the responsibility as a supervisor you also accept the consequences of your actions running a diving operation, or part of it, in what can be a dangerous industry on deck and in the water. Awareness of this responsibility will necessitate you on occasions to have the moral courage to make decisions that can be unpopular to those managers above you and also with those men you are in charge of. Pressure can come from all directions and in many guises.

As you know, or will learn, once you accept the position as a supervisor you are legally responsible under the law for the diving operations or that of the operation qualified by your job description.

You also have a moral responsibility for those you are in charge of and my have more difficulty, should an accident have occurred, justifying circumstances to yourself than to any investigating body that may be set up to judge your actions. It's as well to be completely aware of this responsibility and as a focal point of the way you conduct your operations it will formulate a good basic attitude.

Decisiveness – Being Mentally Alert – Observant

We have now seen that the two skills of moral courage and responsibility complement each other. To say no or yes requires you to be decisive, to be decisive you need, apart from the industry knowledge listed in the initial introduction, to be mentally alert. Normally executive decisions need not be made in haste, they should be a combination of your observations of all that is going on and from listening to what people tell you, this includes those you are in charge of as well as those in charge of you.

So decisiveness is based on industry knowledge and your state of mental alertness, which will govern how much you will observe and hear. What you hear is advice, whether you hear it depends on you. It can come from any source from the client's representative, superintendent or tender.

Decisions are a continual part of your job and vary from judging when to stop or start waiting on weather to scheduling who should rotate and when, for meals.

Communications – Logic

To pass on your decisions you must be able to communicate them. Decisions must be given clearly, loud enough to be heard and sometimes with the authority of an order. A good percentage of your communication is done over a combination of radio/telephone systems and as you all know these can present their own variety of problems.

Succinct expression, describing what you want done is a skill to develop in verbal communications. A long mumbled preamble always creates confusion. Confusion in our industry leads to chaos and increases the probability of accidents. Your main challenge, in your ability to communicate, comes when rebriefing a diver in the water after the job has changed radically from the initial briefing. To watch and hear this done successfully is to admire the state of the art practised by a professional supervisor. This communication skill is one your may require to learn or improve on.

You should develop a vocabulary and phrase length you know is sufficient to get part messages over, with diver confirmation in-between. You must think logically of the step-by- step progression.

Jumbled information presented in a haphazard manner is neither commercial nor safe. When giving a briefing there is a logical sequence you can follow. One example of this is given below, and it can be adapted for briefing an entire diving crew prior to starting a job or talking over the comms to divers in a saturation chamber or bell. In the latter case, this would be termed as a remote briefing and should be preceded by passing in all drawings, photographs and procedures.

Briefing Example

- Introduce yourself, let them know who you are, you may have just joined the worksite and not know the divers on shift or in saturation.
- Let them know, so that they are in no doubt, what your AIM is for the entire job, dive or shift.
- Explain how this aim will be achieved, who will be doing what, the time scale, the equipment to be installed and available to assist the procedures and tests to be followed.

Note : This will be the main body of your brief and may be done using aids as available.

- Question session from the team to clarify any points not understood.
- Summarise the agreed plans and follow it up to ensure that all understand.

This doesn't require to be formalised into a pedantic procedure but is only intended as a general logical guide to follow. It can be extended or condensed depending on how much information has to be passed and how many people you are talking to.

Long briefings need frequent breaks for questions as you cover each section of information.

The other communication skill required is by the written word and as a senior supervisor, becomes an increasingly important requirement. This is not a large hurdle as you already speak and write English, you can verbally communicate your requirements so now you progress to the next step which is to put it on paper.

You need to be brief so stick to the point you are making and present the subject in a logical format. Items can be split under separate headings when required and if you are presenting problems try to offer acceptable solutions as well. It is not the intention in this paper to go too deeply into communication as it is a subject on its own.

Follow up, should you require it, in developing your normal written work, report writing, and instruction technique are available through correspondence courses or formal classes.

Being Opinionated – Confident

A supervisor needs to be opinionated. To be in charge of diving operations you must have opinions on how they should be conducted and progressed. You need to be able to communicate and express these opinions in a logical, positive and confident manner, either verbally or on paper. You will require the confidence, sometimes, to forcefully repeat and follow them up until responded to and then to justify or qualify them.

Be objective and thorough, a poorly prepared and presented opinion, verbal or written, even though it may be valid, can be ignored or neutralised when challenged. Try not to start from a contentious or abusive position, no matter how annoyed you may be over the situation that you are trying to resolve.

Consider the aim you wish to achieve with the individual or organisation you are dealing with and adapt your presentation so you get the result you are aiming for.

If it is a contentious issue, isolate the most important item and work back from that.

Any memos written on the subject are best written then retained for a day before passing on. Without doubt you will rephrase them.

Your opinions will be requested both on technical and operational matters and also on the men working for you. This last requirement – assessments – is an important area of man management and one that must be approached with a responsible, fair and objective attitude and is covered further in part three.

When following up your expressed opinions, you will require an element of confidence. You must know you are right and must not be deflected. This again is having confidence in your knowledge and ability. The existing industry supervisors exams / scheme will, for a lot of supervisors, increase their self-confidence and knowledge by the process of studying and passing the exams.

For the men coming into supervision it will at least give them a base level of knowledge to build on.

You have and will continue to be dealing with people from all areas of the offshore industry; some may know what they are talking about in relation to your skill and some may only think they know. Your management ability is to assess the difference and in the latter case no matter what their title or position, you will need the confidence to pursue your point. You have the responsibility and the right to express strong opinions and raise controversial points, otherwise job progress and safety will inevitably be practised in retrospect. Invariably not everything you say or propose will be right all of the time and the system of sieving and justification will determine how much of what you proposed is correct. However, what you do is stimulate discussion from which a better policy should emerge.

There is a statement that sums this up, "that occasionally it may be as well to be controversial as to be correct".

From strong discussion comes strong policy, do not be afraid of this it is a healthy atmosphere in a potentially dangerous occupation.

Having a Sense of Humour

When you are seen, or proven to be wrong, which must happen at times to everyone who ever takes a management position, one quality that will maintain yourself respect and confidence will be a sense of humour. How could you work offshore without it.

The ability to laugh at yourself as well as situations is an essential requirement. You will be moulding into a team, an intelligent group of men who combine every subtlety of all the regional humours of the UK and a few other countries as well. A well-placed remark or joke can defuse a tense situation or confrontation and put things into perspective. The measure of your depth of command within the team will be illustrated when they realise automatically the point that the fun gives way to work.

Never underestimate the value to a team of a healthy sense of humour, this will be very much orientated around people's mistakes and weaknesses, including yours; the healthy aspect is that it is basically non-vindictive. In the diving business there is an element of black humour, which is a necessary relief valve or block found in any dangerous industry or activity.

Men will deal with dangerous or hazardous situations by shielding their apprehensions or reactions behind a sense of humour that is often misunderstood by outsiders.

Patience / Tolerance

Patience and tolerance are necessary skills in an industry where plans can change by the hour and controlling frustration and temper when dealing with awkward situations. As a supervisor sometimes you can lose your appreciation of how long it can take or how awkward it can be for a diver to complete a task. This is where your previous knowledge or assessment of men will control your approach.

If he is an experienced competent diver you will accept his rate of work, the same task but by a less experienced or unknown diver may make you impatient and intolerant. By observation and listening to him, you can assess if his progress is slowed by difficulties not of his making, that he is overcoming or by problems of his own making due to inexperience or incompetence.

Both of the latter will require your skills as a supervisor to progress the job. Your experience and logical approach plus communication skills now assist to direct the divers, to lose your patience and temper can defeat the object of achieving the aim of the dive. It is a stressful job and saints don't become supervisors, sometimes the frustration is too great and patience and tempers are lost. The aim is to avoid this stage or once reached restore the balance by a combination of decisiveness, humour, patience and direction. It may be necessary to terminate the dive or change the divers out in the bell. You have to balance the loss of confidence to the diver against the safety and productivity you are required to achieve.

Competitiveness

To be competitive in a commercial business is not only a desirable quality it is a fundamental requirement. We are engaged in commercial diving, you are a commercial diving supervisor, if your aim was only to be a diving supervisor then you should be in the holiday business or club diving where you will only be required to run safe fun dives.

You however are required to achieve an aim that is recognised as a commercial product for which profits are expected, or at a minimum to break even. Companies bid competitively against each other for work, so it follows that to gain a contract the profit margin will not be large. You are then hired for your expertise to bring in a job that stays within the profit margin and on fixed price work (lump sum) a job that is completed not no schedule but ahead of schedule.

If you accept a job on any other premise then you are not a commercial diver supervisor. The diving industry does not owe anyone a living; you are offering a professional service and how well you perform it should be the major governing factor concerning your re- employment.

Looking back at the context of divers who may be incompetent or inexperienced you must be competitive in your approach to the loss of time, continuity and efficiency. Here when discussing incompetence we are not talking about the occasional mistake but the continuation of inefficient work despite your direction and advice.

The inexperienced man will normally respond to you, the incompetent generally won't and you have no justification in keeping him in the water or saturation no matter what the personal relationship there may be between you.

Remember that you will occasionally be required to make decisions that will offend those below as well as above.

The divers who rise to be the top hands will also have a competitive aggressive approach. Sometimes you may need to hold them back and it takes strong supervision to manage them; their enthusiasm, if uncontrolled, could be disruptive to efficiency.

However, you will find it easier and more rewarding to be controlling and channelling this energy rather than trying to generate it in complacent and apathetic men. Look for those strong divers and use them, that is your job, they can galvanise mediocre divers into better performance and set inexperienced divers down their same high achieving path.

It’s part of your art of man management, controlling this enthusiasm and energy and directing it correctly.

Motivation on a work site can only come from the top, as a supervisor your shift will mirror your attitude, as a superintendent the entire worksite reflects your approach. The whole system should revolve around this theme in any commercial environment. You run a competitive, efficient, safe operation, the work goes as planned or better, the company succeeds and gets stronger; based on your performance and reports, the shore-based management can plan and bid more effectively, thus get more work, you get employed more.

The top competitive supervisors are never out of work although it may appear that they are trying to put themselves out of a job by completing work ahead of schedule, they are at the same time putting themselves in the position to be the first to be re-employed.

The approach of stretching work out, while theoretically understandable, is practically unacceptable, as without the drive to perform better, be efficient and make a profit there is no commercial industry. Your aim must be to be the top man, never concede that you can't be as good or better than those perceived by others as the top men.

You can respect them and learn from them but must always want to be better than them. This is not an altruistic industry and your ability to earn a living is based on recognition of the performance you turn in consistently, so you must aim to be the first man on the selection lists. You never will be unless you compete.

Finally there is some worth in the observation that an efficient competitive work site will be a safe one. Efficiency does not mean taking shortcuts, it means eliminating unprofessional conduct and utilising your equipment and personnel to maximum ability.

Where that is being done you don't generally find the kind of apathy and complacency that leads to unsafe practice and accidents.

Safety – Imagination and Foresight

Towards the end of the previous section we touched briefly onto safety and although it is not the intention of this booklet to examine safety, what we will do is see how the various skills of a manager assist to assure a safe attitude is generated throughout your team.

As you recall the aim of a commercial diving supervisor is to run a safe, commercial diving operation. We've seen what is required to be commercial and a generalisation was made that an efficient worksite would be safer. It is also a fact that an operation cannot be commercial unless it is safe. While the main aim of safety is to ensure nobody gets killed, injured or put into a situation where either is likely to occur, the other factor in a commercial sense is that incidents cost time.

Industry as a whole does not spend millions on safety out of the single concern for men's welfare; loss of money by shutdown and litigation concerns them as well. When we accept the responsibility to run diving operations it must be your constant concern to make jobs as safe as they can be both on deck and in the water.

You are a Risk Manager and your aim must be to reduce at all times the risks to a negligible or acceptable level. This is Risk Management, what must be considered a large part of our job. You must use your imagination, industry experience and knowledge to develop foresight, utilising your overall experience and knowledge of the offshore industry and not just one part which is commercial diving.

You exercise this foresight by looking and analysing everything, then using your imagination to follow the exercise of "WHAT WOULD HAPPEN IF". You follow through emergency situations that you have to deal with or you think may occur. Nowadays the industry has become proceduralised; who writes or checks and edits these procedures? YOU.

An emergency procedure is a guide, it has failed completely if you require to refer to it, then to follow it step by step when an emergency occurs. The idea of drawing up an emergency procedure is to identify where a likely hazard is, or may occur.

You then formulate a logical approach to handle it, identify what equipment will have to be ordered or modified, prepared and dedicated to assist.

You then make aware to those who will be involved, what is required of them.

This should be followed up with drills, though it is not always possible to practice all emergency drills. This is where your mental rehearsal is necessary. A rule to follow in preparing emergency procedures is, KEEP IT SIMPLE. As far as is practicable one man should not have more than three separate tasks to perform, one primary and two secondary. The system should be flexible with overlaps and realised by all that is a guide not the Holy Writ. It is one of the main responsibilities of a supervisor, on joining a worksite, to identify the established emergency procedures and work through them, physically checking where the back-up equipment is stored and its condition.

Any items you are not happy with or unsure of must be raised with those in charge and responsible for safety.

The supervisor, stand-by diver or the bellman acting as stand-by for diver(s) working out of the bell, should frequently run their emergency drills and actions through their minds. These stand-by divers must have all their equipment ready for instant dressing in, one of the responsibilities of the diving supervisor is to ensure the bellman or standby diver has done this.

Having spent time running all these permutations of disaster through your head and following them up with the preparation of the equipment you expect would be required when things do go wrong, you are mentally prepared.

Come the incident, your imagination and foresight will not leave you with a blank mind; you've already mentally been there and will follow up with a semi-automotive response as the actions required of you click into place.

Don't sit and wait for it to happen, otherwise the reaction is likely to be a blank mind followed by confusion and panic.

There is much made in post accident reports of hindsight, by utilising imagination and foresight and a thorough follow-up, there should not be any incident for which you are not prepared and cannot react to professionally.

Thoroughness

Incorporated in all you do must be thoroughness and attention to detail.

This ensures, as in the previous section, that all preparation is carried out for emergency drills, it also must be part of your commercial approach to the overall job in the preparation of the diving system and equipment to be used or hardware to be installed. Thoroughness in this comes down to checking bolts are greased and nuts run freely, ropes are tied off with knots a diver can handle in gloves, rope ends are taped or spliced (no mare's tails!).

The amount of time wasted just over these three items can be considerable. Your commercial application of foresight and thoroughness means planning so divers are not waiting for equipment that should be prepared ahead.

You may be labelled fussy, but take this as a compliment, as your shifts or worksites will run smoothly.

A cost effective use of time is checking and securing lines on equipment that is lost can cost your operations thousands of pounds, not only in their replacement but in time lost which cannot be regained, this can make the difference between commercial success and failure. Your thoroughness is another factor that governs the safety of your worksite and it should be your aim to cover your diving operation areas frequently during your shift, this is where the second supervisor comes in.

The superintendent will be following his own checks but this doesn't absolve the shift supervisor or LSS from the responsibility of checking his own area. You must follow up the tasks of preparation or improvement and assess the overall attitude of the team to safety and preparation.

You are failing if the superintendent is continually coming to you with a list of items to be addressed and failing as a superintendent if your line managers visit and the worksite is in an unsafe and untidy state.

Never allow the next link up the chain the opportunity to pick holes in your operation.

Being Curious and Adaptable

Your continual curiosity as to what is happening in all parts of your operation will spill over into the general progression of diving techniques and equipment development in your industry. It is still a fast developing business with some very clever people extending the limits and dimensions you can work to.

If you don't keep an interest in what's happening, you will be left behind and eventually unemployed.

Your competitiveness and curiosity will give you a positive approach to what is going on in an industry in which to say "they'll never be able to that" is to be proved wrong time and time again.

Taking this approach, that everything is possible, will naturally make you adaptable and adaptability allied to a competitive approach will make you a flexible supervisor who can approach any job with a positive and determined attitude to make it work.

You have no doubt met and worked with men who when any new innovation is outlined, or when a radically different work scope is proposed, will themselves propose ten ways of not being able to do it or use it, normally coming down heavy on safety as an excuse, thus proving themselves to be safety conscious.

What you must aim to do, and also look for in the men below you, is not how you can't do it but how you can and in a safe manner. You demean your own expertise by criticising others for bringing you problems to solve. You are the up to date practical proponents of the offshore expertise of commercial diving techniques. You must look at the job or equipment and assess it, look what changes or extra development and additions are needed to make it safe and workable.

Make your reports expressing your opinions, suggestions and solutions.

Occasionally you will get presented with a complete non-starter, but this is rare nowadays, so be adaptable and positive to make a job or equipment work safely.

Your recommendations can vary from major, as in changing the vessel to another that will be safer and more efficient for that particular job, to as little as minor onsite modifications and rigging changes.

Loyalty

Finally in this section on the qualities required of a supervisor we'll look at the often- misunderstood subject of loyalty.

Loyalty is a difficult quality to quantify and men will interpret it and give it in different ways, often without realising.

If your workforce respects you, they will also give you a certain loyalty; you in turn are required to reciprocate that commitment. You are responsible for your team in their work and to a certain extent you represent them to your management.

On the other hand you have contracted your services to the company as a manager, by accepting that position it will be assumed that you have commitment and loyalty to the company. You will be obliged to agree to what your company request you to do within the framework of what you consider acceptable and safe practice. The safety side is covered thoroughly by industry procedures and legislation, which you are legally responsible for implementing.

What you consider acceptable will be based on your own prejudices, experience and opinions and will govern how far you are willing to be loyal to the company employing you. Blind loyalty is the domain of idiots and if your present company is instigating policies you perceive as incorrect or illegal you must inform them as you see it, as their offshore manager or part of their offshore management team. Should they not alter their approach or policy and your position becomes untenable then you require the moral courage to stop an operation and request a replacement. This is where you need your confidence to express controversial opinions communicated clearly.

Hopefully your loyalty is never stretched this far or relied on as the ultimate arbiter for sensible agreement.

Present day management and communications normally enable supervisors to maintain a balance of loyalty to their team and the management employing them. You have however taken the first step out of the group complex and must realise that occasionally company loyalty will be perceived by your team to be lacking for an individual who appears to deserve it.

However it may be that the company, while being apparently disloyal to one employee is maintaining its responsibilities and loyalty to the majority.

As you can see loyalty is not easy to give or receive in a hard commercial environment such as you have chose to work in. Effectively, all you can do is realise that you have an obligation as a supervisor, both to the men in your team and the management you accepted to work for. Try to interpret that obligation fairly and not in haste and when found to be in controversial position, in either direction, examine what is causing the problem keeping it in perspective; offshore problems have a tendency to become exaggerated in the isolation of the worksite.

Help to resolve it where possible to your own satisfaction and always with the aim in mind of fulfilling your role as a commercial diving supervisor running a safe efficient operation.

Summary

By deciding to become a supervisor you accept responsibility that sometimes requires moral courage to make decisions that could be unpopular with your superiors and crew, not necessarily at the same time.

Your decisions on all matters are based on your knowledge plus observation and absorption of information gained by listening to briefings and advice. You then pass on your decisions and information by communicating in a logical manner either verbally or in writing.

You are required as a supervisor to have opinions and express them verbally and in written reports. These need to be objective and rational and you will need confidence to back up controversial views and to handle clients and managers.

That confidence will also be required to manage your crew and infuse your competitive attitude and approach into your shift or diving team.

Without this competitive attitude your commercial ability is reduced, as is your potential for employment.

Foresight and imagination help to make a worksite safe and maintain a good continuity of work progression. A thorough approach and attention to detail further complement this. Your curiosity and interest in your own industry and what is happening around you will enhance your adaptability to react to whatever problem or task is presented in a positive, safe manner.

Finally it was proposed what could be required of you in the terms of loyalty, both to the employer and your team, with the conclusion that as a supervisor you will have an obligation to your team as their leader and to your employer as their representative.

This concludes this section on the qualities required of a supervisor. You can see from what may have appeared to some as a list of unattainable combined skills are really quite ordinary, most of which you already possess. What will make them unique is your approach and personality.

If you consider the list again you will see that only communication, instruction and logic are skills that are formally taught, though courses are designed that can develop and improve all the subjects covered and give you a knowledge of where your strengths and weaknesses lie. Until you go on such a course you will have to make your own assessment of this, developing and extending your approach to supervision and leadership.

Aspects Of Supervision

Having covered the qualities listed for developing your leadership potential and their effect on your ability as a manager we will now look at different aspects that affect your job when supervising.

Client Relationships

There is a paper written on this subject by Martin Dane, a knowledgeable and long serving clients' representative, in it he makes the point that the job of the supervisor / superintendent and clients representative is the preferred domain of the mature man with sound industry knowledge. Generally this is now the case with it improving on both sides of the fence.

It is not advisable to approach client relations in an aggressive manner, ideally a good working relationship should be established with all co-operating towards the common aim of a job safety completed within the time scale.

On your side, as the diving contractor, you must provide the diving services to the best of your ability. On day rate work this is not normally a problem. If you are on fixed rate work job variations must be correctly presented, accepted and logged. On a day rate job you can offer your professional expert opinion of how the work should be carried out, however should your client remain adamant that it should be done otherwise, as long as in your assessment it is safe, then you proceed along their guidelines. That's offering and providing a service. Should it turn out that their way does not work, try not to be patronising (it's difficult), more ask yourself why you failed to convince them you were right in the first place. It's a peculiar misconception that the customer is always right and its more the way you handle the situation when he is wrong, that will govern whether they continue to be a customer of your company.

You've all met the customer's representatives who, when on day rate are continually putting pressure on to speed up the work and then go into complete reversal as soon as you're on fixed price work. You then need all your qualities of patience, tolerance, sense of humour and drive to keep things moving along. Client relations in this situation will fall mainly on to the superintendent while the shift supervisor continues with his work; it must not be allowed for client pressure or antagonism to affect the safe efficient running of the diving operation. However should you end up with a client representative who is totally unreasonable and for all your efforts cannot or will not understand or react reasonably to your suggestions and attempts to educate him, you must inform your project management. When informing them you should make them understand that your relationship with the client has deteriorated and is making your position untenable. While you then continue to maintain a diving operation it is for the shore side senior management to sort out the rights and wrongs of the situation with their liaison structure to the client onshore. The situation may be resolved by removing the company representative and for political reasons you may be moved as well, which could seem harsh if you were in the right, but that's the job you're in.

Your own satisfaction will be that you resolved the situation and left a better worksite for your relief.

Ensure your report the facts as you saw them, preferably in writing, to your project and operations managers. This sort of situation is becoming rarer now that more knowledgeable and mature representatives are taking charge of the client's side of operations.

Don't dismiss or underestimate the importance of the clients representative, he affects and assists your operation by interface and liaison, logistics control and access to the worksites. He has a very real responsibility to his hierarchy to see that safety is observed and contractually agreed procedures are followed and expedited efficiently. He will be observing and logging your performance. As QA/QC grows he will increasingly log you for non- conformance practices. Remember he can order a diving operation to be terminated, though he must have a good reason, but he cannot order diving operations to begin against your will, though you must similarly have good reason for not starting.

To summarise, it makes sound commercial sense to establish good relations from the start. As the senior company representative ensure that no pressure from the client is allowed to interfere with the diving and diving supervisor and work together with the clients representative to ensure continuity, safety and efficient completion of the workscope.

The Diving Management Team 10.1.3

This is a system of utilising the men in your team to their maximum potential. On some worksites you may have on the crew; four diving supervisors, two life support supervisors, two rigging supervisors plus one technical supervisor. Added to this on a hyperbaric welding site there will be two welding supervisors plus a welding superintendent. For the site superintendent, this is his management team. This group of men will be the experts in their fields, with experience that will overlap into each other's departments and shifts, without discussion and feedback being encouraged, then the potential of these men is reduced considerably. There is no point of putting a man in a command position if he is not allowed to exercise initiative, express his opinions and give his advice. Supervisors must encourage their assistant supervisors and senior divers in their teams to feedback information and advice.

This way there is a constant stream of information and ideas that are sieved and formulated at the various stages in the chain. The superintendent, acting as the final arbiter, can base his decisions on sound opinions and advice that stretch right back to the rigger on deck or the diver on the end of his umbilical. It is an isolated manager who may be right some of the time and an integrated manager who will have the opportunity to be right most of the time.

Discipline

This is a word with an immediate negative mental image. It is worth looking at the dictionary definition: "branch of instruction; mental or moral training; orderly behaviour maintained (as) among persons under control or command; chastisement. Train to obedience and order; punish".

It is worth noting that it's only at the end that it gets into what most people associate discipline with that is punishment. As a supervisor you are responsible for maintaining discipline on your worksite and it is an important factor in your man management. The consequences of slack discipline in a potentially hazardous occupation can be fatal. Discipline, as we should apply it, is the ability of a supervisor, who by virtue of his man management qualities maintains an orderly shift.

It is not about continual verbal abuse and threats of being fired.

Discipline by physical or financial threats, only works in the short term, even if you can enforce them they are non-productive. You have some leverage in the power to dismiss men from worksites, cut saturation periods short or not put men into saturation at all. For able managers a measure of your ability is in the infrequency of the use of these powers. Arbitrary dismissal and overuse of the threat of the financial penalties you can impose, is a yardstick of your inability to lead or command respect. That's not to say you mustn't use them but it is the subtlety of their use that marks you as a successful manager.

There is no doubt that men respond to positive discipline, in the context of the definition given.

An additional guideline to consider is to "Praise in public and criticise in private".

It is not always possible to follow this but it does not increase your standing as a supervisor to publicly humiliate someone who has had to be shown the error of their ways. A short, sharp general onsite re-direction followed up the separate sort out in private for the man or men responsible, has a much more positive effect. A man will listen and learn more from your message firmly put across, in a logical determined manner, if he is not worrying that everyone else is seeing him reduced to his component parts.

It is possible to extend this principle to men in saturation by having a word with the offending diver(s) in an unoccupied chamber.

A suggested sequence to follow, when delegating work, is that you first request a task to be done and follow up to check if your requirement has been satisfactorily completed.

If not you then issue your instructions as an order firmly so no one is any doubt as to what is required, should this also be ignored you can issue the first warning of the company disciplinary procedure. You should not very often get to this point, but if you do, don't delay in giving the appropriate warning. With the current industrial relations procedures, you can cause a lot more problems when an individual has to be removed from a work site if the set disciplinary sequence has not been followed.

Make yourself familiar with your company disciplinary procedures, as you are responsible for implementing them correctly, when required.

Having considered discipline you can see that it is not a negative concept but one, which when implemented correctly, ensures a well-run orderly worksite and is a major contributory factor to a good overall team attitude.

It will also aid in generating mutual respect between all levels of managed and management.

The Supervisor As An Instructor 10.1.4

When looking at the ability to communicate the technique of instruction was mentioned as part of that skill. This can and is taught extensively and is a large subject in its own right. You have all probably been on courses where some instructors make the most mundane subjects interesting and other instructors reduce fascinating subjects to a mundane level. You may not be called on to lecture or instruct on a formal basis but you need to recognise the fact that you have a real responsibility to bring on men and develop their potential. Some supervisors do not acknowledge this as a requirement of the job that they have contracted to do and consequently will miss out on increasing their team efficiency and adding useful employees to their company workforce.

It is accepted now that men graduate through diving in a sensible progression of courses and offshore experience. Whatever your opinion of the courses, it has to be acknowledged that they are necessary and produce divers trained in the basic theory and skills to an industry accepted standard.

There is no way that schools can fully reproduce the environment and conditions offshore, or all the many work variations that men will come up against.

This is true of all industry courses, as there can be no substitute for experience. Considering this in a mature diving industry, formal training is a requirement that produces a basic diver who requires further development through experience.

His next biggest hurdle in gaining this experience is the attitude of the offshore supervisors and experienced divers who can literally make or break a diver.

New divers need to be made aware of the amount they have yet to learn and that the main instruction will come from the experienced men they will be working with.

As a supervisor you must assess the man from his CV and personal observation plus reports from the experienced divers on your shift that you rely on to induct and instruct. You will need to spend longer briefing new men and insuring that they are familiar with the equipment that they are going to use, above all don't assume their level of competence and knowledge is sufficient just because they have a licence.

If possible schedule their dives to give them work they are capable of and build up their confidence, where possible pair them off with experienced men. Debrief and explain necessary procedures to correct any mistakes made.

Particularly successful work should be acknowledged and this applies to all divers, the most cynical men still appreciate acknowledgement of their efforts although they will maintain a façade of disinterest.

Instruction and induction should naturally be absorbed into your general work attitude so that most won't even realise it’s going on at all. Progressive training takes place with men new to saturation; they are generally experienced as air divers who have now learnt a new technique.

Again the school has not the facilities to put the men into a long saturation and if they had the students couldn't afford it. They cannot simulate long divers where the requirement to produce work, whilst under surveillance by ROV's, adds to the commercial pressures.

It’s ideal but not always possible to induct new saturation divers on 3 man bell runs and here is important not to use him only as the bellman. He should lock out as diver 2 as often as possible.

When acting as the bellman (he should have completed at least one rescue drill), the supervisor should check on him more frequently, making sure he's done his personal checks and he has run through the sequential procedure for locking out as a bellman.

He has in fact done his "WHAT WOULD I FO IF". This is instruction, though not in the formal sense so you will see that your role as an instructor is an inherent part of your job and its worth considering who spent their time to pass on their experience to you.

This attitude and approach has the positive benefit that along the way you will discover and develop talented men and enhance your team and at the end of the day it's their efforts, under your direction, that makes your reputation.

There is a lot of truth in the maxim: "you are only as good as the people you employ".

Geographical Divided Industry 10.1.5

The offshore industry has a geographical split filled with water, which presents problems both in management and logistics. The infrastructure built up over the years to deal with this split works well but can work better if you and the shore side system try harder to narrow the management gap created by this divide.

The main link is between the project manager and superintendent. It's important that there is mutual respect at this level otherwise the professional rapport required will deteriorate and have a detrimental effect on the progress of the job.

A principle of man management that has a very practical application in our industry is to learn and understand the responsibilities of the next job in the chain and this is nowhere more important than in this link-up between the superintendent and the project manager.

The project manager has a responsibility to his company to ensure a cost-effective operation is being run that will economically be in the black at the works end. He relies on you, offshore, to run an efficient, safe operation and to order and use stories in a sensible effective manner, which is why the selection of men for these two key positions is so important to a company.

The project manager on his part must supply an equally efficient logistics and support operation. If you the offshore manager understand the problems that may occur in supplying this service, then a big step has been taken to bridge the gap.

It is no good ordering stores on the expectation that they will be on site the next day.

This particularly applies to gas, bulk stores and individually tailored specialist equipment. Make yourself aware of the frequency of supply boat runs, helicopter freighting arrangements and the priority systems in force, plus the time scales for ordering and delivery of various essential stores.

The project manager and yourself should, before the job starts, identify those items that can cause your operation to be delayed or stopped if they should be lost, broken or break down. Make sure that the backup is there.

The other role of the project manager, here we are talking about after the planning and preparation stage, is the client liaison ashore. This can occupy a large proportion of his time, especially if the client is lump sum and the company are on day rate. It is important that you understand the contract and the ramifications of deviations and non-performance.

It is further essential that you fill in all the gaps of information that a daily report does not include.

Your project manager must be aware of what is going on both in the work scope and the politics of the worksite; don't allow him to go into meetings with half a story or no story at all.

It is important that all relevant information, not exaggerated, is passed on by radio, fax or mail, keeping in mind how sensitive or controversial the content may be. This is the good news as well as the bad.

As the offshore manager you must also assess your onshore project manager and his knowledge of your operation, which will affect your approach and reliance on him. Establish the operational parameters of reporting and logistics from which your job can progress smoothly with an awareness of the geographical divide and the difficulties that are faced by you and the project manager. Having laboured the requirement for the supervisors to learn what a project manager has to do it is equally important that project managers have a real appreciation of the difficulties that the offshore manager faces.

The most effective method of them being aware of this is the offshore visit, an effort not all are willing to make.

This should be further backed up by their involvement in seminars that allow problems to be aired and discussed.

Superintendents and supervisors occasionally should travel to and from worksites via the base. An hour face to face for a brief / debrief can clear any misunderstanding the phone / radio links and faxes may generate.

It is an opportunity for the two managers to plan their approach to the contract and workscope without the delay of mailed instructions and with the discretion / security lacking in most radio links.

Paperwork Reporting 10.1.6

Paperwork is the curse of the practical man and most supervisors see themselves as practical. However without it nobody gets paid and to a certain extent supervisors do the bare minimum to ensure only this happens. Sometimes it seems to be that for every man that does, five others write about it and with QA/QC growing in the offshore industry the paperwork can only increase.

There is a way around it, there is no reason not to use delegation when it comes to paperwork, it doesn't only apply to physical tasks. Split it up amongst the departments; men with low activity jobs can be given responsibility for routine paperwork. Certification logging can be shared by rigging supervisors and saturation technicians. Daily reports should be sectioned so departments that have the everyday monitoring function can do their relevant parts.

You then should find that you are controlling the paperwork only doing that which is necessary for your position.

Reporting you will find is very much your area and was mentioned briefly in the communications section. You will have various formal reporting requirements which are covered by pads of forms; such as failure reports, accident reports, equipment assessment reports, again these can be completed by the relevant technicians or parties concerned, with your final comments added if necessary.

Non-formalised reporting on general matters and contractual subjects will form part of your written communication skill. It is an increasingly important requirement for high quality reporting and assessment to be passed on from offshore managers both during and after the job.

Future contracts can be bid more competitively if all the pros and cons of vessels, equipment and tasks are known generally and not locked away in supervisor's heads. You should consider it part of your job to report all your assessments, positive and negative and the best media for distribution of this is by written reports.

For project managers, post contract meetings can be a lot easier in terms of getting payments if they know before going in which items may be contentious.

It can sometimes produce a more favourable outcome if your project manager can raise this type of item first in the context of his choosing. These pre-emptive tactics are only possible if you have passed on the facts without embellishment.

Finally a very important area of reporting is personnel assessment and this must be approached with a responsible, fair and objective attitude.

Nowadays, personnel assessments could also involve unions. More importantly to the individual concerned are the consequences of a poor write-up, or poorly written one, affecting their capacity to work and learn a living. This is not to say that you should not tell the truth about a man's ability, but in the case of an unfavourable report do not indulge in invective, outline the main faults, point out the possible road to improvement and recommend alternative options that may be better suited to his capabilities.

For example, a diver who is just not physically able to perform in the water may make a good rigger or saturation technician. Being objective in this case would require an assessment of his ability on the surface and if this is deemed adequate, a suitable recommendation can be made. If on reflection the assessment has to be totally negative you must at least have reached this conclusion after careful consideration.

So you can see that paperwork is an important, necessary part of your work as a supervisor, if approached as a task that can be shared out, once properly organised, it leaves you in a controlling position, allowing you to concentrate on the practical applications of your job.

Conclusion

Quite a lot of ground has been covered in this document for what is only intended as an introduction to a large and generally neglected subject. There are specific courses to introduce and develop the qualities of leadership required of supervisors, but until your company instigates a programme of attending these courses, what you must do is to observe and learn from others and develop or improve your own style and technique at whatever level you are at, or are aiming for.

You may disagree or agree with what is in this document, this is how it should be for managers, you have your own ideas and opinions and should be willing to discuss, absorb or discard pre-set notions and ideas. Advice can always be ignored but it is the province of the ignorant bot to first consider it.

Without the drive to improve and adapt, there is no progression and with no push from those below, there is no impetus for those above to also improve.

What has been proposed in this presentation is a set of ideal qualities and skills and it is recognised that nobody is able to aspire to them all, all of the time. You will at times make mistakes, lose your temper and sense of humour and in some way or other violate every precept of leadership laid out here and elsewhere. Everybody in management does, but while dropping standards in one area you may be getting good results in the others.

When jobs are complete or quiet, it’s worth reflecting and analysing your own performance against what you think you should be aspiring to, that way you can seek to improve which is a positive use of hindsight.

Above all remember your aim is to maintain morale in your team and run an efficient, safe, commercial diving operation; if you are achieving that you can't be going far wrong.

Section 11
Appendix

Abdomen
The portion of the body between the thorax and the pelvis containing the majority of the organs of digestion as well as the liver and spleen.

Abduction
Movement away from the midline of the body.

Acidosis
The condition of an excess concentration of hydrogen ions in the body. (This is the opposite of alkalosis.) This may be as a result of either a metabolic problem or a respiratory problem. Treatment relies on correcting the cause of the imbalance.

Actual Consent
Consent by the adult patient, usually in oral form, accepting emergency care. This must be informed consent.

Acute
To have a rapid onset. Sometimes used to mean severe.

Acute Myocardial Infarction (AMI)
Heart attack. The sudden death of heart muscle due to oxygen starvation. Usually caused by a narrowing or blockage of coronary artery supplying the myocardium.

Acute hypoxia
Sudden fall in oxygen concentration within the blood stream. It may be caused by airway obstruction, lung failure or cardiac failure. Signs may be subtle such as confusion or more obvious such as acute loss of consciousness

Adipose
Nature of fat.

Adduction
Movement toward to midline of the body.

Airway
The passage allowing free movement of air into and out of the lungs. The term is also used to describe clinical devices for maintenance of a patent airway; these may range from simple devices such as Guedel airways to endotracheal tubes.

Alveoli
Microscopic air sacs of the lungs where gas exchange takes place with the circulatory system.

Alkalosis
The condition of a decrease in the body's concentration of hydrogen ions or an increase in bicarbonate ions. Like acidosis, this may be caused by respiratory (hyperventilation) or metabolic causes (the ingestion of excess bicarbonate or loss of excess gastric acid following vomiting).

Allergy
Abnormal sensitivity to normally harmless antigens. In the severest form this may result in an anaphylactic reaction.

Amputation
The loss of a digit, limb or appendage, either deliberately (surgically) or as a result of trauma.

Anatomical Position
Standard reference position for the body in the study of anatomy. The body is erect, facing the observer. The arms are down at the sides and the palms of the hands face forward.

Aneurysm
Blood filled sac caused by the localised dilation of an artery or vein. The dilated or weakened section of an arterial wall.

Angina Pectoris
Chest pains often caused by an insufficient blood supply to the heart muscle.

Anoxia
Absence of oxygen. See Hypoxia.

Anorexia Loss of appetite.

Anterior
Front surface of the body or body part.

Antiseptic
Substance that will stop the growth of, or prevent the activities of germs (micro organisms).

Anaemia
An abnormally low haemoglobin concentration in the blood.

Analgesic
A pain-relieving drug.

Anaphylactic reaction
An extreme reaction to an allergen characterised by release of histamine from cells of the immune system and resulting in generalized itching, angi-oedema, collapse, tachycardia, bronchospasm and (in the worst cases) death.

Anterior
In front of or at the forward limits of the body.

Antibiotic
A drug with antibacterial actions.

Antigen
A substance, usually a protein, the body regards as foreign and against which it produces an antibody in an attempt to render the antigen harmless.

Aorta
Major artery of systemic circulation that carries blood from the heart.

Apnoea
Suspension of breathing.

Arrhythmia
Disturbance of heart rate and rhythm.

Artery
Blood vessel supplying tissues with oxygenated blood.

Aseptic
Clean, free of particles of dirt and debris, but not necessarily sterile.

Astringent
An agent causing contraction of organic tissue.

Asphyxia
Loss of consciousness caused by too little oxygen reaching the brain. The functions of the brain, heart, and lungs will cease.

Atrium
Superior chamber of the heart. (Plural-atria).

Avulsion
Piece of tissue or skin that is torn loose or pulled off by injury.

Auscultation
Listening and interpreting sounds as heard through the stethoscope.

Axilla
The armpit.

Bacteriostatic
Inhibiting the growth of bacteria.

Blanch
Become pale.

Blood pressure (BP)
The pressure exerted by the circulating blood on the arteries as it is pumped around the circulation.

Brachial Pulse
Pulse produced by compressing the major artery of the upper arm. Used to detect heart action and circulation in infants.

Bradycardia
Abnormal condition where the heart rate is very slow. The pulse rate will be below 50 beats per minute.

Bronchiole
Small branches of the airway that carry air to and from the alveoli.

Bronchus
The division of the trachea leading down to the alveoli; the two first divisions after the trachea are known as the right and left main bronchi.

Burn
An injury caused by extremes of temperature – hot or cold. Classified as full-thickness or partial-thickness, depending how deep is the extent of tissue damage. Other causes of burns include chemicals and electricity

Cannula
Hollow tube that can be inserted into a cavity to allow for fluid to be introduced or removed.

Capillary
Microscopic blood vessel where exchange takes place between bloodstream and body tissues.

Carbon Dioxide Retention
An increase in the concentration of carbon dioxide within the blood stream, often secondary to respiratory failure.

Carbon monoxide (CO)
A colourless, odourless gas. It has the ability to combine with haemoglobin in an almost irreversible manner, displacing oxygen and causing hypoxia of the tissues.

Cardiac
Refers to the heart.

Cardiac output
The volume of blood pumped out by the heart in one minute. It is derived from the stroke volume (the amount of blood pumped per heartbeat) multiplied by heart rate.

Carotid arteries
The two major arteries that can be felt in the neck giving arterial supply to the face and brain.

Cardiogenic Shock

Failure of the cardiovascular system brought about when the heart can no longer develop the pressure needed to circulate blood to all parts of the body.

Cardiopulmonary Resuscitation
The re-establishment of the heart and lung action, by artificial ventilation and external cardiac compression.

Cardiovascular
Concerning the heart & blood vessels.
Catheter - flexible tube passed through body channels to allow for the drainage or withdrawal of fluids.

Cephalic
Refers to the head.

Cerebral oedema
An increase in the fluid around the cells in brain tissue with resultant swelling. A number of causes include head injury (the most common). It may present with signs of raised intracranial pressure owing to the closed nature of the skull.

Cerebrospinal Fluid
Clear watery fluid that helps to protect the brain and spinal cord.

Cervical
Relating to the neck or to the interior end of the uterus.

Chin-lift
A manoeuvre to open the airway by pulling forward the point of the chin.

Chronic
Opposite of acute. It can be used to mean long and drawn out or recurring.

Clavicle
(The Collar bone) The supporting bone articulating between the scapula and the sternum.

Clonic Phase
Second phase of a convulsion seizure, with the patient exhibiting violent body jerks, drooling, and possible cyanosis. Most convulsions last 1 to 2 minutes

Coccyx
Lowermost bones of the vertebral column. They are fused into one bone in the adult.

Coagulopathy
An abnormal condition characterised by a decreased ability of the blood to clot. In trauma, this may be caused by continual bleeding and an inadequate replacement of coagulation factors after large blood loss.

Coma
Deep unconsciousness with no response to vocal or painful stimuli and absence of spontaneous eye movement.

Comminuted Fracture
Fracture where the bone is fragmented or turned to powder.

Concussion
State of stupor or temporary unconsciousness caused by a blow to the head. There is no laceration or bleeding in the brain.

Conjunctiva
The membrane that lines the eyelids and the sclera of the eye.

Contraindicated
Condition, sign, or symptom that makes a particular course of treatment or procedure inadvisable.

Contrecoup
The head injury sustained on the opposite side of the head to the site of the blow. It results from the movement of the soft brain against the cranium on the opposite side.

Contusion
Bruise. The simplest form of closed wound where blood flows between tissues causing a discolouration.

Convulsion
Uncontrolled muscle spasm, often violent.

Core Temperature
Body temperature measured at a central point, such as within the rectum.

Cornea
Transparent covering over the iris and pupil of the eye.

Coronary
Refers to the blood vessels that supply blood to the heart muscle. Many people use this term to mean heart attack.

Cranium
Braincase of the skull. Many people use the term skull when they mean cranium.

Crepitus
Grating noise or the sensation felt. Caused by the movement of broken bone ends rubbing together. Also a crackling sound.

Crowing
A typical sound made when a patient breathes. It usually indicates airway obstruction.

Cutaneous
Pertaining to the skin.

Cyanosis
The blue colour seen at the periphery or centrally caused by the inadequate oxygenation of blood, which thus contains too much deoxyhaemoglobin which has a bluish colour.

Dead space
The area of the lung that is in contact with oxygen but is not being perfused with blood; also applied to the volume of air that is contained within the trachea and the bronchi which never reaches the gas exchange surface.

Diaphragm
The musculotendinous sheet that separates the thoracic cavity from the abdominal cavity.

Diastole
The period of time during the cardiac cycle when the heart is relaxed and blood enters the atria or ventricles.

Diastolic Pressure
Pressure exerted on the internal walls of the arteries when the heart is relaxing.

Dilation
To enlarge, expanding in diameter.

Disinfect
To destroy harmful microorganisms, but not necessarily their resistant spores.

Dislocation
Displacement (pulling out) of a bone end that forms part of a joint.

Distal
Away from a point of reference, such as the shoulder or the hip joint. More distant to.

Distended
Inflated, swollen or stretched.

Dysphasia
Difficulty in speaking, due to a brain leasion.

Dyspnea
Difficult or laboured breathing.

Electrocardio-Gram (ECG)
A trace of the electrical activity of the heart normally taken as 12 differing views of the heart. Used to diagnose abnormalities of the heart such as arrhythmias and myocardial infarction.

Embolism
Movement and the lodgement of a blood clot or foreign body (fat or air bubble) inside a blood vessel. The foreign body is called an embolus.

Emergency Medical Technician (EMT)
Professional level provider of emergency care. This individual has received formal training and is state certified.

Emphysema
The abnormal presence of air in tissues or cavities of the body.

Epidermis
Protective structure that overhangs the larynx and hinges backwards during swallowing to prevent food entering the larynx.

Epiglottis
Flap of cartilage and other tissues that is the superior structure of the larynx. It closes off the airway and diverts solids and liquids down the esophagus.

Epistaxis
Nosebleed.

Eructation
Belching. The escape of gas from the stomach, through the mouth.

Erythema
A superficial redness of the skin.

Esophagus
Muscular tube leading from the pharynx to the stomach.

Eustachian Tube
The tube connecting the middle ear to the throat.
Fainting - simple form of shock, occurring when the patient has a temporary, self-correcting, loss of consciousness caused by a reduced supply of blood to the brain. Also called psychogenic (SI- ko-JEN-ic) shock.

Extradural
Literally, outside the dura; particularly refers to the cerebral bleed associated with a temporal fracture where the middle meningeal artery bleeds into the extradural space compressing the cerebral substance.

Femur
The thigh bone.

Fibrillation

Uncoordinated contractions of the myocardium resulting from independent individual muscle fibre activity.

Fibrin
Fibrous protein material formed and utilized to produce a blood clot.

Fibula
Lateral leg bone. Flexion - bending. To lessen the angle of a joint.

Flail chest
A chest wall that as a result of trauma has two rows of multiple rib fractures leading to paradoxical movement.

Flexion
Movement between two bones, generally in a direction to decrease the angle between them.

Fracture
An injury to the bone at which the continuity of the bone is broken. There are a variety of classifications, but one important feature of note is whether the skin has been broken over the fracture site (compound or open fracture) or not (closed).

Gastro
Used as a beginning of words in reference to the stomach.
Genitalia Uen-i-TA-le-ah) - external reproductive organs.

Greenstick Fracture
Split along the length of a bone, giving the appearance of a green stick bent to its breaking point.

Gag reflex
The reflex occurring in response to irritation of the pharynx.

Gangrene
Death of tissue, often due to inadequate blood supply as the main cause, though a variety of other conditions such as cold injury may also cause gangrenous changes. Often divided into wet or dry gangrene: typically, wet gangrene follows major tissue damage such as crush injury.

Glasgow Coma Scale (GCS)
A swift method for assessing and monitoring the conscious level of a patient. It is based on the eye response, the verbal response and motor response.

Guarding
The contraction of the abdominal muscles to protect a painful area from the pressure of an examining hand.

Haematuria
Passage of blood in the urine.

Haematoma
A collection of blood within the tissues; this may be as a direct result of trauma or of surgery.

Haemoglobin (HB)
The red pigment found in red blood cells that is responsible for the carriage of oxygen around the body.

Haemoptysis
Coughing up blood from the lung.

Haemorrhage
The loss of blood – a term normally referring to rapid loss of a large quantity of blood either internally or externally.

Haemothorax
The filling of a pleural cavity with blood, usually after trauma to the chest or following thoracic surgery.

Hemiparesis
Paralysis on one side of the body.

Hemiplegia
Paralysis of one half of the body. The lesion is on the side of the brain opposite to the side paralised.

Hepatic/hepato
Pertaining to the liver.

Hyper-
Prefix meaning increased.

Hyperthermia
Greatly increased body temperature.

Hyperventilation
Increased rate and depth of breathing.

Hypervolaemia
A larger than required circulating volume, generally the result of overtransfusion, though overdrinking (particularly in the presence of reduced renal function) may also give rise to it.

Humerus
Arm bone.

Hypercapnia
An increased amount of carbon dioxide in the blood.

Hyperglycaemia
Excess of sugar in the blood.

Hypertension
Above normal blood-pressure.

Hypo -
Prefix meaning low or inadequate.

Hypoglycaemia
The blood sugar level is less than normal.

Hypotension
A low blood pressure which is inadequate for perfusion of the vital organs. This may be as a result of abnormalities of the heart, side effects of drugs in excess or loss of circulating fluid (for example bleeding).

Hypothermia
A pathologically low body temperature (normally defined as below 35°C), most frequently due to exposure to cold conditions.

Hypovolaemic shock
The state of inadequate perfusion (and therefore oxygenation of the tissues) due to a fall in the circulating volume (usually due to blood loss) and a subsequent fall in blood pressure. Excessive loss of body fluids due to other causes (for example, diarrhoea) can also occasionally cause this.

Hypoxaemia
Low level of oxygen in the blood.

Hypoxia
A fall in the concentration of oxygen in cells. This may result from inadequate oxygenation due to a decrease in atmospheric oxygen, inadequate respiration (due to a reduction in the respiratory drive, an obstruction of the respiratory tract or lung injury) or inadequate circulation (for example, shock).

Infarction
Localized death of tissue resulting from the discontinuation of its blood supply.

Inferior
Away from the top of the body. Usually compared with another structure which is closer to the top (superior).

Infra -
Prefix meaning below or beneath.

Inter-
Prefix meaning between.

Intra -
Prefix meaning within.

Intravenous (IV)
Into a vein (administration of fluid or drugs.

Ischaemia
An inadequate flow of blood to part of the body, caused by constriction or blockage of the blood vessels supplying it.

Jaw-thrust
A manoeuvre to open the airway by pushing the mandible forward, normally with the fingers behind the angle of the mandible.

Joint
A junction between two bones. This may be classified in a number of ways, for example by its structure (for example, a ball and socket joint such as the hip) or by its type (for example, fibrous, cartilaginous or synovial).

Jugular
Pertaining to the neck (for example, jugular vein, the major vein running on the right and left of the neck alongside the carotid artery draining blood from the face and head).

Laceration
Jagged edged open wound. See cut.

Lactic acid
One of the waste products of protein and carbohydrate metabolism. It may accumulate in certain conditions to cause a metabolic acidosis.

Laparotomy
Surgical exploration of the abdominal cavity.

Larynx
Airway situated between the pharynx and the trachea. The voice box.

Laryngo-
Relating to the larynx.

Lateral
To the side, away from the midline of the body.

Ligament
Fibrous tissue that connects bone to bone.

Log roll
Manoeuvre to move a casualty to expose the back but maintaining in-line stability of the whole spine.

Lumbar
(Latin *lumbus*, the loin) General term referring to the lower back between

the thorax and the pelvis, (for example, lumbar spine).

Lumbar Spine
Vertebrae of the lower back, consisting of 5 bones.

Malleolus
(Latin, a little hammer) Rounded, bony protuberances found on the inner (medial) and outer (lateral) aspect of the ankles.

Medial
Toward the vertical midline of the body.

Mediastinum
Central portion of the chest cavity (thoracic cavity) containing the heart, its greater vessels, part of the esophagus, and part of the trachea.

Meninges
Three membranes surrounding the brain and spinal cord.

Metabolic Shock
State of shock due to a loss of body fluids (dehydration) and a change in body chemistry.

Metacarpals
Hand bones.

Metatarsals
Foot bones.

Myocardium
Heart muscle.

Narcotic
A drug that has pain-relieving properties and causes sleep.

Necrosis
The death of tissue, often due to ischaemia.

Neurogenic Shock
Caused when the nervous system fails to control the diameter of the blood vessels. The vessels remain widely dilated, providing too great a volume to be filled by available blood.

Nystagmus
An involuntary, rapid movement of the eyeball.

Oedema
An abnormal collection of fluid around tissue and cells or within tissue spaces.

Oesophagus
The muscular structure that carries food from the oropharynx to the stomach, linking the two structures.

Open Pneumothorax
The collapse of a lung with entry of air into the pleural space and direct communication of the pleural space with the external environment. Also known as a 'sucking' chest wound.

Ophthalmo-
Relating to the eye.

Opiates / opioids
Morphine and related drugs which may be used for pain relief. They have a tendency to cause respiratory depression and nausea. They maybe administered subcutaneously, intramuscularly or intravenously.

Oropharyngeal Airway
Curved breathing tube inserted into the patient's mouth. It will hold the base of the tongue forward.

Osteo-
Relating to bone or bony.

Oxygen (O_2)
A colourless and odourless gas which is vital for cellular metabolism. In conditions of shock and respiratory deficiency its supplementation forms an important part of therapy.

Palpation
To examine a casualty by feeling with the hand(s).

Pancreas
A large glandular retroperitoneal structure lying across the posterior midline of the abdomen.

Paradoxical breathing
Generally associated with traumatic damage to the chest, resulting in instability of the chest wall such that on inspiration the chest wall collapses in and the lung fails to expand.

Paraesthesia
Disorder of sensation, e.g. a feeling of tingling or as of pins & needles.

Paraplegia
Spinal lesion. From lesion below total paralysis.

Paralysis
No power or sensation or movement of any part.

Patella
Kneecap.

Penetrating Wound
Puncture wound with only an entrance wound.

Perforating Wound
Puncture wound with an entrance and an exit.

Perfusion
The passage of blood through a tissue at a rate adequate to supply it with necessary nutrients and remove toxic metabolites.

Peri-
Prefix meaning around.

Pericardium
The sac that surrounds the heart.

Peritoneum
The lining membrane of the abdominal cavity, enfolding all the abdominal cavity. Organs in the abdomen may be within the peritoneal cavity or retroperitoneal (behind the peritoneal cavity): examples of the latter are the kidneys and pancreas.

Peritonitis
Inflammation of the abdominal cavity due to bacterial, chemical or other causes. The most common causes include appendicitis, perforation of an ulcer or perforation of the small or large bowel.

pH
The measure of acid and base balance within the body. It is a measure of the concentration of hydrogen ions present in the blood (the log of the reciprocal of the hydrogen ion concentration). Normal body pH is 7.4. In cases of acidosis (metabolic or respiratory) the pH falls. In alkalotic conditions (metabolic or respiratory alkalosis) the pH rises.

Pharynx
The throat. It is divided into the nasal cavity (nasopharynx), the oral cavity (oropharynx) and the larynx (laryngopharynx).

Plasma
Fluid portion of the blood. It is blood minus blood cells and other structures (formed elements).

Platelet
Formed elements of the blood that release factors needed for form blood clots.

Pleura
The lining tissue that coats the inside of the thoracic cavity, the mediastinal contents and the lungs, allowing movement of the lungs relative to the thoracic wall.

Pneumothorax
A collection of air within the pleural space leading to collapse of the lung. This may be caused by a spontaneous leak from the lung or from perforation of the thoracic wall, (for example, in stabbing). When a leak exists with a 'one-way valve' effect, the pressure of the pneumothorax may increase, leading to distortion of the mediastinum, decreased venous return and collapse: this is known as a tension pneumothorax.

Postero-
Prefix meaning back.

Posterior
Back.

Pre -
Prefix meaning in front of.

Pro-
Prefix meaning before.

Proximal
Usually referring to a point on a limb which is closer to the trunk than another point, (for example, the elbow is more proximal than the fingers).Close to a point of reference such as the shoulder or hip joint. Used with distal, meaning away from.

Prone
Lying face down.

Psychogenic Shock
See fainting.

Pulmonary
Pertaining to the lungs and respiratory system.

Pulmonary Circulation
Circuit of blood travelling from the right ventricle of the heart to the lungs and returning to the left atrium.

Pulmonary Oedema
The accumulation of excess fluid, firstly within the interstitial tissues of the lung and in severe cases within the actual alveoli of the lungs. Most commonly caused by congestive cardiac failure, though also associated with other acute conditions such as following acute head injury, near drowning and following inhalation injuries.

Pulse
The expansion and contraction of an artery as a result of the intermittent

flow of arterial blood; can be detected by palpation or other means.

Pulse Pressure
The difference between the systolic and diastolic blood pressure. A reduction in the pulse pressure as a result of an increase in the diastolic pressure may be one of the first and subtle signs of shock.

Radial pulse
The pulse of the radial artery which can be felt in the wrist; because of the ease with which it can be felt, it is the most frequently palpated.

Rebound tenderness
The pain felt on sudden release of a hand palpating the abdomen. It is seen in conditions of inflammation of the peritoneum.

Rectum
Lower portion of the large intestine ending with the anus.

Referred pain
Pain felt at one site but caused by disease at another anatomical site, (for example, hip disease may present with knee pain).

Respiration
The process of inhaling oxygen-rich atmospheric air and exhaling carbon dioxide-enriched air.

Respiratory acidosis
The condition of increased carbon dioxide and carbonic acid (thus an increased hydrogen ion concentration) due to failure of excretion of carbon dioxide by the lungs. This may be due to suppression of the respiratory centre in the brain (for example, head injury, drugs, and so on) or lung disease.

Respiratory alkalosis
A condition characterised by a decrease in the concentration of carbon dioxide in the blood stream. Like respiratory acidosis it may be caused by lung disease, through hyperventilation and excess excretion of carbon dioxide (for example, asthma or pneumonia). Other causes may include drugs and a variety of medical conditions.

Respiratory Shock
State of shock caused by too little oxygen in the blood. Usually due to lung failure, where the patient is unable to adequately fill the lungs.

Retro-
Prefix meaning behind.

Retrosternal sternum.
Behind the Sacrum - fused vertebrae of the lower back, inferior to the lumbar spine.
At a cellular level, the process of cellular exchange of oxygen as a fuel, metabolising it into carbon dioxide and excreting it.

Rule of nines
An approximate formula that may be used to calculate the surface area of a burn: 9% is allocated to each arm and the head; 18% (2 x 9) to each leg and the front and back of the trunk; and 1% to the perineum.

Sacrum
Fused vertebrae of the lower back, inferior to the lumbar spine.

Scapula
Shoulder blade.

Semi-
Prefix meaning half.

Septic Shock
Form of shock caused by severe infection. Toxins from the infection cause the blood vessels to dilate and plasma to be lost through vessel walls.

Septum
A partition between two cavities.

Shock
Reduced perfusion of tissues inadequate to maintain their metabolic rate and oxygenation. It may have many causes, which fall into five main groups: hypovolaemic, septic, cardiogenic, spinal and anaphylactic.

Skin Traction
A method for attaching bandage or material (either adhesive or non-adhesive) to the skin of a limb in order to apply a corrective force reducing a fracture or orthopaedic deformity.

Spleen
Organ located to the left of the upper abdominal cavity, behind the stomach. It stores blood and destroys old blood cells.

Sphygmomanometer
A device for measuring the arterial blood pressure.

Spine
The collective term for the group of bones which articulate together to form the backbone. It contains the spinal cord.

Spinal Cord Injury
Traumatic damage of the spinal cord. The results depend on the level of the cord where the injury occurs and the severity of the cord damage. Cord damage below C5 and above T1 is associated with quadriplegia, while damage below T1 produces paraplegia. The effects depend on the severity of the damage and may range from temporary to permanent. Transection of the cord is associated with spinal shock characterised by warm peripheries, low blood pressure and absence of sensation and movement below the level of the injury.

Spleen
A vascular organ in the upper left quadrant of the abdomen. Its role is primarily producing cells for the lymphoreticular system. Traumatic damage may result in severe haemorrhage owing to its vascular nature.

Splint
Any device that may be used to immobilise an injured part of the body.

Sterile
Free of all life forms.

Sternum
Breastbone.

Stokes-Adams Syndrome
Attacks of syncope or fainting, due to cerebral anaemia in some cases of complete heart block. The heart stops, but breathing continues.

Strain
Injury to muscles or tendon, caused by overexertion.

Subcutaneous
Beneath the skin. Usually refers to the fatty and connective tissue layer found beneath the dermis.

Subconjunctival Haemorrhage
Bleeding which occurs under the membrane lining the outer side of the eyeball.

Superior
Toward the top of the body. Often used *in* reference with inferior, meaning away from the top of the body.

Sub-
Prefix meaning under.

Subarachnoid Haemorrhage
The presence of blood within the subarachnoid space.

Supine
Lying flat on the back.

Supra -
Prefix meaning above.

Surgical Emphysema
The presence of gas in the subcutaneous or deep tissues of the body that has been forced there due to a leak of air from the lungs or trachea (rarely the gut). It may indicate the presence of a penetrating neck wound or a pneumothorax, for example.

Symptom
Evidence of injury or illness told to you by the patient.

Systemic
Refers to the entire body.

Systole
The part of the cardiac cycle in which the heart contracts and blood is expelled into the aorta.

Systolic Blood Pressure
Force exerted by the blood on the artery walls when the heart is contracting.

Tachycardia
An abnormally fast pulse rate, generally defined as a pulse rate above 100 beats per minute.

Tarsals
Ankle bones.

Tendon
Fibrous tissue that connects muscle to bone.

Therapeutic
Science & art of healing and the treatment of a disease.

Thoracic Cavity
Anterior body cavity above the diaphragm. Protects heart and lungs.

Thoraco-
Relating to the chest.

Thorax
Chest.

Thready Pulse
A pulse that is weak or difficult to feel: may be related to a small pulse volume (pulse pressure) secondary to shock.

Tibia
The main weightbearing bone of the lower limb below the knee joint.

Tinnitus
A ringing or roaring sound in the ears.

Tonic Phase
First state of a convulsive seizure where the patient's body can become

rigid for up to 30 seconds per episode. Can be longer in diving.

Tourniquet
Last resort used to control bleeding. A band or belt is used to constrict blood vessels to stop the flow of blood.

Trachea
The main air passage connecting the lungs to the oropharynx and nasopharynx.

Traction
The placement of a limb or body part under tension; often used in orthopaedics to correct deformity, realign broken bones and as a temporary method of pain relief at a fracture site.

Trans-
Prefix meaning across or over.

Transverse
At right angles to the long axis of the body (this plane is also at right angles to the coronal and sagittal planes).

Trauma
Injury caused by violence, shock or pressure.

Triage
The classification and sorting of casualties into groups based on the severity of injury and chance of survival. Successful triage aims to do the most for the most, even if resources are limited.

Ulna
The long bone of the forearm that runs on the inner aspect from the elbow to the wrist. At the elbow it forms the olecranon.

Unconsciousness
The inability to sense and respond to external stimuli, due to a variety of causes.

Valsalva manoeuvre
Breathing out against a closed glottis to increase intrathoracic pressure.

Vasoconstriction
The narrowing of the blood vessels, particularly the arterioles and veins. This may be accomplished by a variety of stimuli and is useful in the response to shock or to control blood pressure.

Vasodilatation
The widening of the various small vessels (see vasoconstriction) brought about by relaxation of the smooth muscle in the walls of the vessels.

Vein
Any blood vessel that returns blood to the heart.

Ventilation
The process of exchanging gases from within the lung to the atmosphere.

Ventral
Front of the body or body part. See Anterior.

Ventricle
Inferior chamber of the heart. Ventricles pump blood from the heart.

Vertebra
One of the constituent bones of the spinal column. It may be a cervical, thoracic, lumbar, sacral or coccygeal vertebra.

Viscera
Internal organs. Usually refers to the abdominal organs.

Vital Signs
In **DMT** care, pulse rate and character, breathing rate and character, blood pressure, and relative skin temperature. Pupil reaction.

Whiplash injury
Forced flexion/extension injury of the neck often seen following a road traffic accident.

Xiphoid
Inferior process of the sternum.

COLORIMETRIC TUBES Appendix 2 11.2

Colorimetric Tubes

Colorimetric tubes, e.g. Dräger, MSA, are commonly used offshore, notably for the measurement of carbon dioxide in bells and chambers but also for the identification and quantification of other trace gases.

The tubes give a readout due to colour change brought about by the reaction between gas tested and the chemical indicator.

The tubes are calibrated to be used on the surface so special care must be taken when they are used under pressure.

Over 100 Different Detection Tubes Are Available:

- Some hints on the use of colorimetric tubes:
  - Check pump gas tightness by inserting unopened tube and compressing bellows. If the bellows open then there is a gas leak.
  - Open inlet end of tube first, then outlet end.
  - Insert tube into pump with arrow pointing to pump.
  - N = number of pumps, i.e. N = 5 = 5 pumps.

Note: Some colourmetric tubes have a dual detector and are identified as N1 and N5 (number of pumps) e.g. if using the N1 and there is no trace/discolouration, pump it 4 more times & read the N5 scale

  - Take reading from end of discoloration.
  - Do not use the same tube twice. However some tubes can be used twice (read instructions)
  - Ensure that the tube is in-date.
  - Always allow bellows to fully expand after each pump.

Note: Tubes normally give a reading in percent or parts per million (ppm).

To Convert This Reading To A Partial Pressure:

At Depth Readout in % x 10 = partial pressure in mbar

1% x 10 = 10mbar

Readout in ppm = partial pressure in □bar

10,000ppm = 10,000 micro bar **= 10 mbar**

On Surface Readout in % x Abs Pressure x 10 = partial pressure in mbar

Readout in ppm x Abs Pressure = partial pressure in□bar

100ppm X 10 ATA = 10000microbar **= 1mbar**

Humidity has no influence on readings.

HSE

Health and Safety Executive

Diver's breathing air standard and the frequency of examination and tests

HSE information sheet

Diving Information Sheet No 9 (Revision 1)

Introduction

This diving information sheet (DVIS) is part of a series of information sheets providing guidance on diving at work.

It gives recommendations on the correct standard to be used for assessing the quality of divers' breathing air and includes revised guidance on acceptable levels of carbon monoxide (CO). It also provides guidance on the frequency of tests.

Unit symbols

There are two unit symbols used in this DVIS for 'per metre cubed'. Quotations from EH40/2005 *Workplace Exposure Limits*[1] are shown as .m-3, quotations from BS EN 12021: 1999 *Respiratory protective devices. Compressed air for breathing apparatus*[2] are shown as /m3.

Legislation

The Control of Substances Hazardous to Health Regulations 2002 (as amended) (COSHH)[3] and the associated Approved Code of Practice (ACoP) and guidance[4] apply.

Standard for diver's breathing air

For compressed air used by divers, BS EN 12021[2] should be used and not BS 4275 as stated in paragraph 178 of the COSHH ACoP and guidance.[4]

BS EN 12021[2] supersedes the previous standard, BS 4001.

BS EN 12021[2] applies to both SCUBA and surface supplied diving air supplies.

The National Foreword to BS EN 12021[2] requires that all contaminants should be kept to as low a level as possible and shall be not greater than 10% of the UK 8-hour time weighted average (TWA) workplace exposure limits (WELs). These WELs are detailed in HSE publication EH40[1] (see Note 1). The maximum contaminant levels specified in BS EN 12021 are already 10% of the UK 8-hour TWA WELs with the exception of CO. Ten per cent of the 8-hour TWA WEL for CO is 3.5 mg.m-3 (3 ppm).

Taking into account the requirements of the National Foreword to BS EN 12021,[2] the standards for breathing air are detailed below. All measurements are at atmospheric pressure.

- The oxygen content shall be in the range of 21% (+_ 1) by volume (dry air).
- Lubricant content (droplets or mist) shall not exceed 0.5 mg.m-3.
- Carbon dioxide content shall not exceed 500 ml.m-3 (500 ppm).
- Carbon monoxide content shall be as low as possible but not exceed 3.5 mg.m-3 (3 ppm).
- The air shall be without significant odour or taste.
- There shall be no free liquid water.
- The maximum water content of the air measured at:
  - a compressor system outlet for filling cylinders, should not exceed 25 mg.m-3.
  - a cylinder outlet, cylinder pressure from 40 to 200 bar, should not exceed 50 mg.m-3.
  - a cylinder outlet, cylinder pressure >200 bar, should not exceed 35 mg.m-3.

Water content below 40 bar

There is no maximum water content specified for air supplied below 40 bar, ie low pressure air compressor supplies for surface supplied diving equipment and compression chambers. However, dew point limitations apply.

The dew point shall be sufficiently low to prevent condensation and freezing. Where the apparatus is used and stored at a known temperature, the pressure dew point shall be at least 5 °C below the likely lowest temperature. Where conditions of usage and storage of the compressed air supply is not known, the pressure dew point shall not exceed -11 °C. For further advice see Appendix 1.

Other contaminants

A risk assessment should be carried out to establish if any other contaminants should be tested for in addition to those specified in BS EN 12021.[2] There are two points to note:

- You should check the compressor lubricant safety data sheet and/or the compressor manufacturer's operation and maintenance manual to see if there are any specific substances that should be tested for.
- The location of the compressor inlet should be in a position that is unlikely to allow contaminated air to be drawn in. Local potential sources of contamination should be identified, such as ventilation exhausts, and the owners asked what is being exhausted into the atmosphere. If there is any doubt, additional tests for the likely contamination and increased frequency of tests may be necessary.

Frequency of tests

A competent person (see Note 2) should test the quality of the air supplied for breathing apparatus at least once every three months. More frequent tests should be conducted if contamination is foreseeable within this three-month period.

Additional methods of assuring air quality

Monitor filter life by measuring running hours or the volume of cylinders filled. Both of these methods rely on the contamination not exceeding the levels assumed by the manufacturer in setting the recommended hours or throughput.

A more reliable method of assurance is to monitor the air quality on-line.

One technique of monitoring on line is to measure the moisture content.

- Filter cartridges are usually designed so that the drying element becomes saturated before there is any deterioration of the other elements. Therefore monitoring the moisture content of the air at the filter outlet can indicate when the filter has reached the end of its life.
- On-line moisture content measurement equipment can be:
  - built into the filter element;
  - a separate measuring device;
  - a simple visual indicator.
- The provision of on-line moisture content measurement equipment will be of particular benefit where the air is for sale, as it will provide visible assurance to the user of the gas.

CO can be produced within a compressor as a result of breakdown of the lubricating oil caused by pyrolysis (chemical decomposition by heat). Pyrolysis can occur when the system is hot, but not necessarily overheating and the resulting short-term high levels of CO would not necessarily be identified during periodic sampling. To minimise this hazard provision of a CO catalyst in the filter system and/or online monitoring for CO content should be considered.

Before fitting any such additional devices, you should seek the views of the compressor and/or filter manufacturer.

Appendix 1 - Advice on establishing the pressure dew point limit

HSE commissioned a research project to provide advice on how to establish that the pressure dew point limit does not exceed the limits specified in BS EN 12021.[2] Two proposals for guidance have been established.

Simple operational guidance

Using the requirement that the water content should have a pressure dew point that does not exceed (ie reach a higher temperature than) -11 °C, an extension of the levels specified in the original table in BS EN 12021[2] has been derived. The new calculated values, together with the existing limits from BS EN 12021[2] (ie water content at 40, 200 and 300 bar), are presented in Table 1.

Table 1 Simple operational guidance

Nominal maximum supply pressure bar	Maximum water content of air at atmospheric pressure and 20 °C $mg.m^{-3}$
5	290
10	160
15	110
20	80
25	65
30	55
40	50
200	50
>200	35

This is likely to be the simplest way of interpreting the requirements of BS EN 12021[2] for low supply pressures and is recommended as the preferred system. However, it does not take into account ambient temperature or provide any flexibility in permitted levels based on local climatic conditions.

Flexible operational guidance

A more flexible method of establishing the maximum permitted water content has been developed but this requires a more complex presentation. The details are outside the scope of this DVIS, but can be obtained from HSE Research Report 427 *Moisture levels in compressed breathing air* at: www.hse.gov.uk/research/rrpdf/rr427.pdf.

Notes

1 Workplace Exposure Limits (WELs) are Occupational Exposure Limits (OELs) set under COSHH,[3] in order to help protect the health of workers.

2 A 'competent person' is a person having a combination of training, knowledge and experience that will mean they can do the job required in a safe and efficient manner, using the test apparatus provided for the task. The dutyholder will have to decide who the 'competent person' will be. An appropriately qualified employee could fulfil the requirement.

References

1 EH40/2005 *Workplace Exposure Limits: Containing the list of workplace exposure limits for use with the Control of Substances Hazardous to Health Regulations 2002* (as amended) Environmental Hygiene Guidance Note EH40 HSE Books 2005 ISBN 978 0 7176 2977 0

2 BS EN 12021:1999. *Respiratory protective devices. Compressed air for breathing apparatus* British Standards Institution ISBN 0 580 32082 0

3 *The Control of Substances Hazardous to Health Regulations 2002* SI 2002/2677 (as amended) The Stationery Office ISBN 0 11 042919 2

4 *Control of substances hazardous to health (Fifth edition). The Control of Substances Hazardous to Health Regulations 2002 (as amended). Approved Code of Practice and guidance* L5 (Fifth edition) HSE Books 2005 ISBN 978 0 7176 2981 7

Further reading

Commercial diving projects offshore. Diving at Work Regulations 1997. Approved Code of Practice L103 HSE Books 1998 ISBN 978 0 7176 1494 3

Commercial diving projects inland/inshore. Diving at Work Regulations 1997. Approved Code of Practice L104 HSE Books 1998 ISBN 978 0 7176 1495 0

Recreational diving projects. Diving at Work Regulations 1997. Approved Code of Practice L105 HSE Books 1998 ISBN 978 0 7176 1496 7

Media diving projects. Diving at Work Regulations 1997. Approved Code of Practice L106 HSE Books 1998 ISBN 978 0 7176 1497 4

Scientific and archaeological diving projects. Diving at Work Regulations 1997. Approved Code of Practice L107 HSE Books 1998 ISBN 978 0 7176 1498 1

The Diving at Work Regulations 1997 SI 1997/2776 The Stationery Office 1997 ISBN 0 11 065170 7

For British Standards see: www.bsi-global.com

For Stationery Office publications see: www.tso.co.uk

Further information

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This document contains notes on good practice which are not compulsory but which you may find helpful in considering what you need to do.
This document is available web-only at: www.hse.gov.uk/pubns/dvis9.pdf.

Published by the Health and Safety Executive DVIS9(rev1) 06/08

U.K. LEGISLATION APPENDIX 4 11.4

Acts

- Offshore Safety Act 1992
- Health and Safety at Work etc. Act 1974 Part 1

Statutory Instruments

SI 263 The Health and Safety at Work etc. Act 1974 (Application outside Great Britain) Order 1995

SI 738 The Offshore Installations & Pipeline Works (Management & Administration) Regulations 1995

SI 743 The Offshore Installations (Prevention of Fire & Explosion, and Emergency Response) Regulations 1995

SI 825 The Pipelines Safety Regulations 1996

SI 913 The Offshore Installations and Wells (Design & Construction, etc.) Regulations 1996

SI 1513 The Health and Safety (Consultation with Employees) Regulations 1996

SI 1592 The Construction (Health, Safety & Welfare) Regulations 1996

SI 1671 The Offshore Installations & Pipeline Works (First Aid) Regulations 1989

SI 1993 The Offshore Electricity and Noise Regulations 1997

SI 2051 The Management of Health and Safety at Work Regulations 1992

SI 2776 The Diving at Work Regulations 1997

SI 2792 The Health & Safety (Display Screen Equipment) Regulations 1992

SI 2793 The Manual Handling Operations Regulations 1992 (as amended)

SI 3117 The Offshore Installations (Safety Case) Regulations 2005

In practice, ‘agency’ agreements exist between the various Departments of State having formal responsibility for the various Acts and Regulations.

These result in the division of responsibilities summarised at the start of this section.

UK Government Diving Inspectors have the right to visit and inspect, within reason, any site, installation or vessel from which diving operations are being carried out.

Within the terms of the relevant statutory instruments, they may examine all plant and equipment and hold discussions with all personnel concerned with the operation. It is clearly necessary for them to develop a rapport with key personnel in order to assist in the improvement of safety standards without inhibiting the efficiency of the diving operation.

Good communications between the Inspectors and relevant personnel, depending on the nature of particular problems and circumstances, is clearly vitally important.

NORWEGIAN LEGISLATION APPENDIX 5 11.5

Framework Regulations:

Sec 2 States the provisions of the working environment act and these regulations cover MUO in the Petroleum sector

Sec 5 On the responsibility according to the regulations

Sec 9 On Risk Reduction

Sec 10 On competence

Sec 11 On HES culture

Sec 13 Covers management system and the responsibility of the obliged party and the PSA carries out supervision of the management system

Sec 14 States the party responsible shall ensure that contractors fulfil the rules and regulations of HES

Sec 18 When using a standard recommended in the guidelines (e.g. NORSOK) as a means of complying with the requirements of the HES Regulations, the party responsible may as a rule take it that the regulation requirements have been met

Sec 20 States what HES matter should be covered in a plan for installation and operation of facilities (including MUO)

Sec 24 On development concepts (including MUO)

Sec 44 The operator and the party responsible (see Sec 13) for a MUO may conclude an agreement as to who is to be regarded as responsible for co-ordinating the HES of the enterprise

Sec 45 On joint working environment committees

Sec 63 Entry into force and repeal of regulations

Management Regulations:

Sec 1 On risk reduction

Sec 2 On barriers

Sec 3 On management of HES

Sec 4 On objectives and strategies

Sec 6 On acceptance criteria for risk

Sec 7 On monitoring of HES

Sec 8 On decision criteria

Sec 9 On planning

Sec 10 On work processes

Sec 11 On manning and competence

Sec 12 On information

Sec 13 On requirement to analyses

Sec 14 On risk analysis

Sec 15 On risk analysis

Sec 16 On risk analysis

Sec 17 On risk analysis

Sec 18 On data collection

Sec 19 Record and exam of hazard and accident

Sec 20 On non-conformities

Sec 21 On follow-up

Sec 22 On improvement

Technical and Operational Regulations

Chapter I Introductory Provisions

Chapter II General Provisions for Designing Onshore Facilities

Chapter III Design Of Areas, Installations, Systems and Equipment

Chapter IV Working Environment Factors In The Design Of Onshore Facilities

Chapter V Fire And Explosion Protection In The Design Of Onshore Facilities

Chapter VI General Provision For Conducting Activities

Chapter VII Competence And Information For Conductiong Activities

Chapter VIII Planning, Operations And Control During Activities

Chapter IX Emergency Preparedness

Chapter X Health Related Matters

Chapter XI Concluding Provision

Facilities Regulations:

Sec 1 Controlling physical measures of safety functions (mentions pressure, humidity, temperature and gas composition in diving facilities)

Sec 2 Requirement to facilities in these regulations also apply to systems and equipment used for MUO

Sec 3 On choice of development concept (inc. MUO)

Sec 7 On safety functions

Sec 9 On plant, systems and equipment references NORSOK U-100 and AODC 035 (Safe use of electricity underwater)

Sec 12 On evacuation routes

Sec 13 On indoor climate (inc. MUO) references NORSOK U-100

Sec 15 On location and handling of flammable and explosive goods. References NORSOK U-100 (Gas Handling)

Sec 16 On instrumentation for monitoring and recording

Sec 17 Systems for internal communications references NORSOK U-100

Sec 18 On communication equipment references NORSOK U-100

Sec 20 Covers information presentation

Sec 22 On noise references NORSOK U-100

Sec 36 The chambers (internal and external) system, gas storage and control areas should have fixed fire-fighting systems

Sec 40 On rescue equipment references NORSOK U-100

Sec 43 On means of evacuation references NORSOK U-100

Sec 66 Systems and equipment for MUO mentions bell and chamber minimum dimensions (same as NORSOK) and also it shall be possible to have controlled disconnection of a habitat if vessel loses position

Activities:

Sec 1 Requirement to facilities in these regulations also apply to systems and equipment used for MUO

Sec 2 On working environment committees

Sec 3 On safety and health personnel

Sec 4 On medical equipment examinations (inc. MUO)

Sec 6 On the health service (inc. MUO)

Sec 19 On competence on HES references NORSOK U-100

Sec 21 On practice and drills references NORSOK U-100

Sec 22 On procedures to prevent situations of hazard and accident references NORSOK U-100

Sec 29 On monitoring and control of HES references NORSOK U-100

Sec 34 On chemical hazard references NORSOK U-100

Sec 64 On establishing emergency prepardness references NORSOK U-100

Sec 67 On emergency prepardness plans references NORSOK U-100

Sec 68 On handling situations of hazard and accident references NORSOK U-100

Sec 81 On positioning (inc. MUO)

Sec 82 On work and operation of electrical installations references AODC 035 Code of Practice for safe use of electricity underwater

Sec 84 Operational actions shall be taken during MUO, so that those who take part in the operations are not subject to injury/illness, and so that the probability of hazard/accident is reduced. References NORSOK U-100

Sec 85 Provisions relating to the time periods (for MUO) as per NORSOK U-100 except bell run time in

Regs From start of trunk depressurisation to trunk equalisation.

NORSOK

U Series Rts From Clamp Off To Clamp On:

- **U-100** Manned Underwater Operations
- **U-101** Diving respiratory Equipment
- **U-102** Remotely Operated Vehicles (ROV) Services
- **U-103** Inshore Diving

Currents, Sea States and Weather

Surface Conditions

Before a diving operation begins, careful consideration must be given to the existing and probable changes in surface conditions of sea, visibility and air temperatures, as well as to the presence and expected movements of ships in the vicinity of the operation. Any of these factors may affect the satisfactory performance of the operation.

Weather and Sea States

A rough sea may well endanger the diver, particularly when he is operating close to the surface, around a small craft, which may be moving violently, and when he is leaving the water. Sea-sickness may become a serious problem and prevent a diver from carrying out a dive. A rough sea may render impossible the efficient mooring of a diving boat.

The state of the sea will have considerably more effect on the surface support team than it will on the diver. A rough sea will interfere with the exchange of lifeline signals, but, in particular, will make the recovery of an unconscious diver a difficult and dangerous operation - one of the major factors to consider when deciding whether or not diving should take place. As rule, surface diving in open water becomes impracticable in winds stronger than Force 4.

In water, decompression is also adversely affected by wave action, especially the shallow stops for standard air decompression. Supervisors must plan dives so as to allow due regard to any wave action or any expected deterioration of the weather.

Remember also that a diver may not be affected by waves or current at depth but he may be affected on his ascent. Likewise, it may be impossible to deploy the standby diver in an emergency.

In deep water, the motion of the water caused by surface waves diminishes rapidly with depth, so that at a depth of half the wave length a diver can barely feel the motion of the waves. For example, if the wave length is 40 metres the water will be almost still at a depth of 20 metres. In shallow water the motion diminishes less rapidly with depth.

Apart from tides and currents, all the sea's activities are the result of wind, which affects the sea in three distinct ways, by the speed of the wind, by the length of time that the wind has been blowing and by the distance that the wind has blown over the water (the fetch). Locally produced disturbances are called seas and are different from remotely produced ones called swells. Swells may even be the product of a weather system from across the ocean.

A cross swell is caused by a fresh swell being formed from a different direction from the residual swell. The result can produce a most uncomfortable motion, which may complicate shallow water operations.

Maximum Wave Height

This is the maximum height of crest to trough over a 10 minute period. This includes swell.

Significant Wave Height

Most of the terms in the UK Meteorological Office's 'subscribers' reports are self- explanatory, but one deserves further explanation. "Significant wave height" is defined as the average height of the largest one third of all waves, which was recorded over a period of 10 minutes.

A close approximation of significant wave height may be obtained by observing the height of the largest wave in any 2 minute period. Observers should note that the foreshortening effect of looking down from the deck of an installation is considerable.

Eyeball estimates can be very inaccurate. A convenient scale should be marked on one or more of the installation's legs to aid more accurate assessment.

Wind Driven Currents

The wind also causes the sea surface to move as a current. The direction of this wind driven surface current is not the same as that of the wind but at an angle of 45_o to it. In the northern hemisphere it is 45_o to the right of the wind direction, while in the southern hemisphere it is 45_o to the left. This effect is due to the earth's rotation and is called the Coriolis effect.

The strength of the wind driven current lessens with increasing depth. Also the direction of travel turns progressively away from the direction of the wind. For example, at 11 metres the current direction is 90_o to the wind direction. This spiralling change of direction is known as the Ekman Spiral. Its effect increases with its distance from the equator.

Except in very shallow water, the surface current speed is equivalent to approximately 3% of wind speed. It decreases, however, at a rate which depends on the stability of the entire water column, the length of time the wind has been blowing, the uninterrupted distance over which it has blown (the fetch), and the size of the waves present.

Wave Definitions

- **The Wave Form** is the curve of the surface of the sea seen in elevation. Anyone wave form extends from a point on a wave surface (for example a crest) to the equivalent point on the next wave.
- **The Wave Length** is the horizontal distance between one crest to a preceding or a succeeding one, along the long of advance.
- **The Wave Height** is the vertical distance from trough to crest on one wave form.
- **The Wave Speed** is that with which the wave form is moving relative to the undisturbed body of water, measured horizontally in the direction of the advance of the wave form.
- **The Still Water Level** is that which a body of water will assume when unaffected by wave forms.
- **The Wave Train** is a succession of waves proceeding as a group in a given direction.
- **The Period of a Wave** is the time interval between the passing of two successive crests or troughs.

Sea State Tables 11.6.2

Sea state tables are normally expressed in tabular form. This usually corresponds quite closely to the **Beaufort Scale** which attempts to relate wind speed to the behaviour of the environment. The difference between the "sea states" and the Beaufort Scale is that sea state has the advantage of referring to the actual sea condition at the time of observation.

The Beaufort Scale refers to the sea condition in a fully arisen sea; this can take hours to achieve in any wind condition.

As an example, in open reaches of the North Sea, a wind speed of 30 knots from one direction for an hour results in a sea state of 5/6.

The Beaufort Scale

Beaufort Scale	Wind Speed (Knots)	Description
0	0	Calm, sea like a mirror
1	1 - 3	Light air, ripples only
2	4 - 6	Light breeze. large wavelets (0.2m), crests have a glassy appearance
3	7 - 10	Gentle breeze, Large wavelets (0.6m) crests beginning to break
4	11 - 16	Moderate breeze, small waves (1m), some white horses
5	17 - 21	Fresh breeze, large waves (3m), many white horses
6	22 - 27	Strong breeze, large waves (3m), probably some spray
7	28 - 33	Near gale, mounting sea (4m) with foam blown in streaks downwind
8	34 - 40	Gale, moderately high waves (5.5m), crests break into spindrift
9	41 - 47	Strong gale, high waves (7m), dense foam, visibility affected
10	48 - 55	Storm, very high waves (9m), heavy sea roll, visibility impaired. Surface generally white
11	56 - 63	Violent storm, exceptionally high waves (11m), visibility poor.
12	64 and over	Hurricane, (14m) waves, air filled with foam and spray, visibility bad.

Gale Warnings	
Gale	Winds of at least Beaufort force 8 (34-40 knots) or gusts reaching 43-51 knots
Severe Gale	Winds of force 9 (41 – 47 knots) or gusts reaching 52-60 knots
Violent Storm	Winds of force 11 (56 – 63 knots) or gusts of 69 knots or more
Hurricane Force	Winds of force 12 (64 knots or more). Note the term is Hurricane force: the term hurricane on its own is only to imply a true tropical cyclone.
Expected	
Imminent	Expected within 6 hours of time of issue
Soon	Expected within 6 to 12 hours of time of issue
Later	Expected more than 12 hours of time of issue

Meaning of Terms Used in Weather Bulletins

Visibility	
Good	More than 5 n.miles
Moderate	2-5 n. miles
Poor	2 miles - 1,100 yards (1,000 metres)
Fog	Less than 1,100 yards (1,000 metres)

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