Topics in Basic Sciences –

for Theme 20.1 of the AFOEM training curriculum

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The topics are arranged here in the approximate order in which they appear in Theme 20.1 of the AFOEM Training Curriculum.

This is one of three documents that go together to assist you to prepare for questions in your Stage A exam on curriculum Theme 20.1. More than that, an understanding what's written here will give you perspective and the ability to anticipate what to expect with industrial exposures.

Because this will be largely revision of things you learnt in high school, I suggest the best use of your time would be to start first with the quiz. This is Document 1. Then, for any questions about which you are uncertain, read the commentary on the quiz questions. That is Document 2. Then, for anything for which you seek a longer explanation, come to this document and use the table of contents above.

I am willing to discuss these things with you if these documents don't assist you enough.

PHYSICAL AGENTS

SI Units and prefixes used with them

A measurement assigns a number to a situation, an object or a creature in order to represent the quantity of an attribute there. The number is nearly always assigned according to a rule; that rule places the attribute on an agreed scale. Having this rule means that the measurement may be told to others without confusing them. The units of measurement used in most (not all) areas of occupational medicine is the international system of units whose abbreviation (système international d'unités) in the French language is SI.

ATTRIBUTE	UNIT OF MEASUREMENT & SYMBOL
amount	mole (mol) [1 mole = 6.02×10^{23}, i.e. nearly one trillion trillion]
temperature	kelvin (K) or degrees Celsius (^{o}C)
volume	litre (L) or cubic metre (m^3) [1000 L = 1 m^3]
pressure	pascal (Pa)
force	newton (N)
energy	joule (J)
power	watt (W)
frequency	hertz (Hz)
noise intensity	watt per square metre ($W.m^{-2}$)
sound level	bel (B)
relative molecular mass (molecular weight)	dalton (da)

Very often, the basic unit is too big or too small for a particular purpose. For example, if you want to measure the mass of particles suspended in air then the unit of grams is too big. Instead we measure in units of $\frac{1}{1000}$ of a gram, i.e. *milli*grams. On the other hand, the gram is too small for an adult person's mass – so we weigh people in *kilo*grams. Thus we see prefixes such as 'milli-' and 'kilo-' attached to units of measurement. Examples follow:

PREFIX WITH ABBREVIATION	MEANING	EXAMPLE
Larger than 1		
tera- (T)	one trillion times ($10^{12} \times$)	terajoule (TJ)
giga- (G)	one billion times ($10^{9} \times$)	gigahertz (GHz)
mega- (M)	one million times ($10^{6} \times$)	megalitre (ML)
kilo- (k)	one thousand times	kilowatt (kW), kilogram (kg)
hecto- (H)	one hundred times	hectare (Ha), hectopascal (HPa)
deca- (da)	ten times	Rarely used – people just say '10 grams' rather than '1 decagram'. 'deca' appears in terms such as *decade*, *decahedron* and *decathlon*.
Smaller than 1		
deci- (d)	one tenth of	decibel (dB), decilitre (dL)
centi- (c)	one hundredth of ($10^{-2}\times$)	centimetre (cm)
milli- (m)	one thousandth of ($10^{-3}\times$)	milligram (mg), milliampere (mA)
micro- (μ)	one millionth of ($10^{-6}\times$)	microsecond (μs)
nano- (n)	one billionth of ($10^{-9}\times$)	nanomole (nmol)
pico- (p)	one trillionth of ($10^{-12}\times$)	picowatt (pW)
femto- (f)	one quadrillionth of ($10^{-15}\times$)	femtolitre (fL)

Energy

Energy is the property of a thing or substance that gives it the *ability to change* or to maintain itself against a tide of change. Energy is the 'currency' of change and may be endowed or conferred because of, for example, height, charge, velocity, temperature, chemical structure. Waves (e.g. light, x-rays) transfer energy from one thing to another without transferring matter.

Sound

Sound is tiny repeating pressure waves in air that travel fast. Sound originates from rapid vibrations – hundreds or several thousands of times a second. Correspondingly, sound typically has hundreds or several thousands of little peaks of pressure passing a fixed point every second at a speed of around one-third of a kilometre per second.[1] The count of such waves that pass in each second is measured in *hertz*. Each extra vibration per second is one more hertz. This is formally referred to as the *frequency* of sound and it largely determines the pitch of sound that we hear – high note or low note, tinkle or gong, soprano or base.

Intensity is the vigour with which the particles of air move backwards and forwards (oscillate) in a sound wave. It is related to amount of pressure in each wave – in fact, pressure × pressure, to be exact. Formally, a physicist would measure intensity in units of energy crossing an area of one square metre in each second (picowatts per square metre, pW.m^{-2}) but, as explained further on, we measure something called 'intensity level' in decibels rather than plain intensity.

Intensity is the physical characteristic most closely aligned with loudness. Yet, intensity is *not* exactly the same as loudness because the ear is more sensitive to some sound frequencies than to others. A young person's ear is more sensitive to the consonant sounds in our speech than the vowel sounds. This frequency-related acuity gradually deteriorates with ageing.

If there are two sounds, we can pick a small difference in intensity if the sounds are quite soft, but we can only only a large difference if the sounds are loud. Thus, measurement of intensity must take account of little differences when sounds are soft but need only bother with big differences when sounds are loud. The special measure that takes account of this is called the intensity *level*. Intensity *level* is measured by using a logarithmic unit called the *decibel*.[2] But, being logarithmic has some disadvantages – you can't simply add decibels. Making a sound twice as intense ***adds** just 3 decibels*, so 85 + 85 = 88 decibels. (see the section below on **logarithms**)

There is a large range of intensity between a very loud sound and a sound that is only just discernible. One advantage of decibels is to condense this range to manageable proportions. There are meters to measure sound pressure. The inner electronics of the meter converts pressure to an intensity level in decibels.

Noise-induced hearing loss involves the little cells in the inner ear that help to amplify soft sounds, the so-called external hair cells. It affects only that band of cells that amplify high-pitched sounds – which are the consonants, b, f, p etc. – made with the tongue and lips. This is important because it is consonants that give the meaning to words, yet consonants are *not* usually the loudest part of an uttered word. The loss causes consonants to become muffled. It also affects a person's ability to detect one voice among a clamour of others in a noisy room, such as at a party. A person with this type of hearing loss relies to some extent on lip reading to make sense of what another person is saying.

Logarithms

Some numbers can be formed by multiplying together a series of identical factors, thus:

100 000 = 10 x 10 x 10 x 10 x 10 [5 identical factors].

The factors may be any number, e.g. 128 = 2 x 2 x 2 x 2 x 2 x 2 x 2 [7 identical factors].

Even fractional numbers can be used:

4 ≈ 1.259 x 1.259 x 1.259 x 1.259 x 1.259 x 1.259 [6 identical factors].

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[1] The speed of sound in air, *c*, is $20.\sqrt{T}$ metres per second, where *T* is the absolute (thermodynamic) temperature measured in kelvin, K. Where, for example, the air temperature is 16°C, i.e. 16 + 273 = 289K, then *c* = $20 \times \sqrt{289}$ = 20 x 17 = 340 metres per second.

[2] An intensity level of 0 decibels is equivalent to 1 picowatt per square metre, the average threshold of hearing of a young person with healthy ears for a sound of frequency 1 kilohertz. Zero decibels does *not* mean zero sound. Some animals, e.g. dogs, can hear sounds at intensity levels lower than 0 decibels.

Over the centuries, a pair of special terms has come to be applied to situations like this. The repeated factor may be called a *base number* and the count of times that it appears is called a *logarithm*.

Using the examples shown above, we say it thus:

Because there are 5 factors, the logarithm of 100 000 is 5 when the base number is 10.

Because there are 7 factors, the logarithm of 128 is 7 when the base number is 2.

Because there are 6 factors, the logarithm of (approximately) 4 is 6 when the base number is 1.259.

You may wish to extend the number of factors. In that case, you simply add one to the value of the logarithm for each factor added. Thus:

Because the logarithm of 100 000 is 5 when the base number is 10, the logarithm of 1 000 000 (i.e. 100 000 x 10) is 5 + 1 = 6.

Because the logarithm of 128 is 7 when the base number is 2, the logarithm of 1024 (i.e. 128 x 2 x 2 x 2) is 7 + 3 = 10.

What goes for multiplication goes in reverse for division:

Because the logarithm of 100 000 is 5 when the base number is 10, the logarithm of 10 000 (i.e. 100 000 ÷ 10) is 5 – 1 = 4.

And because the logarithm of 100 000 is 5 when the base number is 10, the logarithm of 1 (i.e. 100 000 ÷ 100 000) is 5 – 5 = 0.

In fact, whatever the base number, the logarithm of 1 is always 0.

Also, the logarithm of 1/10 (i.e. 100 000 ÷ 1 000 000) is 5 – 6 = −1.

For base numbers that are greater than 1, the logarithm of any value between 0 and 1 is always negative.

Using logarithms as a form of presentation is a convenient way of handling very large numbers. In occupational medicine, large numbers are changed to logarithms in two common situations of measurement:

- pH, the inverse measurement of the concentration of hydrogen ions in a solution (discussed later in this document);
- decibels, the measurement of the level of sound intensity in a room or emitted by an audiometer.

Sound level measurements are given in decibels. A decibel is a logarithm based on an irrational[3] number, $10^{0.1}$, which, to three decimal places, is 1.259.

Question: What is twice the intensity of 85 dB, i.e. how do we multiply 85 dB by 2?

Now, $2 \approx 1.259 \times 1.259 \times 1.259$, so the logarithm of (approximately) 2 is 3 when the base number is 1.259. And 85 dB is $(1.259..)^{85}$, i.e. around 315 million times the intensity of sound that is only just audible to a healthy young ear. Expressed in another way, the logarithm of 315 000 000 is 85 when the base number is 1.259 (to 3 decimal places)

The important thing about a logarithm is that *adding logarithms* is the same as *multiplying the numbers* upon which those logarithms are based. Because 85 dB is already a logarithm, all we do is to add the logarithm of 2 to 85. The logarithm of 2 (based on 1.259) is 3, so 85 + 3 = 88 dB. Therefore, a sound of 88 dB is twice as intense as a sound of 85 dB, i.e. approximately twice as damaging to the ear. The take-home message is that just a few extra decibels can be a whole lot more damaging to a worker's ear.

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[3] An irrational number cannot be formed by dividing one whole number by another. It is not a ratio – hence "ir-ratio-nal".

Similarly 3.15 ≈ 1.259 x 1.259 x 1.259 x 1.259 x 1.259, so the logarithm of (approximately) 3.15 is 5 when the base number is 1.259.

By the same reasoning as we just used, adding 5 dB is the same as increasing the intensity of sound about three-fold. For example, 25 dB is about three times as loud as 20 dB. Say you measured a male worker's hearing threshold with an audiometer two years ago and found that his hearing threshold at a frequency of 4kHz was 20 dB. You measure it again today and find a hearing threshold of 25 dB, i.e. 5 dB higher. Don't be lulled to think "Oh, that's *only* 5 decibels." In fact, if the reading is accurate, it means that, for the worker to hear sound at 4 kHz, the audiometer had to emit around *three times* the intensity of sound than was required two years before. This difficult reasoning is one of the problems of using logarithmic measurements.

Thermal environment – heat and cold

Heat

Heat is gained by the body from the use of muscles (80% of energy goes to heat), by radiation of heat to people's bodies from large hot surfaces, and from high air temperatures. Heat may be lost from the body in these circumstances if a cool breeze plays across the skin and by the evaporation of sweat, through the latent heat of vaporisation of water[4].

Radiant heat, whether from the sun or from any hot thing, is infrared (electromagnetic) radiation. Every object radiates heat in proportion to the fourth power of its absolute temperature in kelvin, i.e. 310 kelvin (= 37°C) for afebrile humans. This means that every cooler object within range gains net heat by radiation from every warmer object.

SOURCES OF HEAT

EXTERNAL CONDITIONS	radiant heat	foundries, glass manufacture
	high air temp.	Summer conditions
WITHIN THE HUMAN BODY	high physical activity	the chemical processes that give energy to the cells of the body

During any activity, the body attempts to automatically maintain a constant temperature in the brain and other internal organs by balancing out heat gain and heat loss.

In conditions where heat is gained rapidly, the major means of dissipating heat is the *evaporation* of sweat from the skin, i.e. the energy lost from the body in converting the water of sweat into water vapour. In hot, humid conditions such as a laundry or a tropical workplace, sweat is less likely to evaporate than in dry conditions; hence more sweat tends to drip from the skin rather than to evaporate. Because then heat loss is difficult to achieve, the pace of work (i.e. the vigour of muscle activity) must be slackened. After a week or two under such conditions, workers become 'acclimatised' with a lower heart rate and a higher volume of sweat that itself is more dilute.

The effects on the body from heat gain could potentially be assessed using the deep body temperature, pulse rate and weight changes (as a guide to sweat loss). Such measures would intrude into work routines and so typically environmental assessments are made instead.

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[4] *Latent heat of evaporation*: The quantity of heat that must be absorbed to convert a liquid to a vapour at the same temperature. The heat required for the conversion of sweat into water vapour is drawn from the skin and so cools the skin as the transformation occurs from liquid to vapour. Sweat that simply drips from the skin on to the ground has no cooling effect.

Cold

Indoor workers with frozen foods, e.g. meat packers, can develop frostbite. Outdoor workers performing sustained activities in conditions of low temperature, wind and damp can be susceptible to both localised cold injury as well as lowered body temperature. Those involved in quarry work, deep-sea fishing, diving, fire-fighting have a higher risk. The risk of Raynaud's phenomenon is increased by a combination of cold and vibration as can occur from wet drilling of rock in a quarry on cold mornings.

Cold environments cause:

- constriction of superficial blood vessels in the skin;
- increased metabolic heat production through voluntary movement and shivering.

As core body temperature falls, oxygen consumption falls by approximately 7% per Celsius degree. Below 35°C consciousness becomes dulled causing disorientation, irrational thinking, forgetfulness and hallucinations. Below 30°C, semi-consciousness and confusion may occur, and as myocardial repolarisation is slowed, ventricular fibrillation is a risk.

The lower the patient's core body temperature, the more aggressive needs to be the treatment. Mild hypothermia can be treated by external warming. At temperatures below 30°C, active internal warming is required with warm IV fluids, warm humid oxygen, even peritoneal lavage. If the patient's pulse or breathing is absent, standard cardio-pulmonary resuscitation is continued along with internal warming.

Changes to ambient pressure

The traditional measurement of pressure in medicine is been millimetres of mercury (mm Hg). For some purposes in medicine (and occupational health), the SI unit – pascal, or more usually, kilopascal (kPa) – has replaced mm Hg. Standard atmospheric pressure at sea level is around 760 mm Hg or 100 kPa. Therefore to convert mm Hg to kPa, you divide by 7.6; to go the other way, you multiply by 7.6.

Some approximate pressure conversions would be:

In mm Hg	60	80	100	120	140	160
In kPa	7.9	10.5	13.2	15.8	18.4	21

Diving

For every ten metres of descent in water, the pressure increases by one atmosphere (100 kilopascals). At constant temperature, the mass of gas absorbed by a given mass of liquid, with which it does *not* combine chemically (e.g. nitrogen in blood), is directly proportional to the partial pressure of the gas above the liquid. Thus, much more gas will be dissolved in blood if a diver spends time at depth than would be in the same person's blood were they sitting in a boat.

This may create a problem when the diver ascends. At 30 metres depth, the pressure is 4 atmospheres (3 atmospheres of water plus one of air) so a climb to 20 metres depth lowers the pressure to 3 atmospheres, i.e. 25%. A further climb to 10 metres depth lowers the pressure another 33%; and a climb to the surface will halve the pressure from what it was at ten metres depth.

With every pressure drop in breathed air, the blood has less capacity to hold gas. If the pressure falls too rapidly, gas will bubble out of the blood. This is the same as what happens when you unscrew the top from a bottle of carbonated soft drink. Large bubbles in the heart will mean that its muscle will compress air rather than blood and so no blood will be ejected. Large bubbles in major vessels will interrupt blood flow to brain, kidneys and other vital organs. Smaller bubbles will interrupt blood flow to patches of body tissue such as articular cartilage of joints of the lower limb. This can later lead to osteoarthritis of those joints in middle life.

Surface tension

Surface tension is the property of a liquid that makes it behave as if its surface (in contact with air or another fluid) is enclosed in an elastic skin. The property comes from intermolecular forces that have a net attractive effect. A molecule on the interior of a liquid experiences interactions with other molecules equally from all sides, whereas a molecule at the surface is affected only by molecules subjacent to it in the liquid[5]. Surface tension is responsible for the formation of liquid drops and soap bubbles, and, inversely, for the absorption of liquids by porous substances and the ability of liquids to wet a surface.

Because of surface tension, the surface of a drop of liquid tends to contract, causing the pressure inside the drop to exceed the external pressure. The excess pressure inside the drop tends to burst it, but this tendency is balanced by the surface tension. For a spherical drop of radius, r, and surface tension, T, the difference between internal and external pressure, δP, is given by: $\delta P = 2T/r$, when all are expressed in SI units. Since most formulae relating to spheres and circles contain the constant, π, it is perhaps surprising that the above formula, $2T/r$, does not. This is because surface tension is defined as the force acting over the surface *per unit length* of surface perpendicular to the force, i.e. force per unit of perpendicular length. Therefore, T already has built within it $2\pi r$ – the circumference of the sphere.

There is a rough parallel between surface tension and cardiac muscle function. When a ventricle starts to contract, just before the outlet valve opens, it becomes approximately spherical and the tension in the muscular syncytium of the heart wall acts like a biologically-enhanced form of surface tension on the blood in the chamber. A heart starts to fail when r has already increased and when, because of the weakened state of the muscle, T can increase no further. Then the formula, $\delta P = 2T/r$, indicates that, with r (the denominator) increasing yet T unable to 'keep pace' with this increase, the intra-ventricular pressure due to contraction of the heart will fall, and so cardiac output will drop.

Surface tension has a different basis from *viscosity* – the ability of a fluid to *resist* flowing. For example, elemental mercury has a high surface tension but a viscosity not much greater than water; it will flow readily down a fine bore needle.

Electromagnetic radiation

Electromagnetic radiation results from the acceleration of electric charge and the associated electric and magnetic fields. Electromagnetic radiation can be thought of either as a wave travelling at the speed of light – 3×10^8 metres per second in a vacuum – or as a stream of tiny packets of energy (called photons) travelling at the same speed. The energy that this form of radiation can apply to molecules in cells is proportional to its frequency (inversely proportional to its wavelength). Only the very high frequency photons have enough energy to ionise atoms such as those on DNA molecules. Such high energy electromagnetic radiation includes ultraviolet C, x-rays and gamma rays.

Ionising radiation also includes atomic particles – alpha particles, beta particles (electrons), neutrons. In comparison with x-rays, alpha particles have very low penetration – they can be stopped or scattered by a puff of smoke or a sheet of tissue paper. However, alpha particles that are brought into *intimate* contact with internal body tissues can be very damaging at a molecular level. For example, a person continually inhaling an alpha-emitting air-contaminant (e.g. radon and its more long-lived 'daughter' elements) into the lungs in a long-term occupation (e.g. in some underground mines) will be at increased risk of lung cancer.

The schema on the next page shows the inter-relations of the different types of radiations. It is not to scale – e.g., visible electromagnetic waves are a very small part of the spectrum.

a) Electromagnetic spectrum. There are major divisions into *ionising* and *non-ionising* radiation depending whether the radiation has sufficient energy to make atoms electrically charged and hence cause mutations.

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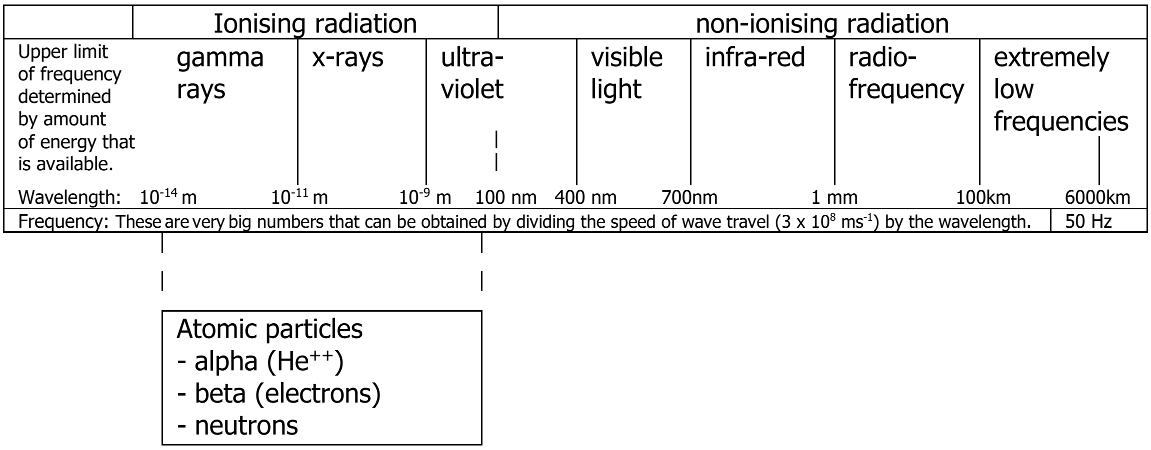
[5] In fact, there will be some attraction between the molecules in the liquid and those in the air, but such attraction will be very minor compared with that of the many close molecules in the liquid.

- *Ionising* radiation includes gamma rays, x-rays, and high energy ultraviolet.
- *Non-ionising* radiation spectrum spans:
  - the less energetic ultraviolet radiation
  - visible light (the rainbow of violet, indigo, blue, green, yellow, orange, red)
  - infra-red (radiant heat, e.g. the warmth of the sun)
  - radio-frequency (includes microwaves, mobile phones)
  - magnetic fields around the alternating (50Hz) current in electric wires

b) Atomic particles – extremely tiny particles that come from spontaneous change to the unstable nuclei of large atoms. Like x-rays and gamma rays, they ionise other atoms:

- alpha particles[6] (helium nuclei, He^{++});
- beta particles (electrons);
- neutrons of various energies.

c) Nuclear or atomic radiation is a loose term used to describe a mix of the ionising parts of the electro-magnetic spectrum and atomic particles.



Two units of ionising radiation commonly appear in medical literature – the gray and the sievert. These are defined as follows:

gray (abbreviated Gy)

unit of *absorbed dose* of ionising radiation and of the energy imparted by that dose. It is equal to a delivery of 1 joule per kilogram of irradiated material. One gray equals 100 rads. So, 1 rad = $\frac{1}{100}$ gray, i.e. 1 rad = 1 centigray (1 cGy).

sievert (abbreviated Sv)

this unit concerns absorption of ionising radiation and is the '*effective dose*'. It is like the gray except that it is adjusted for *both* the type of radiation (e.g. alpha, beta, gamma) *and* the different sensitivities to radiation of various body tissues according to a scale devised by the International Commission on Radiation Protection.

The difference in potency of the different forms of ionising radiation is taken account of by using a radiation weighting factor, W_R. Weighting factors range from 1 (for x-rays and electrons) to 20 (for alpha particles). The '*equivalent dose*' for any one particular body tissue equals the absorbed dose (measured in grays) × W_R. The *equivalent dose* is measured in sieverts.

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[6] The nuclear fragment with two protons and two neutrons is a far more stable entity than, say, a particle with one proton and three neutrons or a particle with two protons and one neutron. This means that alpha particles have this fixed 2 + 2 configuration rather than a random scatter of different combinations of neutrons and protons.

However, the usual situation in a workplace is that several body parts are exposed to the radiation. So, for workplace exposures, the '*equivalent dose*' for every body part is further multiplied by a tissue weighting factor that is relatively higher for the gonads and bone-marrow than for the skin. The products of all these multiplications are added together to give what is termed an '*effective dose*'. The effective dose may be described as "the 'tissue-weighted' equivalent dose summed over all tissues and organs of the body." It too is measured in sieverts.

The tissue-weighting factors reflect the respective sensitivities of the various tissue functions to the effects of radiation. Thus, for the purposes of tissue weighting, the gonads are considered to represent 20% of the body whereas the whole skin is considered to represent just 1%.

[Unfortunately, the adjectives 'equivalent' and 'effective' are abstract words that both start with the letter 'e' and so there is potential for confusion.]

One sievert is equal to 100 rems. The rem is an older unit.

Lasers

Lasers are intense beams of ultraviolet, visible or infrared rays. They are intense because the beam consists of a single wavelength in continuous or pulsed forms. The most intense lasers are Classes 3B and 4 where direct or reflected exposure can cause burn eye tissue. Ultraviolet typically coagulates proteins of the cornea whereas the longer wavelength of visible or infrared radiation can burn retinal tissue causing scotomas and reducing visual acuity and fields. Infrared lasers, being invisible, present an insidious danger. The high risk comes with a single high intensity exposure and not a more sustained low-level exposure.

The greatest use of lasers is in construction where they provide alignment and grade levels on projects such as dam construction, tunnelling, dredging and pipe laying. Shields and barriers are standard procedure for working with powerful lasers. Remote viewing equipment is sometimes used. Special goggles may not offer complete protection where beam reflection occurs. They should not be used in fog or rain because water droplets will scatter the beam.

Ultraviolet

Ultraviolet (UV) radiation from the sun is said to have three bands:

- UV A: long wave, lower frequency with wavelengths from 400 to 320 nanometres (nm).
- UV B: middle wave with wavelengths from 320 to 280 nm.
- UV C: short wave, higher frequency with wavelengths from 280 to 200 nm.

A nanometre, nm, is one billionth (10^{-9}) of a metre.

UV C is ionising radiation. When this higher frequency UV enters the higher atmosphere, it splits oxygen (O_2) molecules. The resulting single atoms may re-combine as O_2 or, as the allotrope, O_3, i.e. ozone. All the sun's UV C is absorbed in the upper atmosphere in this process. The ozone created there further reacts and, in the process, most of the UV B is absorbed. Although only a small proportion of this UV B does reach the surface of the earth, it is enough to increase the risk of sunburn.

Acute excessive exposure to UV B in sunlight notably causes erythema and even blistering (sunburn) or, when fair skin receives moderate exposure to UV B over a long period, cell mutations can change the behaviour of surface cells and increase the probability of various skin cancers.

Sudden episodes of ultraviolet glare can occur during arc welding. The unprotected eye, if exposed to such a welding flash, is likely to develop a period of keratoconjunctivitis that painfully lasts for several hours.

Electric shock

Electric shock from alternating current (AC) causes tetany and sweating; direct current (DC) causes a form of electrolysis. Most tissue damage results from the heat produced by the current as it passes through. Where resistance to the passage of DC current is high (e.g. in the skin, the bones and nervous tissue), heat coagulation, even charring, can occur. Domestic electricity (240 volts, 50 hertz AC) can depolarise heart and nervous tissue to the extent of causing ventricular fibrillation. Lightning injuries (high voltage DC) tends to cause asystole but also causes tearing of tissues due to a shock wave ripple through the body of the victim.

Overhead electric power lines are sometimes, depending on the light or the background, hard to see. And, on very hot days, they lengthen and sag; then, clearance for, say, fork-lift trucks is a little lower than usual and can trap the unwary.

Electrocution is death caused by electric shock.

Inverse square law

It is within nearly everyone's experience that the warming effect of a campfire declines rapidly as you move away from it. In parallel vein, if you place a small lighted electric globe – say a Christmas tree light – inside a cardboard carton, then the inner walls of the carton will be quite brightly lit. However, if the same lighted globe were made the sole means of illuminating a darkened bedroom, the light-energy of the globe would be spread over a far greater surface area than in the carton. As a result, the walls would be very dimly lit indeed.

Let's now contrive a small lit globe suspended in the centre of a partly inflated round balloon (by means of lacquer bands and a spot of glue). The inner walls of the balloon will be lit by the globe. If more air is blown into the balloon, the surface area of its wall will increase. As the entire wall recedes evenly from the globe, its level of illumination will decrease evenly in proportion to the rate of increase in surface area.

Thus in mathematical terms:

$$\text{level of illumination} \propto \frac{1}{\text{surface area}}$$

[$\propto$ is a mathematical symbol that means 'is proportional to']

But, for a sphere, $\quad \text{surface area} \propto (\text{diameter})^2 \quad$ [Surface area of sphere = πd^2]

So, $$\text{level of illumination} \propto \frac{1}{(\text{diameter})^2}$$

This relationship between decrease in illumination (for a light) [or rate of warming (for a campfire)] with increase in the square of the distance from the source of energy is called the *inverse square law*.

It applies to local exhaust ventilation systems. When there is a small exhaust (suction) inlet such as a pipe poking through a wall, the air drawn into the inlet comes from the sphere (or hemisphere) of air that surrounds it. Because the air *is* drawn from the surrounding sphere (rather than just from directly in front), the velocity of movement of the air declines rapidly as you move away from the inlet – again, approximately according to the inverse square law:

$$\text{velocity of air movement toward the inlet} \propto \frac{1}{(\text{distance from inlet})^2}$$

SUBSTANCES

Some principles

For a substance to do harm within the body, *enough* of it must get in. Government rules aim to minimise workers' exposure to substances; they set limits of exposure. The principle that should guide exposure to substances at work has the acronym 'ALARP' - as low as reasonably practicable.

Changing the *dose* of a substance will change either the *severity* of effects *or* the *probability* of their occurrence or both.

Substances *at work*, if they enter the body, typically do so by *inhalation* or by *absorption through intact skin*. Ingestion may be a supplementary route, e.g. through biting dirty fingernails or smoking a cigarette held by dirty hands, but is rarely the major route of entry.

Exposure to airborne substances is often estimated by air tests. The *dose* absorbed may be measured for some substances (e.g. metals, pesticides) by blood or urine tests.

Substances may waft in the air as gases/vapours, or as aerosols. *Aerosols* may be either fine liquid droplets (a mist or fog) or tiny particles. A *gas* is a substance with a boiling point of less than about 20ºC. The gaseous form of a liquid with a higher boiling point than this is called a *vapour*. A *mist* of fine liquid droplets in the air above a liquid is created by machinery spinning through a liquid or by fine bubbles rising through a liquid and breaking the surface. A *fog* occurs when a vapour is present in the air and the air cools until the vapour starts to condense. That is why you can see your exhaled breath in front of you on a chill morning; its warm water vapour condenses as it cools. Condensation to large droplets forms dew.

Toxicokinetics

Toxicocokinetics is the study of *movement* of toxins into, within and out of the body, i.e. *what the body does to the toxin*. On the other hand, *toxicodynamics* is the study of the *effect* of a toxin and its mechanism of action, i.e. *what the toxin does to the body*.

- Excessive absorption of most substances has potential for harm.
- Some substances have a therapeutic range of doses lower than the doses that cause the harmful effect. Substances with a therapeutic range are called drugs or therapeutic agents; substances without a therapeutic range are often called toxins.
- Toxicokinetics, the kinetics of toxins, follows the same principles as pharmacokinetics.
- There are two parameters of prime importance – the clearance and the half-life.
- The *clearance* concerns the rate at which a toxin may be taken in, day to day, before it starts to accumulate.
- The *half-life* concerns the time it takes for the amount of a circulating toxin to be reduced by a stated proportion.
- Many toxins are chemically altered in the body. A common initial mechanism, so-called phase 1, is by oxidation. This will commonly *reduce* the toxicity of a substance but sometimes it will *increase* it (e.g. with pesticides whose names end in '-thion'). A group of enzymes much involved in this oxidation are cytochrome p-450. They are in every cell.
- A mechanism of change that follows phase 1 is phase 2. This makes the substance more soluble and so readies it for renal excretion.
- Some toxins, e.g. lead, can cross the placenta or enter breast milk.

Chemical

Chemistry concerns the changing of substances into more useful ones. Therefore, the term *chemical* is typically applied to a substance that represents an alteration from a natural state. Of course, any substance could be called a chemical if it were to be or had been part of a chemical process such as manufacturing or body metabolism. To speak of a 'chemical substance' is a tautology – a bit like saying 'descending downwards'.

Organic chemical

A compound of carbon, usually hydrogen, and often other elements such as oxygen, nitrogen, phosphorus, chlorine. The adjective 'organic' in the context of chemistry is not related to the more recent adoption of the same term by food producers.

The mole

A mole is a unit of quantity, 6.02×10^{23}. It represents the number of molecules in approximately 32 grams of oxygen, or the number of atoms in approximately 12 grams of carbon. In electrolysis, it is the number of electrons that must pass from the cathode to deposit one mole of a univalent cation (e.g. 107.9 grams of Ag^+) as an element,
i.e. 9.65×10^4 coulombs divided by the charge on an electron (1.60×10^{-19} coulombs). Elements react with one another in terms of atoms or of moles, e.g. Al_2O_3 means 2 atoms (or moles) of aluminium chemically combined with 3 atoms (or moles) of oxygen.

Concentration

Concentration is the amount of a substance in each litre of water or of blood, or in each cubic metre of air. In water or blood, it may be talked of in terms of milligrams or millimoles of substance per litre (abbreviated respectively mg/L, mmol/L). In air it may be talked of in milligrams of a substance per cubic metre of air (abbreviated mg/m^3) or, for gases and vapours, in parts per million (abbreviated ppm and equivalent to mL/m^3)

Use of the term 'pesticide' or 'solvent'

These terms refer to the *use to which a substance will be put*, not to the chemistry or pharmacology of the substances themselves. The term *pesticides* includes a variety of substances with very different toxic effects. Similarly with *solvents*.

Periodic table

There are about one hundred elements that singly or in combination make up all matter. Each element is given a symbol and a number that reflects the size of its atoms. The most common display of elements is in a periodic table where members of each 'group', in a column of the table, bear similarities in the way that they react with other elements.

pH

Some substances, when dropped or bubbled into water, will change into something different, a process called hydrolysis. Some substances hydrolyse to form hydrogen ions. The component of a solution that makes it acidic or alkaline is the proportion of hydrogen ions. Acids contain many; strong acids contain many more. Alkalis contain less; strong alkalis contain very few.

The concentration of hydrogen ions in ordinary water is $\frac{1}{10\,000\,000}$ mol/L, i.e. one ten-millionth of a mol/L.

pH is defined as the *negative* logarithm of the concentration of hydrogen ions measured in moles per litre (see footnote[7]). The logarithm of 10 000 000 is 7, and so the logarithm of $\frac{1}{10\,000\,000}$ is –7. The *negative* logarithm of $\frac{1}{10\,000\,000}$ is – (–7) i.e. 7 (because a double negative makes a positive). This is the pH.

A pure, strong acid will have more hydrogen ions in each litre, e.g. it may have $\frac{1}{10}$ mol/L. The logarithm of 10 is 1 and so the logarithm of $\frac{1}{10}$ is –1. The pH is the *negative* logarithm of $\frac{1}{10}$, i.e. – (–1) = 1.

Similarly, a pure strong alkali may have as 'few' as, say, $\frac{1}{100\,000\,000\,000\,000}$ mol/L. The number in the denominator has 14 zeros and so the logarithm of this fraction is –14. The pH, the negative logarithm, is – (–14) = 14.

Why is pH important in toxicology?

Substances with pH well away from 7, e.g. those with a pH of 2 or 12, are likely to harm the first body tissue that they contact. Alkalis[8], particularly, will convert lipid cell membranes into soap i.e. a complete and rapid destruction. Transparent proteins, e.g. in the cornea of the eye, are rapidly coagulated so that they become permanently opaque.

Some gases react with the water content of body mucus in the nose, throat and airways to form acids or alkalis (e.g. sulphur dioxide or ammonia). This sudden change in pH is irritating to the body (i.e. stimulates pain-sensing nerves) and, if it persists, will cause inflammation. Hence, both sulphur dioxide and ammonia are classed as *irritant gases*.

The pH of a medium such as stomach contents or urine as it forms can affect the degree of ionisation of a foreign substance. For example, if the foreign substance itself tends to generate hydrogen ions then, when it is in an acid environment (such as within the stomach), its tendency to form such ions will be less. Being un-ionised[9] makes it more likely to be absorbed into the body. Similarly pH can affect the rate of excretion and, in cases of poisoning, sometimes an effort is made to acidify or alkalinise the urine (by giving another substance) in order to hasten excretion.

This can be expressed in terms of equations. Acids are ionised in basic media. Bases are ionised in acidic media.

$$\text{i.e.} \quad \underset{\text{(un-ionised)}}{HX + H_2O} \rightleftharpoons \underset{\text{(ionised)}}{H_3O^+ + X^-}$$

If more H_3O^+ ions are added (i.e. adding acidity), the equilibrium moves to the left. If base (e.g. OH^-) is added, H_3O^+ ions are consumed, and the equilibrium moves to the right. Un-ionised substances cross lipid biological barriers (e.g. membranes) better than ionised ones.

The following Henderson-Hasselbalch equation, often seen in respiratory physiology, applies to weak acids.

For weak acids: $\text{pH} = \text{p}K_a + \log_{10}\left(\frac{[\text{ionised}]}{[\text{un-ionised}]}\right)$. Square brackets here mean 'the plasma concentration of' and the pK_a indicates the tendency of an acid to ionise – the *lower* the pK_a, the greater that tendency. The pK_a is the pH at which an acid is 50% ionised and 50% un-ionised. Weak acids have pK_a values between 3 and 7.5.

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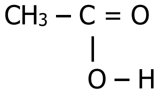
[7] In fact, the pH doesn't refer to the actual concentration but, instead, to a slightly smaller quantity called the *activity*. However, for our purposes, let's stick with concentration – it's near enough. A few pages back there is an explanation of logarithms. There you would have seen that, since 10 000 000 = 10 × 10 × 10 × 10 × 10 × 10 × 10, the logarithm of 10 000 000 is 7 when the base number is 10. Also the logarithm of 1/10 000 000 is – 7.

[8] *Alkalis* are water-soluble bases.

[9] I have hyphenated un-ionised to distinguish chemistry from industrial relations.

Organic chemistry: aromatic and aliphatic compounds

- Organic chemicals: carbon compounds excluding CO_2, CO, carbides and carbonates.
- Many carbon compounds exist because the covalent C – C single bond is strong, carbon has four valence electrons and therefore a carbon atom can form four single bonds with other atoms, and chains of C – C bonds can be straight or branched.
- Besides hydrogen, other elements can be bound to the carbon chain, the most common being oxygen, nitrogen, sulfur, and chlorine.
- In aliphatic compounds, carbon atoms can be joined together in straight chains, branched chains, or non-aromatic rings (in which case they are called 'alicyclic'). Aliphatic compounds can be saturated, joined by single bonds (alkanes), or unsaturated, with double bonds (alkenes) or triple bonds (alkynes). The simplest aliphatic compound is methane (CH_4).
- The term *hydrocarbon* on its own refers to compounds that contain only hydrogen atoms and carbon atoms. These are often colourless, volatile compounds with low solubility in water.
- Alkanes are hydrocarbons that are found in natural gas and petroleum. Natural gas is mainly methane, CH_4.
- Polymers are compounds consisting of very large molecules, the atoms of which are joined by covalent bonds. *Polymerisation* is a process by which simple molecules join together to form a polymer. A monomer is a simple molecule that can be polymerised.
- Oxidation of carbon atoms is most easily seen by substitution of oxygen atoms for hydrogen atoms. A sequence of oxidation may be expressed as follows, in this case as it applies to the right-hand carbon atom:

Least oxidised	$CH_3 - CH_3$	ethane
	$CH_3 - CH_2 - O - H$	ethanol
	$CH_3 - CH = O$	acetaldehyde
	 $\begin{array}{l} CH_3 - C = O \\ \qquad\;\; \vert \\ \qquad\;\; O - H \end{array}$	acetic acid
Most oxidised	$O = C = O$	Carbon dioxide

- Benzene, C_6H_6, is a compound whose molecular structure may be depicted as a hexagon with carbon atoms at each point, joined alternatively by double or single bonds. This hexagonal ring, the benzene ring, is a very stable structure.
- Carbon chains and other atoms can join on to a benzene ring. Compounds containing a benzene ring are known as *aromatic*.

Diffusion and osmosis

Diffusion is the process in a gas or liquid in which particles of a substance spread out from a region where their concentration is high. For example, if someone else farts quietly in a room with still air, it may take tens of seconds for you to smell it because the odorous molecules diffuse only slowly through the air.

$$\text{Rate of diffusion} \propto \frac{1}{\sqrt{\text{molecular weight}}}$$

The process of fumigation (gassing) of a stack of grain depends on diffusion.

Osmosis is diffusion of a solvent – typically water – through a semi-permeable membrane into a more concentrated solution, tending to equalise the concentrations on both sides of the membrane. The tendency for movement of solvent molecules to a region of greater solute concentration can be prevented or lessened by applying pressure to the more concentrated solution. The pressure necessary to prevent solvent migration is the *osmotic pressure* of the solution. The osmotic pressure depends on the number, rather than the type, of molecules or ions in the solution.

Electrolysis and electrolytes

Electrolytes are substances that dissolve in water to produce solutions that conduct an electric current. If the concentration of an electrolyte in solution is increased, then the electrical conductivity of the solution increases.

Electrolysis is a chemical change effected by the flow of an electric current through a solution or a molten electrolyte (as in the smelting of alumina). The direct current is carried through an electrolytic cell or bath by the ions in solution (or in the molten state). The current is carried into and out of the electrolytic cell by electrodes. The positive electrode is called the anode; the negative electrode in the cathode. The anode attracts negative ions; the cathode attracts positive ions. Oxidation occurs at the anode; reduction occurs at the cathode. In electroplating, the job to be plated becomes the cathode. Electrolysis requires substantial current but often quite low voltages.

Enzymes and enzyme kinetics

A *catalyst* increases the rate of reaction without itself being used up. An *enzyme* is a protein with catalytic ability that is restricted to a limited set of reactions. These define the specificity of the enzyme. Enzymes are designated by the suffix *–ase*. This suffix is commonly (but not always) attached to the name of the reaction being catalysed, e.g. enzymes catalysing hydrolytic reactions are called hydrolases. Virtually all metabolic reactions depend on enzymes which also limit their rate.

The reactant in a reaction catalysed by an enzyme is called the substrate. When an enzyme-assisted reaction is working at its maximum rate, the concentration of substrate declines from, let's say from the plasma, at a constant rate. However, by far the more common situation is where the decline in plasma concentration is *not* constant with time, but *varies with the concentration*. The higher the concentration, the greater the rate of decline in the concentration of substrate.

The rate of action of enzymes can be considered mathematically using the Michaelis-Menten equation. This equation represents a curve that asymptotes to a maximum *rate* of reaction ($V_{\max}$). The K_m (Michaelis constant) is the plasma *concentration* of the substrate at which half the maximum rate of reaction occurs. Cp is the plasma concentration of the substrate and $\frac{dC}{dt}$ is the rate of change of plasma concentration, i.e. the rate of elimination.

$$\frac{dC}{dt} = \frac{V_{\max} \times Cp}{K_m + Cp}$$

$V_{\max}$ relates to the total amount of enzymes available for metabolism. K_m is inversely proportional to the affinity of the substrate for the enzyme, i.e. the higher the affinity the lower the K_m.

Enzyme inducers, which increase the amount of available enzymes, will therefore increase $V_{\max}$ but will not alter K_m. Enzyme inhibitors which act by competing with substrates for metabolism by the same enzyme, will not change the $V_{\max}$, but will increase the K_m. Enzyme inhibitors that act by direct inhibition of the enzyme will decrease the $V_{\max}$ and may or may not alter the K_m.

When the K_m is well above the plasma concentration, Cp, the rate of elimination is almost directly proportional to the plasma concentration. This happens because, with Cp small in relation to K_m, the denominator of the equation becomes dominated by K_m, i.e. the equation becomes effectively $\frac{dC}{dt} = \frac{V_{\max} \times Cp}{K_m}$. Because both $V_{\max}$ and K_m are constants, the equation then becomes $\frac{dC}{dt}$ = constant × Cp, i.e. $\frac{dC}{dt} \propto Cp$. This is a *first-order* reaction.

At plasma concentrations well above the K_m, the rate of elimination becomes independent of concentration. This happens because, with Cp large in relation to K_m, the denominator of the equation becomes dominated by Cp, i.e. the equation becomes effectively $\frac{dC}{dt} = \frac{V_{\max} \times Cp}{Cp}$.

The Cp in numerator and denominator cancel, leaving $\frac{dC}{dt}$ equal to $V_{\max}$, a constant.

In therapeutics, most drugs have K_m values well *above* their therapeutic concentrations and, therefore, have first-order kinetics. A select group of well-known drugs saturate at or around their therapeutic concentrations. For these, concentrations may increase more than proportionally for a given increase in dose, e.g. *phenytoin*.

Thus, for drugs with saturable elimination, dose increases should be made in small increments.

Flammability and explosion

Fire results from a combination of fuel, oxygen and heat. The fuel may normally exist as a liquid (e.g. petrol) but it burns after it vaporises and mixes with oxygen. If there is too much fuel vapour (or gas) and too little oxygen or, conversely, too little fuel vapour (or gas) then a fire cannot be sustained. HAZCHEM signs guide firefighters to the broad qualities of chemicals stored, to any special agent required to extinguish the fire, and to the need for evacuation of nearby premises should a fire occur. In a workplace you visit, you may see a variety of fire extinguishers. Look closely at some of them. Their label (and colour) will delineate their purpose and they will be tagged as to when they were last checked by a responsible authority. The internationally harmonised signage system may also be viewed on the internet.

Flammability limits are two different concentrations of substances in air. Between these concentrations, mixtures of the substance with air will catch fire. Outside the limits fire does not happen because below the lower flammability limit there is too little of the substance (the fuel), and above the upper flammability limit there is too little oxygen.

Explosion is a sudden local increase in the pressure of gases in a space; it creates loud noise and a tendency to burst (an outwardly moving pressure wave).

Gases and gas laws

A gas is a substance consisting of atoms or molecules that are sufficiently mobile for it to occupy the whole of the space in which it is contained. The term may apply more narrowly to a substance that has a boiling point below normal room temperature (20 – 25°C). Also, the vapour of a liquid is sometimes described as a gas; it exists in a gaseous state.

The gas laws are approximate rules based on the assumption of an 'ideal' gas. An ideal gas is simplification that a assists our understanding of gases. It assumes molecules of negligible volume with negligible inter-molecular attractions. In reality, molecules, although tiny, do have some volume. Also, the molecules of gases do attract each other to a small extent which correspondingly reduces the push of the gas on the walls of its container (the pressure of the gas), particularly if the pressure is high. Accordingly, correction factors are introduced to gas laws when an exact answer is needed.

The gas laws of particular relevance in occupational health are:

> *Henry's Law:* at constant temperature, the mass of gas absorbed by a given mass of liquid, with which it does *not* combine chemically (e.g. nitrogen in blood), is directly proportional to the partial pressure of the gas above the liquid. This is relevant to the formation of nitrogen gas bubbles in the blood of divers who ascend too rapidly from a deep or prolonged dive.

Graham's law: This law applies to diffusion, i.e. where molecules of one gas intermingle with those of another *without* bulk movement. The law states that the rate of diffusion of a gas is inversely proportional to the square root of its molecular weight. This applies to the speed with which gas distributes itself in a space, e.g. in fumigating a shipping container, phosphine (PH_3, with its molecular weight of 34) will diffuse faster than methyl bromide (CH_3Br, with its larger molecular weight of 95).

Fick's law: the rate of diffusion of a gas across a permeable membrane (e.g. the wall of an alveolus in the lung) is proportional to the area of the membrane and to the difference between the gas partial pressures on the two sides of the membrane, and is *inversely* proportional to the thickness of the membrane.

Halogens and halogenated organic compounds

- The four common halogens are fluorine, F_2, a yellow gas; chlorine, Cl_2, a greenish-yellow gas; bromine, Br_2, a red-brown liquid; iodine, I_2, a violet-black solid.
- These halogens are more soluble in hydrocarbon solvents than in water, react with most other elements and are strong oxidising agents.
- In inorganic chemical reactions, halogen atoms gain one electron, producing the ions, F^-, Cl^-, Br^- or I^-.
- Halogens, notably chlorine, react with hydrocarbons. When volatile hydrocarbons are halogenated, they become less flammable but more prone to cause narcosis (an effect like drinking alcohol) if inhaled in large quantities. So, some have seen use as anaesthetic gases.
- Halogenated aromatic compounds such as chlorophenols have pervasive odours.
- Halogenated polycyclic compounds, e.g. DDT, polychlorinated biphenyls and chlorinated dioxins are very stable and so tend to persist in the environment.

Inert gases

Six of the gaseous elements tend not to form compounds with other elements except under very special circumstances. One is radioactive – radon. The others are helium, neon, argon, krypton, xenon. Argon forms about 1% of the atmosphere. Xenon, the heaviest of these five and the most oil-soluble, has a general anaesthetic effect; this indicates that anaesthesia results from a physical effect on cell membranes rather than a chemical reaction.

Ions and polar molecules

An ion is an atom or stable group of atoms (e.g. SO_4^{2-}) having a charge of positive (cation) or negative (anion) electricity owing to the loss (positive) or gain (negative) of one or more electrons. Substances that form ions are called electrolytes. [I referred above to SO_4^{2-} (sulphate) as an example of an ion formed from a stable group of atoms. Traditional chemistry books refer to this as the sulphate radical; nowadays it is more common to see it called the sulphate (or sulfate) ion. The term *radical* tends to be applied more to free radicals.]

A polar molecule has one part (one end) with a slightly positive electric charge and one part with a slightly negative electric charge. When the term is applied to covalent molecules, it means that the electrons in some of the covalent bonds are *unevenly shared* between the atoms (as occurs in water) so that one part of the molecule has a slight negative charge and another part has a slight positive charge ($H^{\delta+} - O^{\delta-} - H^{\delta+}$). [Substances made of charged atoms or which have charges around their molecules dissolve in water whereas molecules *without* internal charges mix with oil.]

The term *electronegativity* refers to the relative ability of an atom to retain or gain electrons. The oxygen atom has high electronegativity. This means that when an oxygen atom forms a covalent bond with, say, a carbon atom or a hydrogen atom, the shared electrons, in their movements, spend more time closer to the nucleus of the oxygen atom than the other atom. This is what creates polarity.

Metals

- Metals, in general, are elements with a shiny lustre, are good conductors of heat and electricity, are capable of being shaped or formed (malleable) and are capable of being drawn into a wire or hammered thin (ductile).
- Metals make up most of the periodic table and are on the left-hand side and middle part.
- Heavy metals have a density at least five times greater than water. Some heavy metals have well-recognised toxicity, e.g. lead, mercury; but some non-heavy metals are toxic, e.g. beryllium.
- All metals are heavy *except* those in Groups 1 and 2 of the periodic table plus scandium, titanium and aluminium.

Nanoparticles[10]

Much of what is said here refers to sizes of particles given in nanometres. A nanometre is one billionth of a metre, i.e. 10^{-9} metre, abbreviated nm. The prefix 'nano-' is derived from Latin and Greek words for dwarf. Some approximate sizes of small things in nanometres are:

Atoms	0.1 – 0.5 nm	Particles in tobacco smoke	10 – 4000 nm
Viruses	5 – 300 nm	Particles in oil smoke	30 – 1000 nm
Smallest bacterium	300 nm	Human red blood cell diameter	About 7000 nm

By convention, smoke particles and viruses would generally be referred to as *ultrafine particles* rather than nanoparticles.

Unlike items in the table, a *nanoparticle* is an *engineered* form of matter having at least one dimension (length, breadth or width) less than 100 nm (0.1μm). Engineered nanoparticles are manufactured to have specific properties or composition. They can be approximately spherical or as very fine tubes – about 10 000 times thinner than a human hair.

Nanoparticles have been produced for more than 40 years but the field has gathered pace in areas such as surface coatings and semi-conductors. So-called quantum dots are semi-conductor nanocrystals, 2 – 100 nm in size, that have metal cores and optical and electrical properties useful in biomedical imaging and electronics industries.

Their small size means nanoparticles can float in air for long periods, so may be inhaled. Inhaled particles larger than 20 μm (20 000 nm) aerodynamic equivalent diameter (d_{ae})[11] do not get past the nose (and mouth), most particles 7 – 20 μm d_{ae} deposit in the bronchial tree, and that smaller particles reach the alveoli. A small proportion of these particles 0.1 – 7 μm (100 – 7000 nm) d_{ae} actually deposit in the alveoli but, at particle sizes less than this, nearly half the particles remain in the alveoli.

Smaller particles have a higher toxicity than larger particles of the same composition. Their large surface area compared with mass appears to generate more free radicals and reactive oxygen species than larger particles. This, theoretically, has potential to cause inflammation, kill macrophages and cause fibrosis. Such fears deserve caution but, so far, there is no clear picture of harm from toxicological studies. Low solubility nanoparticles entering the bloodstream are rapidly cleared from the circulation by the reticulo-endothelial system. They are eventually excreted via bile.

Durable nanotubules, somewhat akin to miniature asbestos fibres have had particular scrutiny. Fibres greater than 20 000 nm (20 μm) in length exceed the phagocytic ability of macrophages. Tubules that contain a component of iron are more cytotoxic than other tubules which is interesting because the iron-containing crocidolite is the most potent form of asbestos in causing mesothelioma.

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[10] The source for most of this section is *Safe Work Australia. Engineered nanomaterials: a review of the toxicology and health hazards. Canberra: Commonwealth of Australia, 2009.*

[11] The *aerodynamic equivalent diameter*, d_{ae}, of a particle is its actual diameter multiplied by the square root of its specific gravity, where *specific gravity* is the density of a substance compared with that of water (by ratio).

The human toxicity is still uncertain but, as with other inhaled particles, it seems that:

- There are cellular and tissue mechanisms to deal with the direct toxicity of small doses.
- Morbidity occurs when injury rate exceeds repair rate or when repair processes are compromised.
- Prolonged or inappropriate adaptation to cellular responses can lead to tissue injury.
- With protein coatings, nanoparticles can be antigenic and so their inhalation can stimulate the usual immune response.

Odour threshold

Olfactory receptors respond only to substances that are in contact with the olfactory epithelium and are dissolved in the thin layer of mucus that covers it. Humans can recognize more than 10 000 different odours. The olfactory thresholds for different substances range across many orders of magnitude.

Methyl mercaptan, CH_3SH, in farts and garlic, can be smelled at a concentration of lower than 500 nanograms per cubic metre. Many sulphur-containing organic compounds stink. Their names often have *mercapto* -, *thio*- or –*thion* in them.

Oxidation and reduction

- When an atom loses electrons, it is said to be oxidised; when it gains electrons, it is said to be reduced.
- Oxidation and reduction reactions must occur together; the same number of electrons is gained in the reduction as is lost in the oxidation.
- An oxidising agent brings about oxidation of another chemical species. Common oxidising agents used in industrial processes are oxygen, fluorine, hydrogen peroxide, permanganate, dichromate and concentrated sulphuric acid.
- A reducing agent brings about the reduction of another chemical species. Common reducing agents used in industrial processes are elemental carbon, oxalate, hydrogen sulphide, hydrogen, zinc, sulphur dioxide.
- In electrolysis, ions at the cathode are reduced. At the anode, there is oxidation – which may be of the anode itself.
- For carbon atoms in organic molecules, oxidation is best illustrated by replacement of carbon – hydrogen bonds by bonds from carbon atoms to oxygen atoms. Oxygen atoms are more electronegative than hydrogen atoms and so tend to relatively deprive the carbon atoms of electrons.
- Care is required in storing oxidising agents. If, through spill or mis-handling, an oxidising agent is mixed with a hydrocarbon, a fire and probably an explosion will occur.

Solubility

- A substance to be dissolved is called a *solute*; the medium in which the solute is dissolved is called the *solvent*. The most common solvent is water but, in industry, the term solvent is commonly applied to hydrocarbon liquids, i.e. organic solvents.
- A solution is the homogeneous system established by dissolving a solute in a solvent.
- A one molar (1 M) solution of a substance contains one mole of that substance per litre of solution.
- A saturated solution is one in which no more solute will dissolve at that temperature.
- When an ionic solid dissolves in water, the cations and anions separate from one another.
- A precipitate is the formation of a solid from a solution
- The solubility in water of most ionic substances increase as the temperature of the solution is raised.
- Solubility in water of most gases decrease as the temperature of the solution is raised.
- Most compounds of Na^+, K^+, NH_4^+, and most nitrates, are soluble

Volatile organic compounds

Volatile means 'readily evaporating'. Volatile substances readily contaminate the nearby air with vapour.

Volatile organic compounds are organic compounds that can release vapours into the surrounding air. When the vapour is present in sufficient quantity, it can cause eye, nose and throat irritation, headache, etc. Some volatile organic compounds, such as benzene, are of greater concern than others due to their known adverse health effects at higher concentrations. The term, volatile organic compounds, is often extended to embrace substances that are normally encountered as gases (e.g. formaldehyde).

Classifying hazard terms

In talking about occupational hazards, you will hear people say things like, "Inhaling the *vapour* of *hydrocarbon solvents* may cause *narcosis*". To assist you to use the terminology, fluently, here is a classification of terms.

Classification	Examples
Characterises the danger	acute, chronic, dose, exposure, hazard, risk, safe
Refers to mode of use	pesticide, solvent
Describes the physical form of a substance	aqueous, crystalline, fibre, gas, particulate, vapour
Describes the mode of spread of micro-organisms	aerosol, blood-borne organism
Refers to the ability to change or interact	acid, alkali, boiling point, caustic, flammability, oxidising agent, soluble, volatility
Classifies the family of substances or micro-organisms	asbestos, chlorinated hydrocarbons, organophosphates, oxides of nitrogen, bacteria, viruses, protozoa
Names the agent	ozone, silica, toluene, *Legionella*, *Cryptosporidium*, microwave radiation
Describes the circumstances of likely harm	confined space
Refers to the mode of entry to the body	airborne contaminant, absorption, breathing zone, route of exposure, inhalable, respirable, skin-absorbed
Indicates the effect of the substance or micro-organism on the body	acute, chronic, asphyxiant, carcinogen, irritant, mutagen, narcosis, infection, immune suppression, impaired liver function, toxico-dynamics
Indicates the effect of the body on the substance or micro-organism	toxicokinetics, enzyme, metabolite, oxidise, reduce, volume of distribution, half-life, clearance, phagocytosis
Describes the method of measurement	atomic absorption spectrophotometer, indicator tube, simply sniffing the air
States results of measurement	concentration, decibel, exposure, fibres per millilitre (f/mL), parts per million (ppm), milligrams per cubic metre (mg/m^3), number of bacterial colonies
Classifies means of control	local exhaust ventilation, respiratory protective device
Refers to standards of control	exposure standard

BIOLOGICAL AGENTS

Micro-organisms

Micro-organisms are small living things. There are very many micro-organisms and most do no harm. The ones of interest in the context of occupational health multiply inside human tissue and, in doing so, cause their host discomfort or disease. These are known as *pathogens*. The best known categories of micro-organisms are viruses, bacteria, fungi and protozoa; some other categories are also mentioned here.

Let's first go through the range of micro-organisms and revise the characteristics of each. We'll start with the tiniest.

Prions

These are infectious agents but *not* organisms; they are essentially mere proteins. They became of particular interest to food microbiologists with the outbreak of 'mad-cow disease' in the UK in 1996. Prions are the agents thought responsible for its transmission.

Viruses

A virus is essentially a piece of nucleic acid (either DNA or RNA) which makes its progeny by orchestrating the production of virus particles by a cell. Viruses that lack a lipoprotein envelope (e.g. Hepatitis A, gastroenteritis viruses) can grow in the human gut and be spread by food and water. Viruses *with* a protein or lipoprotein envelope have limited survival outside a host and so are spread in aerosols or inoculations of body fluids from person to person (e.g. measles, coronavirus). Viruses don't respond to antibiotics**;** some respond to specific antivirals.

Bacteria

Most (not all) bacteria have sufficient energy supply to reproduce outside a cell. They have genetic material but no nucleus. They divide by splitting in half. They exist singly or in short chains of two or more. They are classified by shape, oxygen requirement and ability to take up a special stain (developed long ago by a bacteriologist by the name of Gram). Examples of bacteria are *Staphylococcus*, *Salmonella*, and the organisms responsible for cholera and whooping cough. Some bacteria produce toxins locally (e.g. *Staphylococcal* food poisoning) or that circulate generally (e.g. tetanus), and it is these toxins that educe the characteristic forms of disease.

Rickettsia and chlamydia used to be classified separately but are now designated as bacteria. They have a simple cell-type appearance but no intrinsic means of energy production. Thus they can only reproduce *within* cells. Rickettsia are often transmitted to humans by ticks or lice. These two types of micro-organism are susceptible to antibiotics.

Fungi

These simple plant-organisms lack the chlorophyll needed to use carbon dioxide and sunlight to build sugars and structural molecules. They are classified into *yeasts* (single-celled) or *moulds*, which grow as branching filaments called 'hyphae'. Yeasts reproduce by budding, and moulds by branching and longitudinal growth of hyphae. They also reproduce through sexual spores. Yeasts are responsible for *Candida* vaginal infection and a form of pneumonia in immuno-suppressed people. Moulds are best known for invading the skin as with tinea[12] and ringworm. In the occupational setting, some mixtures of fungal and other protein antigens, when inhaled, can give rise to the lung disease known as hypersensitivity pneumonitis (extrinsic allergic alveolitis). Most cases of this condition in Australia concern bird handlers.

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[12] Probably, most foot conditions that are called 'tinea' are instead likely to be simple maceration of the skin of the toes by a combination of moisture, heat and friction.

Protozoa

These are the simplest class of animal and consist of a single nucleated cell. The most important protozoal parasitic infection is *malaria*, which is transmitted by mosquito bite and is endemic in parts of the tropics. Two important causes of water-borne protozoal infection are *Giardia* and *Cryptosporidia*. *Toxoplasma*, passed to a pregnant woman who handles young kittens, can harm the developing foetus. Several less common (mainly tropical) diseases of the blood and gastrointestinal tract are also caused by protozoa.

Worms

An important disease that is increasing among travellers to tropical areas is schistosomiasis (bilharzia). There are many other worm infestations including hydatid disease and pork and beef tapeworms.

Arthropods

Tiny mites are related to spiders. They burrow in the skin and include scabies and the straw itch mite which sometimes appears in stored products that are infested with weevils, moths or beetles. Best-known is the dust mite – a 'camp-follower' of humans. Proteins from this mite, when airborne, can induce sneezing and wheezing.

Ticks, also related to spiders but larger than mites, are found in woodland and bush in many of the warmer parts of the world, including Australia. They transmit Coxiella burnetiid, the organism responsible for Q-fever. This organism infects cattle. The aerosol of infected body fluids when such an animal is slaughtered can, in turn, spread *Coxiella* to workers.

* * *

Australian Standard, AS 2243.3, categorises microorganisims according to the degree of risk in working with them in laboratories. Recommended laboratory facilities and safe working practices are detailed for each risk group.

Risk Group 1 (low individual and community risk)

A microorganism that is unlikely to cause human, plant or animal disease of importance, e.g. *Bacillus subtilis, Escherichia coli.*

Risk Group 2 (moderate individual risk, limited community risk)

A pathogen that can cause human, plant or animal disease but is unlikely to be a serious hazard to laboratory workers, the community, livestock, or the environment. Laboratory exposures may cause serious infection, but effective treatment and preventive measures are available and the risk of spread is limited, e.g. *Staphylococcus aureus,* hepatitis B virus, *Candida albicans,* many parasites.

Risk Group 3 (high individual risk, limited community risk)

A pathogen that usually produces serious human disease but does not ordinarily spread from one individual to another, e.g. *Coxiella*, *Brucella* spp., *Salmonella typhi,* yellow fever virus.

Risk Group 4 (high individual and community risk)

A pathogen that usually produces serious human or animal disease, represents a serious hazard to laboratory workers, and may be contagious, e.g. Lassa fever virus, the causative agent of CoViD-19.

Venoms

Know particularly about the venoms of snakes, spiders and marine creatures.

A useful reference is *Therapeutic Guidelines: Toxicology and Wilderness. Melbourne: Therapeutic Guidelines Ltd.*

EXPOSURE, HAZARD, RISK, SAFE

Exposure is the presence of a substance, micro-organism, or form of energy in the vicinity of a person. An occupational *hazard* is an exposure in a workplace that has *potential* to increase the risk of injury or disease. The term *hazard* is frequently used in company with two other terms – *risk* and *safe*. You will save yourself much confusion if you can clearly distinguish these terms, thus:

hazard	something with *potential* for harm
risk	*probability* that harm will occur and the severity of that harm
safe	of acceptable risk. (Immediately then you ask: "Acceptable to whom?")

The term *hazard* is essentially qualitative. *Risk* adds a quantitative dimension. The term *safe* adds an element of subjective judgment; it's like beauty …. "in the eyes of the beholder".

Avoid placing the term *safe* in inverted commas: to say *a "safe" situation* is like saying *the "fresh" fish* – in each case, use of inverted commas undermines the word they embrace and renders the message ambiguous.

Make sure that you are able to distinguish the terms *hazard*, *risk* and *safe*. In ordinary conversation, some people use the terms *hazard* and *risk* interchangeably but if you, as a health professional, want to think clearly about occupational health, then you will separate them in your mind. A rough analogy in medicine is that the term *hazard* is *qualitative* – like a diagnostic label – whereas *risk* is *quantitative* – like how badly a patient is affected by his or her medical condition. Another analogy would be that *hazard* is like the harmful properties of a drug; *risk* is about the expected dose-related effect of those properties on your patient.

The word *safe* is slippery because it involves personal judgment. It is a useful word when a hazard can be totally removed or be clearly well-controlled (e.g. a fire put out or a laser turned off). Here, there is a dichotomy of 'hazard present' or 'hazard absent', and most people will agree when the situation is safe. However, when a hazard is *attenuated* rather than removed, then people will disagree about the *extent* of attenuation needed before a situation can be deemed safe. Then, to make a judgment of safety is like being offered 50 shades of grey paper that range from palest pearl to near ebony, and being asked to classify them as either white or black; i.e. it is a fraught task. Where there are 'shades of grey' rather than a dichotomy, the term *safe* loses its power to depict the state of a situation. To use it then is to invite dispute.

Safety data sheets are essentially hazard statements. In order to decide the level of risk that a substance presents, we must look at ***how it is used***.

A colleague interested in occupational causes of cancer kindly introduced me to an article *Cogliano JC, Baan R, Straif K and others. Preventable exposures associated with human cancers. J Natl Cancer Inst 2011; 103: 1827 – 1839*. My colleague, impressed with its comprehensiveness, urged me to bring it to the attention of trainees. I said I would do so, but with the caution that it is a very thorough *hazard* statement, but it does little to explain *risk*. I too think it is valuable, but with that proviso.

TALKING WITH OTHERS ABOUT RISK

Let's step away from medicine for a moment. Imagine going into a limestone cave. The stalactites and stalagmites are quite weird, but the cave-guide will explain that people have dubbed this flat stalactite a shawl, or this stalagmite a mother-and-child. Why do they do that? It's because people know about shawls and mothers and feel a little more empowered when they can vocalise their experience in terms of familiar things.

Some of the most profound thoughts can be expressed in simple words; many of the great books illustrate that. If you tell a person something using your own, plain language, then he or she will know that you have brought the concept into your own personal area – that you are attempting to say: "I have thought about this and here is my perspective: …." It also respects the person with whom you are communicating. It says, "Hey, this is what I believe". Merely reciting a textbook or legal definition is like a proclamation from on high, or a call from far, far away. It lacks the softness or the sort of pleasure-in-giving that a truly personal message can bring. Yet expressing sophisticated or abstract ideas in lay terms can risk embarrassment if what you say comes out all wrong. You can feel less vulnerable, less exposed, if you hide behind a technical term.

A central feature of occupational medicine is to solve problems about the health of people and their work. For a doctor to be effective in this requires the ability to *persuade*, e.g. to encourage a worker to adhere to safe ways of working, or to urge an employer to prepare modified duties for a worker recovering from injury but not yet fit for his or her normal work.

Because a doctor encourages rather than coerces, the ability to persuade depends upon creation of understanding *plus* a sincere attempt to try to see the world from the other person's point of view. You cannot persuade a person who doesn't understand you nor who believes you don't care about what is important to him or her.