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Faculty of Medicine and Health Sciences School of Medicine

Medical Sciences & Graduate Entry Medicine

Basic Science Workbook

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INTRODUCTION

We pride ourselves on the Graduate entry medicine (GEM) course in attracting students from a variety of educational backgrounds. For example, students have degrees ranging from English and History to Immunology and Molecular Biology. This provides a rich mix of experiences and enhances the problem-based learning approach. All of you will have something unique to offer this course and enhance the learning experience of others.

Nevertheless, we cannot get away from the fact that medicine is science-based and includes study of subjects such as anatomy, physiology, biochemistry, immunology, virology, microbiology, pathology, genetics and behavioral science! This means that from the first few weeks of the GEM course you will be exposed to several different subjects that support the medical curriculum. This is inevitable on a course that aims to teach things in an integrated fashion. On this accelerated four-year medical degree course, you will also find that for many of these subjects, some basic science knowledge is assumed.

For instance, you are probably aware that smoking is known to damage the lungs. As a medical student you will learn about lung anatomy, lung function, lung pathology and how to examine the lungs. At the microscopic level it is evident that the airways are lined with cells that have cilia to help move particles and microorganisms that can cause harm out of the lungs. Smoking damages these cells so that toxins remain in the lungs. But what are cells? What are organisms and what are toxins, never mind the cilia? So many questions already!

Irrespective of the dysfunction, in order to understand the normal and abnormal functioning in life it helps to know what the body is made of. For example, you will need to know what cells are, what they are made of and how they function. In turn, the functions of the constituents of cells, for example, proteins and fats, can be studied. Many functions of the cell are carried out by proteins, but how are they made and how can they function in so many ways? Organic compounds and inorganic elements all have their role too. Life can function because the body makes use of different types of bonds between atoms for example, covalent and ionic bonds. Changing the environment in which cells work (e.g., by altering the pH) can drastically affect normal function.

Some of the basic science concepts and jargon may be relatively unfamiliar to those of you who have not studied science in detail or who have had a break from studying. The aim of this workbook, therefore, is to provide an opportunity to study and familiarise yourselves with some of the more important concepts that underpin the basic and clinical sciences before you start the course.

When you arrive in September, we will assume that you have a good understanding of the concepts covered in this workbook.

Dr D Hudman

Director of Undergraduate Studies

How to use this workbook

We hope that by completing this workbook, you will gain confidence in this unfamiliar territory. This should enable you to concentrate on appreciating, and subsequently learning, the core biomedical subjects that form the basis of medical study and therapeutics. Employing active learning by completing the activities in the workbook, for example by making extra notes or drawing diagrams will help you prepare for the active approach that we have adopted on GEM.

The topics you will find covered in this workbook are:

1. Math's for medicine [1]
2. Cell structure
3. Atoms, molecules, bonds and ions
4. Common organic compounds
5. Inorganic elements
6. DNA-RNA-protein
7. Amino acids and protein structure
8. SI units, prefixes, concentration and size
9. Medical Linguistics
10. Acids, bases and pH

Within each topic, you will find information detailing its clinical relevance.

We suggest working through the sections in order. Some topics are more challenging and develop ideas that are introduced in earlier topics. We will revisit many of the topics **briefly** in lectures and workshops when you start on GEM, but we will not spend too much time on them.

As self-assessment of learning is an important student activity on GEM, we hope that you will try to answer the self-test quiz questions in each topic as you go along and revise any points that you have not understood.

Throughout, we have highlighted key words when they first appear in **bold** text. Keyword terms We will expect you to know the meaning of these terms when you arrive on GEM in September.

LOOK OUT FOR THE ICONS AND BOXES!

Pointers to the clinically relevance of the topic.

Contain questions for you to apply what you have just studied.

Want to know more or a bit confused about a topic lookout for the embedded YouTube clips.

[1] Reproduced with permission of Dr J Koenig

TOPIC 1: MATH'S FOR MEDICINE

1) Expressing very large and small numbers
    a. Standard form and scientific notation.
    b. Use of prefixes e.g. milli, micro, nano, pico
2) Using ratio and proportion
    a. Converting between units
    b. Units for concentration
    c. Calculating dilutions
    d. Calculating equivalence and adjusting for weight
3) Rates
    a. Calculating infusions

How to use this math's guide

The mathematical concepts have been sequenced so that they build upon each other, so it is best to start from the beginning and work through. The content is chosen based on the mathematical knowledge and understanding of a student who may have done GCSE math's some time ago and got a grade B or 5. Those who have worked at a more advanced level may wish to skim through the text and try the practice questions. The mathematical concepts are at GCSE level but there are a few medical idiosyncrasies which it is important to be aware of particularly in the use of units.

If you would like further explanation (including video) and practice, you could consult:

Biological Science: Exploring the Science of Life. By Jon Scott, Gus Cameron, Anne Goodenough, Dawn Hawkins, Jenny Koenig, Martin Luck, Despo Papachristodoulou, Alison Snape, Kay Yeoman, and Mark Goodwin. ISBN: 9780198783688. To be published July 2022 by Oxford University Press.

1.a Standard Form and Scientific Notation

In biology there are many instances where you might need to calculate and manipulate very large numbers or very small numbers. For example, the number of nerve cells in an average brain might be 10 000 000 000. On the other hand, the length of a cell under the microscope might be 0.000 001m. The number of cell surface receptors for hormones might be 100 000 per cell whilst the concentration of peptide hormone in the extracellular space might be 0.000 000 000 001 M. These very large or small numbers are difficult to read and that is why we use scientific notation or powers.

Table 1.1 The relationship between normal numbers and those expressed as powers of ten.

1 000 000	= 10 x 10 x 10 x 10 x 10 x 10	= 10^6	
100 000	= 10 x 10 x 10 x 10 x 10	= 10^5	÷ 10
10 000	= 10 x 10 x 10 x 10	= 10^4	÷ 10
1 000	= 10 x 10 x 10	= 10^3	÷ 10
100	= 10 x 10	= 10^2	÷ 10
10	= 10	= 10^1	÷ 10
1	= 1	= 10^0	÷ 10
0.1	$=\frac{1}{10}$	= 10^{-1}	÷ 10
0.01	$=\frac{1}{10 \times 10}$	= 10^{-2}	
0.001	$=\frac{1}{10 \times 10 \times 10}$	= 10^{-3}	÷ 10
0.000 1	$=\frac{1}{10 \times 10 \times 10 \times 10}$	= 10^{-4}	÷ 10
0.000 01	$=\frac{1}{10 \times 10 \times 10 \times 10 \times 10}$	= 10^{-5}	÷ 10
0.000 001	$=\frac{1}{10 \times 10 \times 10 \times 10 \times 10 \times 10}$	= 10^{-6}	÷ 10

As you go down the table the numbers are getting ten times smaller.

Notice what happens to the power of ten when you go from 100 to 10 to 1 to 0.1.

Some examples writing large and small numbers in scientific notation:

Example 1.1. Write six thousand in scientific notation…

6000 = 6 x 1000 which is 6.0×10^{3}

To work out the power of ten, count how many digits to the right of the 6.

Example 1.2. I have done an experiment to determine the concentration of drug in solution and the answer was 6237234 molecules/l. Write this in scientific notation.

Count how many digits there are to the right of the 6 and then write 6.237234×10^{6}

In practice you would never be able to measure the concentration of drug to that degree of accuracy. Usually, you would work out how many significant figures are appropriate in this instance. You may decide to write it in 4 significant figures instead, 6.237×10^{6}.

It is just a convention to put the decimal place after the first digit. You could, if you wanted to, write this number in many ways including:

62.37×10^{5}

$= 623.7 \times 10^{4}$

$= 6237 \times 10^{3}$

When you go from 62.37 to 623.7 you're multiplying by 10, so you need to make the power of ten smaller by dividing by 10 so 10^{5} becomes 10^{4}.

Example 1.3. Write 0.00054 in standard form. Count how many digits between the decimal point and the 4.

Answer: 5.4×10^{-4}

Example 1.4. Write 0.0134 in standard form. Count how many digits between the decimal point and the 3.

Answer: 1.34×10^{-2}

You could also write this number in many ways including:

0.0134

$= 0.134 \times 10^{-1}$

$= 1.34 \times 10^{-2}$

$= 13.4 \times 10^{-3}$

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Some practice questions writing numbers in scientific notation:

1) Write 340000 in standard form.

2) Write 0.0000080 in standard form.

3) Fill in the gaps: 0.00475 can be written as _____ x 10^{-2} and _____ x 10^{-3} and _____ x 10^{-4}

4) Write 9859486 in standard form to two significant figures.

5) Respiratory masks filter out particles larger than 0.3×10^{-6} m in diameter. For which of the following hazardous substances should a mask be effective? (Hint: write all the numbers to the same power of ten)

   a. Asbestos fibres: diameter 2.5×10^{-4} m

   b. Diesel exhaust carbon particles: diameter 1.2×10^{-7} m.

   c. Benzene molecules: diameter 6.2×10^{-10} m

   d. Cat hairs: diameter 3.0×10^{-5} m

1.b Using Prefixes

Prefixes are a useful way of abbreviating even further for example 10^{-3} g = 1 mg (one milligram)

Table 2 shows a summary of all of the standard prefixes. The main prefixes in use in biomedical science are shown in bold.

Table 2 Prefixes

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{24}	yotta	Y	10^{-1}	deci	d
10^{21}	zetta	Z	10^{-2}	centi	c
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	µ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atto	a
10^{2}	hecto	h	10^{-21}	zepto	z
10^{1}	deca	da	10^{-24}	yocto	y

To convert from scientific notation to a prefix, first convert the number so that it has a suitable power of ten and then substitute the prefix. Some examples:

Example 1.5. Convert scientific notation to a prefix.	5×10^{-5} g in mg.	5×10^{-5} g = 0.05×10^{-3}g = 0.05 mg
	5×10^{-5} g in µg.	5×10^{-5} g = 50×10^{-6} g = 50 µg
Example 1.6. Convert a prefix to scientific notation.	12pmol = 12×10^{-12} mol = 1.2×10^{-11} mol	
Example 1.7. Convert a prefix to scientific notation.	0.033 ng = 0.033×10^{-9} g = 3.3×10^{-11} g	

Example 1.8. Under the microscope, an epithelial cell looks quite rectangular, and you can use the formula for the area of a rectangle to estimate the area of the cell membrane. Width = 1 µm and length 10 µm. Express the area in scientific notation with m^2 as the units. Repeat your calculation to give the units as $µm^2$.

Using m^2:	Using $µm^2$:
Area = width x length	Area = width x length
= 1×10^{-6} m x 10×10^{-6} m	= 1 µm x 10 µm
= 10×10^{-12} m^2	= 10 $µm^2$
	Note that $µm^2$ means $(µm)^2$ which is $(10^{-6}\ m)^2$ = x 10^{-12} m^2

Example 1.9. Using the cell given in example 1.8, the height has been estimated from other studies to be ~5 µm, what is the volume of the cell (in m^3 in standard form)? Also give the answer in $µm^3$

Using m^3:	Using $µm^3$:
Volume = area x height	Volume = area x height
= 10×10^{-12} m^2 x 5×10^{-6} m	= 10 $µm^2$ x 5 µm
= 50×10^{-18} m^3	= 50 $µm^3$
= 5×10^{-17} m^3	

Some practice questions with prefixes

1) Write 4.6 x 10^{-8} g with an appropriate prefix.
2) Write 9.3 x 10^{8} g with an appropriate prefix.
3) Write 30 µL in standard form.
4) Write 45 mm^3 in m^3.
5) Syringe filters are used to sterilise small volumes of drug solution. The smallest type of syringe filter in common use has a pore diameter 0.22 µm. The filter is attached to the end of a syringe and the solution passed through. Which of the following will pass through the filter? (there may be more than one correct answer)
    a. Mycoplasma: diameter 120 nm
    b. Ribosome: approx. diameter 2 x 10-8 m
    c. Bacillus bacterium: length 4.2 x 10-6 m
    d. Rabies virus: diameter 0.5 µm

Answers to practice questions.

1) 3.4 x 10^{5}
2) 8 x 10^{-6}
3) 0.0475 x 10^{-2} and 4.75 x 10^{-3} and 47.5 x 10^{-4}
4) 9.9 x 10^{6} (note that if the third digit is 5 or more, then the second digit is rounded up so in this case the third digit is 5 which means the second digit, 8, gets rounded up to 9.
5) Pore size = 0.3×10^{-6} m = 3 x 10^{-7} m
    a. Asbestos fibres: diameter 2.5×10^{-4} m - too big since $10^{-4} >> 10^{-7}$
    b. Diesel exhaust carbon particles: diameter 1.2×10^{-7} m – fits through since 1.2 < 3
    c. Benzene molecules: diameter 6.2×10^{-10} m – fits through since $10^{-10} << 10^{-7}$
    d. Cat hairs: diameter 3.0×10^{-5} m - too big since $10^{-5} >> 10^{-7}$
6) 4.6 x 10^{-8} g = 46 x 10^{-9} g = 46 ng
    a. Alternatively, you could write: 4.6 x 10^{-8} g = 0.046 x 10^{-6} g = 0.046 µg
7) 9.3 x 10^{8} g = 0.93 x 10^{9} g = 0.93 Gg
    a. Alternatively, you could write: 9.3 x 10^{8} g = 930 x 10^{6} g = 930 Mg
8) 30 µL = 30 x 10^{-6} L = 3 x 10^{-5} L
9) 45 mm^3 = 45 x $(10^{-3}\ m)^3$ = 45 x 10^{-9} m^3 = 4.5 x 10^{-8} m^3
10) pore diameter 0.22 µm = 2.2 x 10^{-7} m
    a. Mycoplasma: diameter 120 nm = 120 x 10^{-9} = 1.2 x 10^{-7} m fits through
    b. Ribosome: approx. diameter 2 x 10^{-8} m fits through
    c. Bacillus bacterium: length 4.2 x 10^{-6} m too big
    d. Rabies virus: diameter 0.5 µm too big

2. Using ratio and proportion.

2.a Converting between units

It's very important that you have a secure method for converting units – one that works reliably even when you're stressed or if it's 3 in the morning! There are many ways of going about it but one method that works well is the ratio square. Say you want to convert 0.34 mg to µg. First you write down the relationship between mg and µg, remembering that micrograms are 1000 times smaller than milligrams. Then directly underneath you write what you're trying to find, lining up the units to be the same as the ones on the top row. Now you can see that to get from 1 to 1000 you multiply by 1000. Then you need to do the same to the bottom row.

Practice with the following questions.

1) Convert 90 ng to µg
2) Convert 550 µL to mL
3) Convert 0.45 h to seconds
4) Convert 0.035 kg to mg
5) Convert 0.25 dm^3 to mL

2.b Units for Concentrations

The definition of concentration is the amount of substance dissolved per volume of solution, or mathematically:

$$concentration = \frac{amount\ of\ substance}{volume\ of\ solution}$$

Or in symbols, $C = \frac{m}{V}$,

where C = concentration,

m = amount of substance, either in moles or grams,

V = volume of solution, usually in mL or L.

Example: If you have 4 g sodium chloride dissolved in 500 mL water then you simply substitute the numbers into the formula – not forgetting to include the units.

×1000

1 mg = 1000 µg
0.34 mg = ? µg

×1000

$$concentration = \frac{4\ g}{500\ mL} = 0.008\ g/mL$$

Alternatively, we could have used 0.5 L instead of 500 mL and get the concentration in g/L.

$$concentration = \frac{4\ g}{0.5\ L} = 8\ g/L$$

÷5

5 g in 1 L
8.7 g in ? L

÷5

We can think of the concentration as the ratio of the mass to the volume of the solution. For example, if a solution has a concentration of 5 g/L, then there will be 10 g in 2 L or 20 g in 4 L. If we wanted to know what volume would be needed for 8.7 g, we could use a ratio square:

5 g in 1 L is in the same ratio as 8.7 g in 1.74 L

We can also use this approach to work out the mass of substance required for a given volume. For example, how much would be needed for 3.5 L?

5 g in 1 L is the same ratio as 17.5 g in 3.5 L.

A similar approach can be used to convert between mass and moles. For example, the molar mass of KCl is 74.55 g/mol, which in other words is 74.55 g per 1 mole and we can scale that up by 3 to get the mass for 3 moles.

*** Note that the unit **M stands for molar concentration** which is the same as mol/dm^3 or mol/L. So we could say that a 2 mol/L solution of sodium chloride is 2 M.

% weight/volume solutions.

In medicine you will occasionally encounter % as a "unit". It generally stands for "percent weight per volume" and means g per 100 g or g per 100 mL. For example, a 2 % solution of sodium chloride is equivalent to 2 g sodium chloride in 100 mL water.

$$concentration = 2\,\% = \frac{2g}{100\ mL} = \frac{20\ g}{1000\ mL} = 20\frac{g}{L} = 0.02\frac{g}{mL}$$

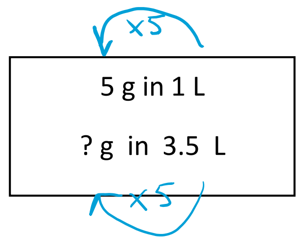
Parts per million

1 ppm is 1 part per million and it means 1 g per 1,000,000 g, or written mathematically:

$$1\ ppm = \frac{1\ g\ solute}{1{,}000{,}000\ g\ water}$$

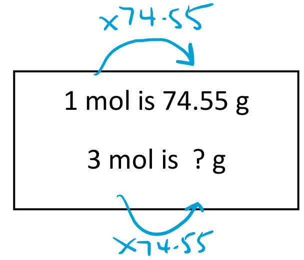
This can be converted to more sensible units by the following procedure:

$$1\ ppm = \frac{1\ g\ solute}{1{,}000{,}000\ g\ water} = \frac{0.001\ g}{1000\ g} = \frac{1\ mg}{1\ kg}$$



Noting that 1 kg of water is equivalent to 1 L,

$$1\ ppm = \frac{1\ mg}{1\ kg} = 1\ mg/L$$



Some practice questions

6) How much urea is present in 10 mL of a 0.01 mol/dm^3 solution?
7) What mass of sodium chloride would be required for 2.5 moles?
8) The molar mass of sodium chloride is 58.44 g/mol. What mass of sodium would be dissolved in 0.5 L of a 0.2 M solution?
9) How much urea is present in 10 mL of a 0.5% solution?
10) How much water would be required to dissolve 120 mg antibiotic to prepare a 25 mg/mL solution?

Answers to questions

1) 1000 ng = 1 µg

90 ng =? µg 90 ÷ 1000 = 0.090 µg

2) 1000 µL = 1 mL

550 µL =? mL 500 µL ÷ 1000 = 0.55 mL

3) 1 h = 3600 s

0.45 =? s 0.45 h x 3600 = 1620 s

4) 1 kg = 1000000 mg

0.035 kg =? mg 0.035 kg x 1000000=35000 mg

4) 1 dm^3 = 1000 mL

0.25 m^3 =? mL 0.25 dm^3 x 1000 = 250 mL

5) 0.01 mol/dm^3 = 0.01 mol/L.

0.01L x 0.01 mol/L = 0.0001 mol

6) One mole sodium chloride is 58.44 g.

2.5 moles are 2.5 x 58.44 = 146.1 g

7) 0.5 L x 0.2 mol/L = 0.1 mol.

0.1mol x 58.44 g/mol = 5.844 g

8) 10 mL x 0.5g/100 mL = 0.05 g

9) 25 mg in 1 mL

120 mg in? Ml is 120 ÷ 25 = 4.8 mL

"1:1000" as a unit for concentration.

You might occasionally see "1:1000" given as a unit for concentration. This should be obsolete but you may still encounter it. For example a 1:1000 adrenaline solution - this just means 1 mg in 1 mL which is 1 mg/mL.

2.c Calculating dilutions

If you were to take 1 mL of a salt solution and add 9 mL water to give a resulting volume of 10 mL, you would have diluted the original solution by a factor of 10. That is, the concentration is 10 times smaller and the volume is ten times larger.

This is what we would call a "1 in 10 dilution", written "1 : 10".

You would still have a 1 : 10 dilution if you had added:

- 10 mL salt solution + 90 mL water to give 100 mL diluted solution
- Or 5 mL + 45 mL → 50 mL
- Or 0.2 mL + 1.8 mL → 2 mL

These are all in the same ratio.

If your starting salt solution had a concentration of 5 g/L then after diluting by a factor of 10, the resulting concentration would be 0.5 g/L (i.e., 5 ÷ 10).

If the dilution factor was 5, and you needed a final volume of 20 mL, then you can set out the calculation like this:

Start with the basic ratio: 1 part + 4 parts = 5 parts

Fill in the corresponding volumes for a final volume of 20 mL

4 mL + 16 mL = 20 mL

And the resulting concentration would be one fifth of the original.

2.d Calculating equivalence and adjusting for weight

Sometimes a patient needs to transfer from one drug to another in the same class, for example from diazepam to clonazepam. In this case 10 mg diazepam is considered to be bioequivalent to 0.5 mg clonazepam. Say the normal dose of diazepam is 2 mg, then to calculate the bioequivalent dose of clonazepam you could set up a ratio square.

÷20

÷5 10 mg diazepam ←→ 0.5 mg clonazepam ÷5

2 mg diazepam ←→ ? mg clonazepam

÷20

2÷20 = 0·1 mg clonazepam

∴ 0·5÷5 = 0·1 mg clonazepam

When adjusting a dose for weight, you can take a similar approach. For example:

Aciclovir is administered at 5 mg/kg. What dose would be required for an 86 kg patient?

×86 5 mg per 1 kg ×86

? mg per 86 kg

5×86 = 430mg

Alternatively, you can use the units to help…

5 mg/~~kg~~ x 86 ~~kg~~ = 430 mg

If you can't remember whether to multiply or divide, just notice that if you multiply, then the kg and per kg cancel out leaving just mg behind which is what you want.

Some practice questions

1) A patient weighing 66 kg requires a drug dose of 0.5 µg/kg. What is the required dose?

2) A patient weighing 92 kg requires a drug dose of 0.45 µg/kg. What is the required dose?

3) Acyclovir is provided at a concentration of 2.5 mg/mL. It is administered at 5 mg/kg. What volume would you administer for a 76 kg patient?

4) The concentration of a stock solution of the antibiotic streptomycin is 25 mg/mL. How much of the stock solution and how much water would be

needed to prepare 100 mL of a working solution with a streptomycin concentration of 2.5 mg/mL?

5) You are given a solution of 1 M NaCl and are asked to take 1.5 mL and add that to 8.5 mL of a complex nutrient growth mixture. What is the resulting concentration of NaCl?

6) A patient was given an intramuscular injection of 0.4 mg adrenaline 1 in 1000 for anaphylaxis. What volume of solution was he given?

7) A 12 year old girl weighing 35 kg requires a 2 mg/kg slow IV bolus dose of an antibiotic. The ampoule contains 80 mg in 2 mL. What volume of solution is required?

8) A 60 year old patient weighing 52 kg requires enoxaparin at a dose of 1.5 mg/kg or 150 units/kg. What dose do you give? Express the answer in both mg and units.

9) a) You are provided with an ampoule of hydralazine 20 mg in 2 mL. How much saline solution 0.9% would you need to add to make a 1 mg/mL solution?

9) b) How much of the 1 mg/mL solution would you need to administer 5 mg?

10) A patient has been prescribed 300 mg daily phenytoin and now cannot swallow so needs to take a liquid form instead. You find out that 100 mg of a capsule corresponds to 92 mg when administered as a liquid. What dose of liquid phenytoin is required?

Answers to Practice Questions.

1) 66 kg x 0.5 µg/kg = 33 µg

2) 92 kg x 0.45 µg/kg = 41.4 µg

3) Concentration =2.5 mg/mL; Dose = 5 mg/kg; 76 kg patient what volume is required?

First work out the dose required: 5 mg/kg x 76 kg = 380 mg.

Then use the dose and the concentration to work out the volume, remembering that $C = \frac{D}{V}$

So $V = \frac{D}{C} = \frac{380\ mg}{2.5\ mg.mL^{-1}} = 152\ mL$

4) Concentration = 25 mg/mL. Need final volume= 100 mL of concentration =2.5 mg/mL

Starting concentration = 25 mg/mL and final concentration is 2.5 mg/mL therefore the dilution factor is 10 so this is a 1 in 10 dilution.

1 part of 25 mg/mL + 9 parts water = 10 parts

10 mL of 25 mg/mL + 90 mL water → 100 mL of 2.5 mg/mL solution.

5) 1.5 mL is added to 8.5 mL so a total volume of 10 mL.

This is a dilution factor of 6.66667 (=10 ÷ 1.5) so the concentration is 1 M ÷ 6.666667 = 0.15 M

An alternative method could be: amount in 1 mL = 1.5 x 10^{-3} L x 1 mol/L = 1.5 x 10^{-3} mol.

This is put into 10 mL total so new concentration = $\frac{1.5\times10^{-3} mol}{10\ \times10^{-3} L} = 0.15 \frac{mol}{L} = 0.15\ M$

6) 1 in 1000 adrenaline is the same as 1 mg/mL. C = 1 mg/mL; D = 0.4 mg what is the volume?

$$V = \frac{D}{C} = \frac{0.4\,mg}{1\,mg.mL^{-1}} = 0.4\,mL$$

7) 35 kg requires a 2 mg/kg slow IV bolus dose of an antibiotic.

Therefore, the dose is 2 mg/kg x 35 kg = 70 mg.

The ampoule contains 80 mg in 2 mL – write this out as a ratio square:

÷40

80 mg --- 2 mL

70 mg --- ? mL

÷40

70 ÷ 40 = 1.75 mL.

8) 52 kg x 1.5 mg/kg = 78 mg

or 52 kg x 150 units/kg = 7800 units

9) a) Starting solution: 20 mg in 2 mL

You want to have a final solution = 1 mg/mL.

Since you have 20 mg, then that needs to be dissolved in 20 mL ($\frac{20\,mg}{20\,mL}$ = 1 mg/mL)

It's already dissolved in 2 mL so you need to add 18 mL.

Alternatively, you could notice that the dilution factor is 10 and the starting volume is 2 mL so the final volume must be 20 mL which means needing to add 18 mL.

9) b) conc= 1 mg/mL; dose = 5 mg

$$V = \frac{D}{C} = \frac{5\,mg}{1\,mg.mL^{-1}} = 5\,mL$$

10) A patient has been prescribed 300 mg daily phenytoin and now cannot swallow so needs to take a liquid form instead. You find out that 100 mg of a capsule corresponds to 92 mg when administered as a liquid. What dose of liquid phenytoin is required?

100 mg solid --- 92 mg liquid

×3 ×3

300 mg solid --- ? mg liquid

92 × 3 = 276 mg

3a Infusions

In an infusion, a solution of a drug is given, usually intravenously, at a constant rate. Sometimes, infusions are preferred to an iv-bolus dose because there is less chance of a very high spike in plasma concentration. In other cases, however, a bolus dose is given to raise the plasma concentration quickly and then administration is continued via an infusion to keep the plasma concentrations maintained at a constant level. Which is chosen depends on a lot of factors including the drug's half-life, mechanism and speed of elimination and the need for close monitoring.

The rate of infusion can be described in two different ways:

- A flow rate – that is the **volume** per unit time is given, e.g. mL/min or mL/h
- A mass rate – that is the **amount of drug** per unit time is given, e.g. mg/h or µg/min

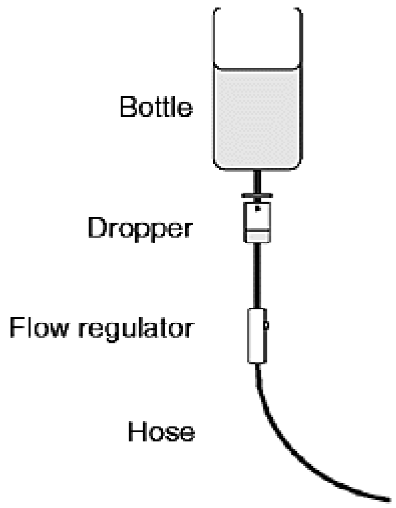
Often, you're just told the drug is given by infusion and you need to infer from the units whether they are referring to a flow rate or a mass rate. Consider a situation where you have a bottle containing drug at a concentration (C) of 10 mg/mL and there is a flow rate (V) of 1 mL/min. How much drug (A) is being administered each minute?

Think about what is happening in one minute… There's 1 mL being administered each minute. How much drug is there in that 1 mL?

Amount = concentration x volume

= 10 mg/mL x 1 mL

= 10 mg.



So the mass rate in this case is 10 mg per minute, which is written 10 mg/min.

Therefore, in general terms we can write:

Infusion mass rate = concentration x infusion flow rate

(mg/min) (mg/mL) (mL/min)

This is analogous to:

Amount (mg) = concentration (mg/mL) x volume (mL)

Example: we have an infusion flow rate of 2 mL/min and a drug concentration of 4 mg/mL, what is the rate of drug administration?

Infusion mass rate = concentration x infusion flow rate

? = 4 mg/mL x 2 mL/min

Infusion mass rate = 8 mg/min. Notice how the units help you here.

Example: What infusion flow rate is required to deliver 12 mg/min? The drug solution has a concentration of 1.5%.

Two steps are required here:

1) Convert 1.5% to mg/mL: $1.5\% = \frac{1.5\ g}{100\ mL} = 0.015\frac{g}{mL} = 15\frac{mg}{mL}$

2) $infusion\ mass\ rate = concentration \times infusion\ flow\ rate$

Rearranging this equation:

$$infusion\ flow\ rate = \frac{infusion\ mass\ rate}{concentration}$$

$$infusion\ flow\ rate = \frac{12}{15}\frac{mg/min}{mg/mL}$$

Infusion flow rate = 0.8 mL/min

Some practice questions

Q1. A patient receives an initial bolus dose followed by an infusion. If the initial bolus dose was 60 mg and the drug was infused for 6 hours at 2.8 mg/h what is the total dose?

Q2. A patient was given an initial dose followed by an infusion. If the initial bolus dose was 18 mg and the drug was infused at a rate of 970 µg/min for 28 hours, what is the total dose given?

Q3. A patient requires an infusion of lidocaine. If the infusion rate is 0.8 mg/min and the concentration of lidocaine is 1 % what infusion flow rate is required?

Q4. A man weighing 66 kg requires infusion at 0.5 µg/kg/h. What is the required infusion rate (given in µg/min)?

Q5. A drug is provided at a concentration of 2%. What infusion rate would be required for an 85 kg man at a dose rate of 30 mg/kg/h?

Q6. A patient requires a 20 mg/min infusion. From a 1.0 % solution, what should the infusion flow rate be?

Answers to practice questions

Q1. 60 mg + 6 h x 2.8 mg/h = 60 + 16.8 = 76.8 mg

Q2. 18 mg + 0.97 mg/min x 28 h x 60 min/h

= 18 mg + 1629.6 mg

= 1647.6 mg

Q3. 1 % = 1 g / 100 mL = 0.01 g/mL = 10 mg/mL

$$infusion\ flow\ rate = \frac{0.8}{10}\frac{mg/min}{\frac{mg}{mL}} = 0.08\frac{mL}{min}$$

0.08 mL/min x 60 min/h = 4.8 mL/h

Q4.

Step 1, scale for body weight. 66 kg x 0.5 µg/kg/h = 33 µg/h

Step 2, convert from µg/h to µg/min. 33 µg/h = $\frac{33\ \mu g}{h} = \frac{33\ \mu g}{60\ min} = 0.55\frac{\mu g}{min}$

Q5.

Step 1, scale for body weight. 85 kg x 30 mg/kg/h = 2550 mg/h

Step 2, convert 2 % to mg/mL. 2% = $\frac{2\ g}{100\ mL} = 0.02\frac{g}{mL} = \frac{20mg}{mL}$

Step 3, calculate infusion rate. $\frac{2550\frac{mg}{h}}{20\frac{mg}{mL}} = 127.5\frac{mL}{h}$

Step 4, convert mL/h to mL/min. $127.5\frac{ml}{h} = \frac{127.5\ mL}{60\ min} = 2.125\frac{mL}{min}$

Q6. $infusion\ flow\ rate = \frac{20\ mg.min^{-1}}{10\ mg.mL^{-1}} = 2\frac{mL}{min}$

TOPIC 2: CELL STRUCTURE

INTRODUCTION

There are approximately 10 million million cells in the human body. These cells are organised into the tissues and organs that perform all the essential functions we require for life. Even though these various cells have very different sizes, shapes and functions, almost all of them contain the same cellular machinery or **organelles**, enclosed in a cell membrane.

Cellular Organelles

The cell membrane (**plasmalemma**) is composed of a double layer of **phospholipid** molecules with embedded **proteins** (see Figure 1.1). The plasmalemma acts as the barrier between the fluid inside the cell (**intracellular fluid**) and the fluid outside the cell (**extracellular fluid**). The intracellular fluid is also known as the **cytoplasm**. Entry or exit of substances across the cell membrane is tightly regulated. The plasmalemma may have some surface specialisations, such as **cilia**.

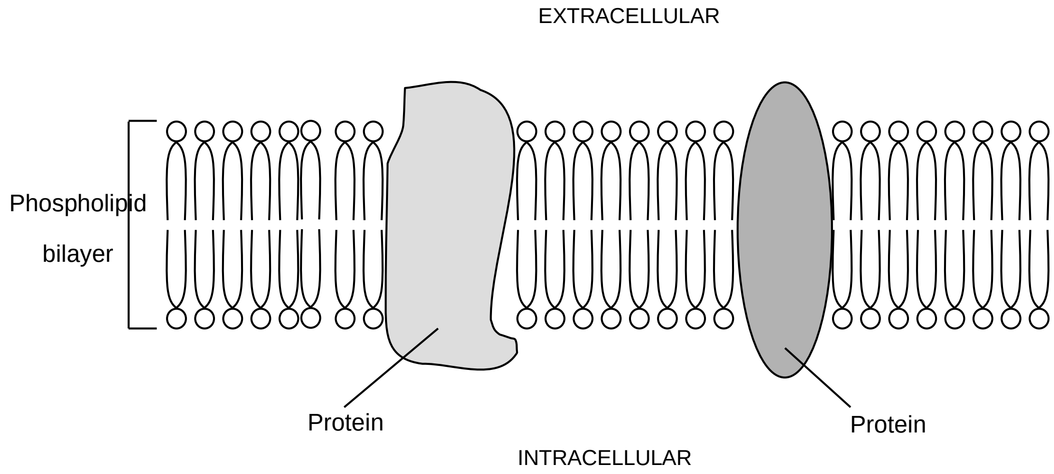


Figure 2-1 Structure of the plasmalemma

The cytoplasm contains all the substances necessary for the various functions of the cell (e.g. growth, movement, secretion, absorption). Within the cell there are numerous organelles, each with a specific function or set of functions (Figure 1.2, Table 1.1).

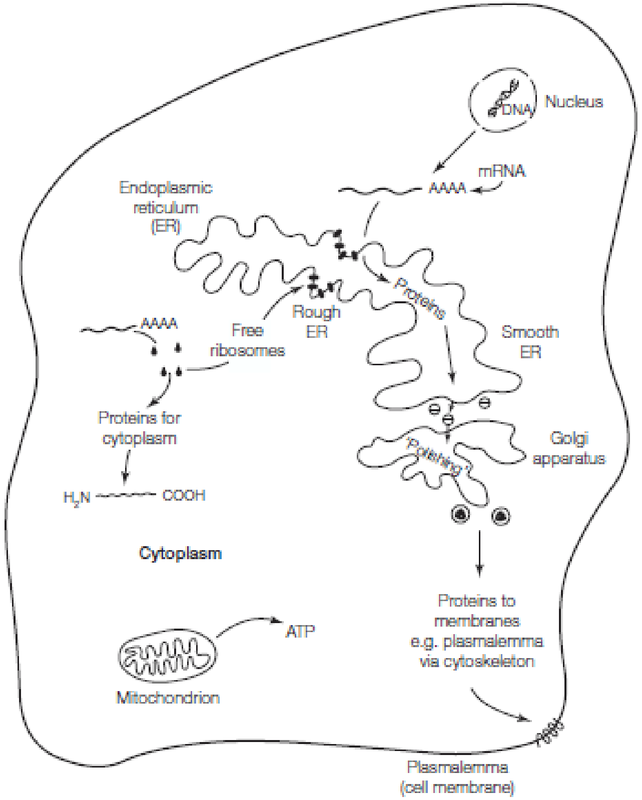


Figure 2-2 Schematic diagram of cellular organelles

The nucleus is the control centre of the cell. It contains the 'blueprint for life', deoxyribonucleic acid (DNA). Everything that the cell does is controlled by expression of the genes on DNA that encode for proteins (see Topic 5). The nucleus itself is separated from the major intracellular compartment, the cytoplasm, by a nuclear membrane.

When genes are transcribed, the **ribonucleic acid (RNA)** that is produced moves into the cytoplasm and is translated into protein on **ribosomes**. As such, these can be thought of as the manufacturing-plants of the cell. If the protein is destined for export from the cell or is destined for a cell membrane, the ribosome will move to the **endoplasmic reticulum**, an intracellular membrane system.

When such proteins are synthesised, they are 'polished' before final use. Small **vesicles** (lipid bags) bud off from the endoplasmic reticulum, pass to the **Golgi**

apparatus where they are modified (post-translational modification), before being packaged into further vesicles that are exported from the Golgi apparatus.

Table 2.1 Functions of major cellular organelles

Organelle	Major function(s)
Nucleus	Site of most of the cell's DNA; Transcription of DNA into RNAs takes place here
Ribosomes	Site of translation of messenger RNA into protein
Endoplasmic reticulum (ER)	Intracellular membrane system – rough ER has ribosomes that translate mRNAs into proteins destined for membranes in the cell or for transport out of the cell
Golgi apparatus	Intracellular membrane system that is the site of much post-translational modification of proteins into their final forms
Mitochondrion	Site of mitochondrial DNA. Major site of energy production in the cell

Most cellular functions are regulated by proteins that act as biochemical catalysts (**enzymes**). Enzymes can exist in the cytoplasm or in other intracellular spaces such as the Golgi apparatus, the nucleus, or the **mitochondrion**.

The mitochondria are the organelles in which the majority of the cell's energy storage molecule **adenosine triphosphate (ATP)** is synthesised. A molecule of **glucose** can be used by the cell to yield more than 30 molecules of ATP, which can then be used to power any of the energy-dependent processes in the cell. These can be as diverse as pumping of ions out of the cell, cell shortening (contraction) or conversion of one chemical substance into another. The mitochondria can be thought of as the power stations of the cell. Mitochondria also contain their own circularly arranged DNA, passed down from mother (but not father) to child (maternal inheritance). **Mitochondrial DNA** encodes for some, but not all, mitochondrial proteins. Mitochondria may originally have been intracellular bacteria that developed a symbiotic relationship with us and other species.

Clinical relevance

Understanding cell structure and function can now help explain some of the damaging effects of smoking. For example, we know that smoking can cause frequent airway infection (bronchitis). This is because smoking damages the cilia on the cells that line the airways. The function of cilia is to keep fluid moving from deep in the lungs to the upper parts of the airways; when the cilia are damaged or lost, this results in defective clearance of mucus from the airways, meaning that bacteria can cause infection.

Another example is a disease called myoclonic epilepsy with ragged red fibres (MERRF). In this disease, caused by a genetic mutation in mitochondrial DNA, the mitochondria aggregate towards the outside of muscle cells (cardiac and skeletal muscle) and have deficient ATP-synthesising ability. This results in muscle weakness, lack of co-ordination of movement and can lead to death from respiratory or cardiac failure.

There will be a series of lectures on basic cell biology in the first few weeks of the GEM course. Use this topic as an introduction.

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Self-test questions for topic 2

(For each question choose the single best answer)

2.1 In what part of the cell does DNA transcription mainly happen?	
A	cytoplasm.
B	endoplasmic reticulum.
C	Golgi apparatus.
D	mitochondrion.
E	nucleus.

2.2 What is the major lipid component of the plasmalemma?	
A	cholesterol.
B	linoleic acid.
C	myelin.
D	phospholipid.
E	triglyceride.

2.3 What is the major energy-storage molecule in human cells?	
A	adenosine diphosphate (ADP).
B	adenosine monophosphate (AMP).
C	adenosine triphosphate (ATP).
D	cyclic adenosine monophosphate (cAMP).
E	guanosine triphosphate (GTP).

2.4 At which organelle does translation of mRNA into protein occur?	
A	Golgi apparatus
B	mitochondrion
C	plasmalemma
D	nuclear membrane
E	Ribosome

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2.5 Which of the following statements is true?	
A	Mitochondrial DNA encodes only some of the proteins necessary for mitochondrial function
B	Mitochondrial DNA is arranged in 46 chromosomes
C	Mitochondrial DNA is inherited from the father
D	Mitochondrial DNA mutations do not affect male offspring
E	Mitochondrial enzymes can produce 5-10 molecules of ATP from one molecule of glucose

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TOPIC 3: ATOMS, MOLECULES, BONDS AND IONS

Introduction

All living and non-living things are made up of chemicals. The ancient Greeks recognised that all matter was composed of minute building blocks and although they were not sure of their existence, they used the word **atomata** to describe them. Today these building blocks or chemical **elements** are named and given abbreviations based on the first or first and second letter of their Latin or English name. Each element is made of smaller units of matter called **atoms**; in any given element all atoms are of the same type.

Structure of Atoms

An atom consists of two basic parts; a centrally located **nucleus** and **electrons** which move around the nucleus. The nucleus contains positively charged particles called **protons** and uncharged particles called **neutrons**. Each proton carries one positive charge. The overall effect is that the nucleus is positively charged. Each electron is negatively charged and carries one negative charge. The number of electrons in an element always equals the number of protons and thus the atom is electrically neutral.

The atoms of one element differ from another element predominantly because of the number of protons. For example, hydrogen has one proton, helium has two protons and carbon has six protons. The number of protons in an atom is called the **atomic number**. The **atomic mass** is the total number of protons and neutrons in an atom.

Carbon (C) has an atomic number of 6. You would expect the atomic mass of carbon to be 12 (protons + neutrons), but some atoms of carbon exist with more neutrons. These are other **isotopes**. The ^{13}C form has one extra neutron. Carbon exists mainly as ^{12}C but about 1% of carbon exists as ^{13}C so the atomic mass of carbon is 12.01. Some unstable isotopes, which are radioactive, are used in medicine particularly in nuclear medicine to help diagnose and treat cancers.

The video explains how there are 92 naturally occurring elements, one for each kind of atom, and how they are arranged into a table according to their relative weights.

QUESTION 3.1: CHECK OUT A PERIODIC TABLE TO FIND THE ATOMIC NUMBER (ATNO) AND ATOMIC MASS (AMU) (TO THE NEAREST WHOLE NUMBER) OF NITROGEN, OXYGEN, PHOSPHORUS, SODIUM, AND CHLORINE AND ADD THEM TO THE TABLE BELOW.

	Atomic Number	Atomic Mass
	ATNO	AMU
Nitrogen (N)		
Oxygen (O)		
Phosphorous (P)		
Sodium (Na)		
Chloride (Cl)		

Like to visualise information. Watch a very straightforward video with information about atomic structure

Electrons

The electrons concentrically orbit around the nucleus in an organised manner. Each of these orbits is called an **energy level**. The inner energy level only holds 2 electrons and the next, 8. The third energy level can hold up to 18 electrons but can be stable with only 8. The fourth energy level can hold 32 electrons. The energy levels fill with electrons from the innermost outwards and electrons 'pair up' as the energy level fills.

Thus, an atom of oxygen (O), which has 8 electrons, would have 2 electrons in the first level and 6 in the second level, with room for 2 more electrons in the second level. The electrons in the second energy level of an oxygen atom exist as two sets of paired electrons and two unpaired electrons (Figure 2.1).

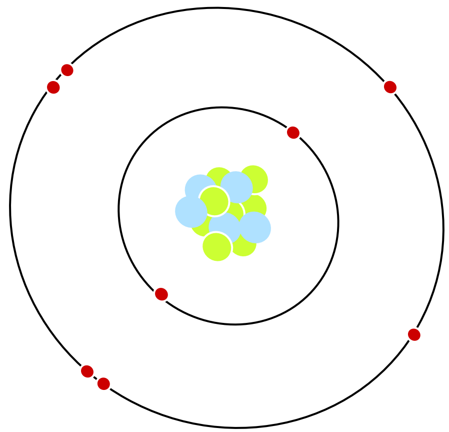

Figure 3-1 Schematic diagram of an oxygen atom. Electrons are represented as small dots orbiting the nucleus in two energy levels.

The number of electrons in the outermost energy level determines much of the atom's chemical properties. Atoms attempt to fill their outermost energy levels. Atoms with a full outer energy level, such as helium or neon, are inert. Most other atoms have outer energy levels that are incomplete. This creates opportunities to take on or share electrons. When two or more atoms combine to try to fill their outer energy levels a molecule is formed. A molecule contains two or more atoms of the same element or of different elements. Atoms in a molecule are held together by chemical bonds, which are a form of potential energy. Chemical reactions are simply the making and breaking of bonds between atoms.

Covalent Bonds

In a **covalent bond**, the atoms do not lose or gain electrons but share pairs of electrons. For example, if the first energy level can hold up to two electrons and hydrogen has only one electron, then a hydrogen atom will have only one electron in its first energy level. Hence, two hydrogen atoms can combine, and the two electrons are shared between the atoms. The electrons circle the nuclei of both atoms. The sharing of one pair of electrons is described as a single covalent bond (Figure 2.2). However, two or three pairs of electrons can be shared, forming double or triple covalent bonds respectively. Covalent bonds do not necessarily have to be formed only between atoms of the same element.

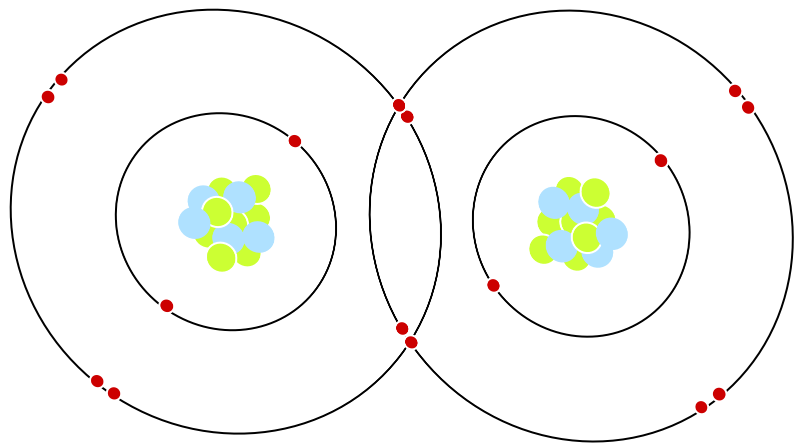

Figure 3-2 Sharing of two pairs of electrons between two oxygen atoms, forming diatomic molecular oxygen (written as O2 or O=O, where = denotes the presence of a double bond)

QUESTION 3.2: HOW MANY ELECTRONS ARE THERE IN THE OUTER ENERGY SHELL OF A CARBON ATOM AND HOW MANY OTHER CARBON ATOMS CAN BE JOINED COVALENTLY TO A SINGLE CENTRAL CARBON ATOM?

ANSWER:

The ability of carbon to form these bonds and create stable compounds is essential for life. Carbon (C), hydrogen (H), oxygen (O), together with nitrogen (N) and phosphorus (P) combined in millions of different ways, account for most biological molecules.

If atoms equally share the electrons, and each atom equally attracts the electrons then this is referred to as a **nonpolar covalent bond**. If, however, there is an unequal sharing of electrons, with one atom attracting the electrons more strongly, then this is referred to as a **polar covalent bond**.

QUESTION 3.3: HOW MANY ENERGY LEVELS DO SODIUM AND CHLORINE HAVE AND HOW MANY ELECTRONS CAN EACH LEVEL HOLD?

ANSWER:

Hydrogen Bonds

Hydrogen bonds occur when a hydrogen atom covalently bonds to an oxygen or nitrogen atom but is also attracted to another oxygen or nitrogen atom. These bonds are weak but if they occur in large numbers, they can provide stability as in DNA, for example.

Ionic Bonds

Atoms are electrically neutral because the number of positively charged protons and negatively charged electrons are equal. However, when an atom loses or gains an electron the charge changes. For example, a sodium atom (Na) has one electron in its outer energy level; sodium can give up this electron to become an **electron donor**. The atom now has a positive charge and has become a sodium ion (Na^+). Similarly, chlorine (Cl) has 7 electrons in its outer energy level and can pick up an electron to become an **electron acceptor**. In gaining an electron from another element, a chlorine atom becomes negatively charged and becomes a chloride ion (Cl^-). The positively charged sodium ion and the negatively charged chloride ion attract each other. This attraction is called an **ionic bond** and in this example sodium chloride (common salt) is formed.

Atoms that have outer energy levels less than half full (such as sodium) aim to lose electrons and become positively charged ions called **cations**. Similarly, atoms with energy levels that are more than half full (such as chlorine) aim to gain electrons and become negatively charged ions called **anions.** Molecules made up of these ions are formed by ionic bonds.

QUESTION 3.4: WHICH OF THE FOLLOWING ELEMENTS FOUND IN THE BODY BECOME CATIONS AND WHICH BECOME ANIONS? *(CIRCLE THE CORRECT ANSWER IN THE TABLE BELOW)*

Iodine	Anion / Cation
Magnesium	Anion / Cation
Potassium	Anion / Cation
Calcium	Anion / Cation

Clinical relevance

Energy is required to break and make covalent bonds. When we digest food by breaking bonds between atoms in a molecule, the energy released is used to build up other molecules for creating and repairing tissues. Some foodstuffs have a higher calorific value than others, based solely on the number and type of covalent bonds they contain.

A hydrogen atom that has lost its outer electron is a hydrogen ion. Hydrogen ions, which are simply single protons, make solutions acidic. In the stomach a high acid concentration is built up by pumping hydrogen ions into the stomach fluid. Drugs called proton pump inhibitors can reduce the amount of acid being produced; useful if you have painful acid reflux.

Ions in solution are essential for life and many are kept in fine balance by the body. See the section on inorganic elements for further details.

Additional resourses

These websites may present some of the information in a way that you find more accessible.

http://www.nottingham.ac.uk/nursing/sonet/rlos/science/atomic_bonding/index.html

http://www.nottingham.ac.uk/nursing/sonet/rlos/science/atomic_structure

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Self-test questions for topic 3

3.5 Which one of the following statements about atoms is correct?	
A	An element can contain atoms of different types
B	Isotopes of the same element have different numbers of protons
C	The atomic mass is the total number of protons in an atom
D	The nucleus of an atom contains protons and neutrons
E	The number of electrons in an atom is called the atomic number

3.6 Which one of the following statements about electrons is correct?	
A	Electrons are arranged in energy levels around the nucleus
B	Electrons move around and collide with the nucleus
C	In a triple covalent bond two pairs of electrons are shared
D	The first energy level can hold up to 8 electrons
E	The second energy shell can be filled before the first

3.7 Which one of the following statements about ionic bonds is correct?	
A	An ion that can gain an electron is called an electron donor
B	If an atom gains an electron in its outer energy level, then it will become negatively charged
C	In an ionic bond, electrons are shared between one or more atoms
D	One sodium ion will be attracted to 2 chloride ions
E	Positively charged ions are called anions and negatively charged ions are called cations

3.8 Which one of the following is a feature of covalent bonds?	
A	A covalent bond cannot be formed between atoms of two different elements
B	A covalent bond in a molecule of hydrogen involves sharing 4 electrons
C	Carbon can form a covalent bond with 5 hydrogen atoms
D	In a covalent bond the atoms share pairs of electrons
E	In a nonpolar covalent bond, atoms equally attract the electrons

TOPIC 4: COMMON ORGANIC COMPOUNDS

Introduction

There are many different compounds within the body. These can be divided into two groups, **organic** or **inorganic** compounds. Organic compounds always contain carbon and hydrogen. They frequently contain oxygen and nitrogen and, sometimes, sulphur and phosphorus. **Carbohydrates**, **lipids**, **proteins**, and **nucleic acids** are all organic compounds.

Carbon is an element that forms covalent bonds quite easily, as its outer energy level is half filled (see topic 3). A carbon atom can form four bonds with other elements. This means that carbon can combine with many different types of atoms to form large molecules of different structures and functions.

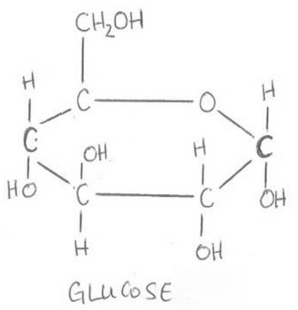
Carbohydrates

Carbohydrates are important to the body. They perform a diverse range of functions. Carbohydrates contain carbon, hydrogen and oxygen usually, but not exclusively, with a ratio of 2 hydrogen atoms to 1 oxygen atom. For example, **ribose** ($C_5H_{10}O_5$), **glucose** ($C_6H_{12}O_6$) and **sucrose** ($C_{12}H_{22}O_{11}$) are all carbohydrates.

Carbohydrates are classified into three groups based on their size:

1. ***Monosaccharides***; these are simple sugars with 3-7 carbon atoms; an example is glucose, a ***hexose*** (6 carbons), the main energy supplying molecule (Figure 3.1)

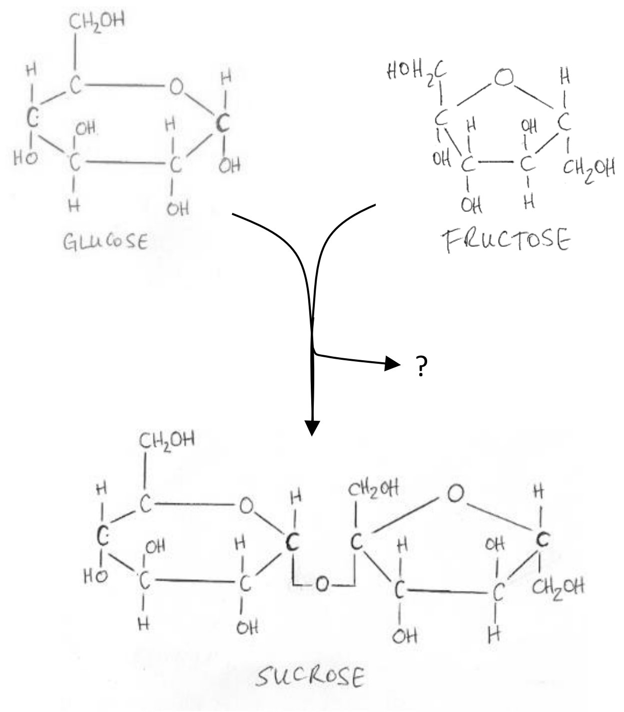
Figure 4-1. The molecular structure of glucose



Simple video of chain and ring glucose structure.

2. ***Disaccharides***; these are two monosaccharides joined chemically. For example, sucrose, a disaccharide, is formed when glucose and fructose (both monosaccharides) combine (Figure 4.2):

Figure 4-2 Glucose and fructose combine to form the disaccharide sucrose



If water is added to disaccharides, they can be broken down (hydrolysed) into smaller and simpler molecules. In the case of sucrose, the products would be glucose and fructose. Another example is the hydrolysis of the disaccharide lactose to produce glucose and galactose.

3. ***Polysaccharides***; these are several monosaccharides joined together. An example of a polysaccharide is ***glycogen***, a branching chain of monosaccharides.

Some 5-carbon sugars (***pentoses***), specifically ribose and ***deoxyribose***, are essential in the formation of nucleic acids; you will learn more about this in topic 5.

Lipids

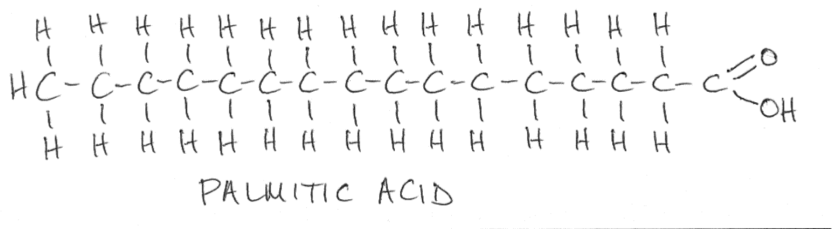
Lipids are made up of carbon, hydrogen and oxygen but do not have the 2:1 ratio of hydrogen to oxygen that is common to carbohydrates. Lipids are usually insoluble in water. Examples of lipids are **triglycerides**, phospholipids, steroids, carotenes, vitamin A and **prostaglandins**. Two are discussed here, triglyceride and prostaglandins.

Triglyceride has two components, **glycerol** and **fatty acids**, which are combined in the ratio of 1 glycerol molecule to 3 fatty acid molecules. The fatty acids that make up triglycerides can be short, medium or long chain fatty acids and they can also be **saturated** (high in hydrogen content with no carbon-carbon double bonds), or **unsaturated** (lower in hydrogen content with some carbon-carbon double bonds). Monounsaturated fatty acids have a single carbon-carbon double bond and polyunsaturated fatty acids have two or more carbon-carbon double bonds. Figure 3.3 shows the structure of palmitic acid, a fatty acid obtained from palm oil.

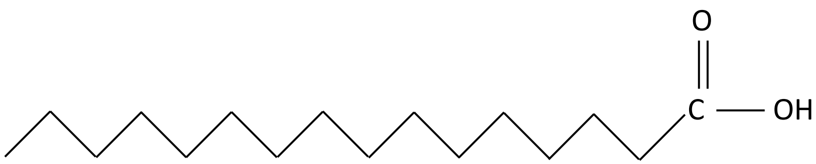
QUESTION 4.1: IF GLUCOSE AND FRUCTOSE ARE COMBINED AS IN FIGURE 3.2, WHAT OTHER MOLECULE INDICATED BY THE (?) WOULD BE FORMED AS PART OF THE REACTION?

ANSWER:

Figure 4-3 Structure of palmitic acid



or



QUESTION 4.2: IS PALMITIC ACID A SATURATED OR UNSATURATED FATTY ACID?

ANSWER:

Triglyceride and fatty acids are important fuel sources for the body, having a higher calorific value per gram (9 calories per gram) than sugars and proteins (4 calories per gram), but they are also important in the synthesis of the constituents of cell membranes.

Prostaglandins (PGs) are membrane-associated lipids produced in all nucleated cells of the body and they influence the function of the cell. The prostaglandins are synthesised from arachidonic acid, which is a polyunsaturated fatty acid. Prostaglandins can act as local chemical messengers, contributing to such diverse processes as the inflammatory response, dilation and constriction of blood vessels and the regulation of body temperature.

Proteins

Proteins are responsible for many activities within the body. For example, they can function as enzymes (speeding up biochemical reactions), antibodies (helping to fight infection) or hormones (acting as intercellular messengers).

Proteins are more complex in structure than carbohydrates and lipids. They contain carbon, hydrogen, oxygen, nitrogen and small amounts of sulphur and phosphorus. The building blocks of proteins are **amino acids**. When two amino acids combine a **dipeptide** is made, when three amino acids combine a **tripeptide** is formed and when a chain of amino acids are combined a **polypeptide** is formed. The bonds between the amino acids in a protein are called **peptide bonds**. There are twenty different amino acids, so protein structure is very variable.

For more on amino acids and protein structure, see topic 7.

Nucleic acids

Nucleic acids are also organic compounds. In the body, nucleic acids take the form of DNA (deoxyribonucleic acid) and RNA (ribonucleic acid) and are essential in directing all cellular processes. Nucleic acids are composed of carbon, hydrogen, oxygen, nitrogen and phosphorous. You will learn more about nucleic acids in topic 5.

Clinical relevance

Some knowledge of the structure of organic molecules is essential for the study and practice of medicine. For example, it is important to know about the structure, calorific value and biological role of the various foodstuffs that we ingest. An individual may be eating no more than their normal daily calorie requirements, but if a large amount of the calories come from fat, particularly saturated fat, then this can be detrimental to health. Another individual may not be eating enough protein and may become seriously malnourished. Another may eat too much ‘rich’ food, ingesting too many nucleic acids, and suffer from gout as a result of high levels of uric acid in the blood (from the metabolism of nucleic acids).

You will learn more about these topics as you study with us, but it is important to try to grasp these basic facts before you start.

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Self-test questions for topic 4

4.3 Which one of the following statements about carbohydrates is **incorrect?**	
A	Carbohydrates can be classified into three major groups; monosaccharides, disaccharides and polysaccharides
B	Carbohydrates usually contain hydrogen and oxygen atoms in the ratio of 2:1
C	Disaccharides are two monosaccharides joined chemically by hydrolysis
D	Monosaccharides containing 6 carbon atoms are called hexoses
E	Polysaccharides are several monosaccharides joined together through dehydration synthesis

4.4 Which one of the following statements about lipids is **incorrect?**	
A	Lipids are made up of carbon, hydrogen and oxygen
B	Lipids have a 2:1 ratio of hydrogen to oxygen
C	Prostaglandins (PGs) are produced from arachidonic acid
D	Triglyceride has two components, glycerol and fatty acids
E	Unsaturated fatty acids have a lower hydrogen content than saturated fatty acids

4.5 Regarding proteins, which one of the following statements is **correct**?	
A	Proteins are chains of monosaccharides
B	Proteins are synthesised from amino acids by hydrolysis of peptide bonds
C	Proteins can act as hormones
D	Proteins do not contain nitrogen
E	Proteins have the same calorific value as triglycerides

TOPIC 5: INORGANIC ELEMENTS

Introduction

In contrast to organic compounds, which contain carbon and hydrogen and mostly contain covalent bonds, inorganic compounds lack carbon, are small in size and are usually have ionic bonds. Inorganic compounds are vital to the body. Examples of inorganic compounds include water, many salts, acids and bases.

Water

Water (H_2O) is the most abundant inorganic compound within the body, with 60% of red blood cells, 75% of muscle tissue and 92% of blood plasma being made up of water. Water has many different functions, for example: -

Water

acts as a solvent

can participate in chemical reactions such as those within digestion

can absorb and release heat slowly

plays an important role in heat evaporation and the cooling of the body

acts as a body lubricant, for example, in saliva

provides the aqueous environment for chemical reactions to take place in cells

The properties of water depend on the unequal distribution of electrons between the two hydrogen atoms and the oxygen atom. Electrons are displaced towards the oxygen atom and away from the hydrogen atoms, giving the oxygen a slight negative charge and the hydrogens slightly positive charges. This means that water molecules are attracted to each other and to other atoms and compounds.

If inorganic acids, bases or salts are dissolved in water within the body's cells ionization occurs and they dissociate into ions. These ions are called **electrolytes** because the solution can conduct an electrical current.

QUESTION 5.1: WHAT ARE THE TERMS FOR COMPOUNDS THAT LIKE WATER AND THOSE THAT DISLIKE WATER? WHICH TERM APPLIES TO FATS AND OILS?

ANSWER:

Minerals and electrolytes

Minerals have many roles in the body including fluid balance; acid-base balance; nerve and muscle functions; providing strength and rigidity for bones and teeth; and as components of enzymes involved in energy metabolism.

Saliva, blood and most other bodily fluids taste salty because they contain sodium chloride (NaCl). Cells, on the other hand, have a low intracellular concentration of sodium, but a high concentration of potassium. Energy is needed to maintain this difference in the concentration of these ions in the intracellular and extracellular space. Iron is essential for the transfer oxygen around the body. Lack of iron causes anaemia and symptoms of tiredness, pale skin, and shortness of breath on exercise.

QUESTION 5.2: WHAT ARE GOOD FOOD SOURCES OF IRON?

ANSWER:

QUESTION 5.3: DESCRIBE TWO WAYS IN WHICH IRON CAN BE LOST FROM THE BODY.

ANSWER:

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Clinical relevance

Movement of sodium and potassium across cell membranes forms the basis of nerve and muscle function. The ionic concentrations in different departments control water movement around the body. Blood tests often include measurements of electrolytes.

Some minerals, for example calcium, are very carefully regulated by the body. A low level of ionised calcium in the blood can cause increased nerve excitability and a condition called tetany, with tingling fingers, muscle spasms and convulsions. If the muscles surrounding the larynx are involved, then breathing can be affected. Another metal element that can cause problems if present in too high a concentration is potassium because this affects the function of the heart.

Some inorganic elements are only required for health in tiny amounts, but if missing cause significant problems. They usually perform an essential role within enzymes, so if not present the enzymes cannot function correctly. Examples are zinc, copper, and selenium. Iodine is essential to produce thyroid hormone. Lack of iodine results in a goitre, an enlarged thyroid gland. This shows as a swelling at the front of the neck. The gland enlarges because it is working too hard to produce the hormone which is required for normal cellular functions.

Additional resources

These websites may present some of the information in a way that you find more accessible.

http://www.nottingham.ac.uk/nursing/sonet/rlos/science/body_elements/

Crossword

Overleaf is a crossword based on the names of some of the most common inorganic elements in the body. Look at the clues and see if you can work out the answers through self-directed learning.

Across

1. This inorganic element can be found in vitamin B_{12}.

3. Together with oxygen, this common element forms a group which is used to activate or deactivate many enzymes.

4. This element is an essential part of the enzyme carbonic anhydrase, which is important in the transport of carbon dioxide in the blood.

7. An extracellular cation essential in blood where it helps maintains water balance.

8. A cation which helps maintain the structure of DNA and RNA. It is also abundant in bone.

Down

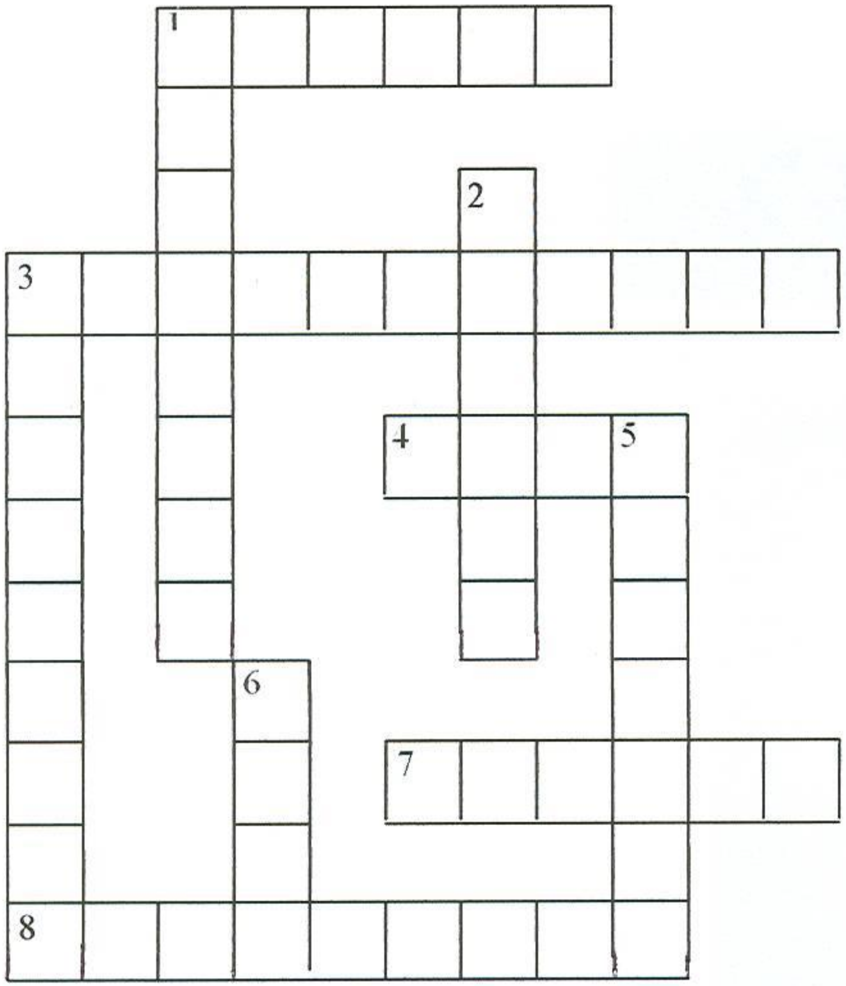
1. An anion in common salt which is important in water movement between cells.

2. Vital for production of thyroid hormones by the thyroid gland.

3. The major intracellular cation.

5. An essential component of bones and teeth, it is required for blood clotting and muscle contraction.

6. Plays a key role in the protein haemoglobin which is found in the red blood cells.



TOPIC 6: DNA – RNA - PROTEIN

Introduction

Nucleic acids are very large organic molecules which contain carbon, hydrogen, oxygen, nitrogen, and phosphorus. There are two types of nucleic acid:

- **Deoxyribonucleic acid (DNA) and Ribonucleic acid (RNA)**

The basic building blocks of nucleic acids are **nucleotides**. A nucleotide is made up of three constituent parts:

1. **A nitrogenous base**, a ring-shaped structure containing atoms of carbon, hydrogen, oxygen and nitrogen. There are four different nitrogenous bases in DNA: ***adenine*** (A), ***thymine*** (T), ***cytosine*** (C), and ***guanine*** (G). Adenine and guanine have a double ring structure and are referred to as *purines*. Cytosine and thymine are smaller, single-ringed structures and are referred to as ***pyrimidines***. An easy way to remember this is that the ones with the letter 'y' in their name (cytosine and thymine) are pyrimidines
2. **Deoxyribose**, which is a monosaccharide. This sugar contains five carbon atoms and it is thus called a pentose
3. **A phosphate-Group**

The parts of a nucleotide molecule are arranged as follows:

phosphate------sugar------base

Several nucleotides joined together make a polynucleotide chain:

phosphate-----sugar-----base
|
phosphate-----sugar-----base
|
phosphate-----sugar-----base
|
phosphate----sugar----base

DNA

DNA is the form of nucleic acid that is contained in the nucleus of the cell. This DNA comprises the **genome**. A DNA molecule (Figure 5.1) is made up of two polynucleotide chains.

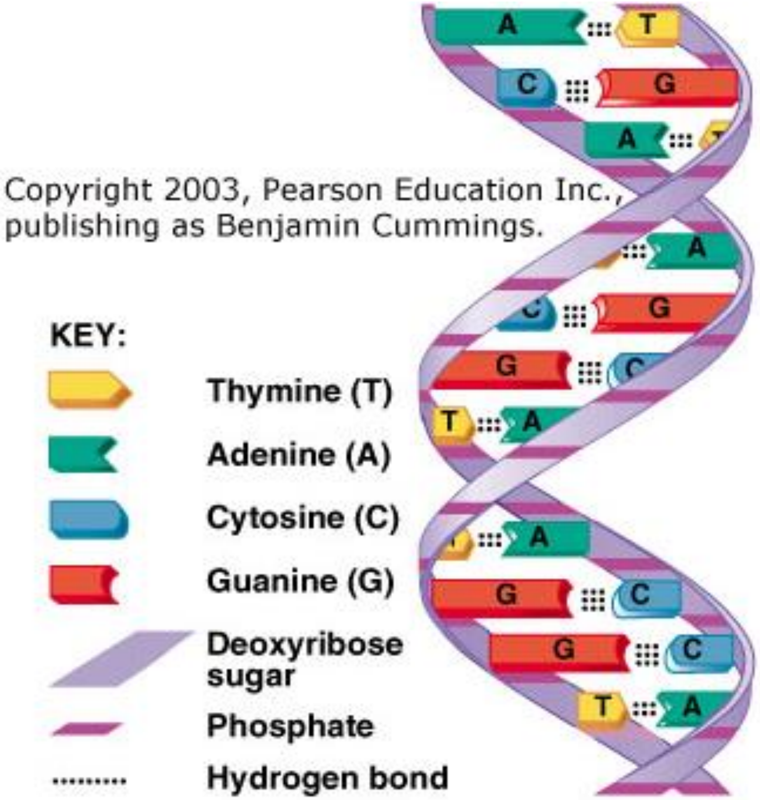


Figure 6-1 The structure of a molecule of DNA

The two strands of DNA are twisted around each other in a 'double helix' that is, in some respects, like spiral staircase. The phosphate and deoxyribose groups are rather like the banisters of the staircase. The steps in the staircase are formed by paired bases: cytosine always pairs with guanine and adenine always pairs with thymine. The order of bases in the DNA molecule is the 'genetic code'. Thus, a base sequence might be written 5'-TGGTTGCTACA-3' with the complementary (opposite) strand having the sequence 5'-TGTAGCAACCA-3'. When writing a base sequence, the convention is to go from the 5' end to the 3' end of the DNA strand (we'll explain the 5' and 3' notation when you arrive on GEM). The two strands run in opposite directions so that the pairing happens as illustrated in Figure 5.2.

5' TGGTTGCTACA 3'

| | | | | | | | | |

3' ACCAACGATGT 5'

Figure 6-2 Pairing of complementary bases on two strands of DNA

RNA

RNA is the form of nucleic acid that is involved in protein synthesis. There are three main types of RNA that are involved in different parts of this process (messenger RNA, ribosomal RNA and transfer RNA; also called mRNA, rRNA and tRNA, respectively). RNA differs from DNA in several ways:

- It is single stranded.
- The sugar in the RNA nucleotide is ribose (another pentose monosaccharide)

RNA does not contain the base thymine, but the base **uracil** (U) instead

Protein Synthesis

Cells synthesise large numbers of diverse proteins, which perform many different functions. They may be enzymes, antibodies, or hormones, for example. Genomic DNA contains the genetic instructions for making proteins. Protein synthesis occurs in two steps, transcription and translation.

Transcription

During transcription, the sequence of bases in a part of the DNA is copied (hence 'transcription') by synthesis of mRNA. The strand of the DNA double helix that carries the genetic code is called the coding strand or 'sense' strand. The double helix strands separate or 'unzip' as the hydrogen bonds that hold the base pairs together break. An mRNA molecule that has the same sequence as the 'sense' strand of DNA is synthesised, the one exception being the substitution of uracil for thymine. The mRNA then moves out of the nucleus to a ribosome.

Translation

Translation describes the process of synthesis of protein on a ribosome using an mRNA template (Figure 5.2). The building blocks of proteins are amino acids

(See the following topic for details). The various amino acids are chemically bound to specific tRNA molecules. This combination of amino acid and tRNA is known as **aminoacyl tRNA**. Each aminoacyl tRNA can bind to a specific three-base (triplet) sequence on mRNA known as a **codon** (e.g., AUG). The complementary triplet on tRNA (e.g., CAU) is known as an **anticodon**.

This 3D animation shows how proteins are made in the cell from the information in the DNA code.

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Figure 6-3 Codon-anticodon pairing and mRNA translation

```
amino acid (methionine)        proline (next amino acid)
                        |          |
                       tRNA       tRNA
                        |          |
anticodon    ——>       UAC        GGU
                       | | |
(mRNA molecule)……AUGCCAAAU…… (mRNA molecule)
                        ↑
                      codon
```

Through base pairing, the anticodon on a specific tRNA binds to the codon of mRNA. This only occurs when the mRNA is attached to a ribosome.

As each tRNA attaches to the mRNA via codon-anticodon pairing, the ribosome moves along the mRNA and the next tRNA and its corresponding amino acid will move into position. The two amino acids are joined by a peptide bond, the tRNA detaches from the mRNA, and the released tRNA can be recycled to pick up another available amino acid molecule. This process continues with the protein chain getting longer (elongation). When the protein is completed, further synthesis is terminated by a **stop codon** on the mRNA (UAA, UAG or UGA). The protein is then released from the ribosome for folding and further post-translational modification.

QUESTION 6.1: WHICH CODON(S) ON MRNA ENCODE FOR THE AMINO ACID ARGININE? (MOST BIOLOGY TEXTBOOKS WILL HAVE A COPY OF THE GENETIC CODE TABLE)

ANSWER:

Clinical relevance

A number of diseases are caused by **mutations** in genomic DNA (changes in the sequence of bases) that result in the formation of mRNA that has the 'wrong' sequence, which subsequently leads to the synthesis of proteins that have an incorrect amino acid sequence and do not function properly. One example is sickle cell disease, in which a single nucleotide change, in the gene encoding one of the subunits of haemoglobin, results in a single mistake in the amino acid sequence of the protein. This causes crystallisation of the haemoglobin in the patient's red blood cells and can result in painful blockage of small blood vessels by the mis-shapen red blood cells. In some cases, it can be fatal.

You will learn more about transcription and translation in the first few weeks of the GEM course and more about genetics as you progress.

Self-test for topic 6

Choose the single best answer from the 5 options for each question.

6.2 DNA structure includes	
A	adenine
B	amino acids
C	base-pairing between adenine and guanine
D	ribose
E	uracil

6.3 Which one of the following statements is correct?	
A	Adenine in the DNA template matches a thymine in the mRNA strand
B	Cytosine in the DNA template matches an adenine in the mRNA strand
C	During transcription, a copy is made if the 'sense' strand of DNA
D	During transcription, genetic information encoded within the DNA is copied into a strand of RNA called transfer RNA (tRNA)
E	The double helix of DNA remains tightly bonded

6.4 Which one of the following statements is incorrect	
A	Messenger RNA (mRNA) leaves the nucleus after transcription
B	Protein synthesis occurs on ribosomes
C	RNA does not contain thymine
D	AA used in protein synthesis come from aminoacyl mRNA
E	Protein synthesis includes transcription and translation

6.5 Regarding translation, which one of the following statements is correct?	
A	A codon is a triplet of nitrogenous bases on tRNA
B	An anticodon is a triplet of nitrogenous bases
C	One end of the mRNA binds with an amino acid
D	One end of the tRNA binds with two nitrogenous bases
E	Protein synthesis is halted by a termination anticodon

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TOPIC 7: AMINO ACIDS AND PROTEIN STRUCTURE

Introduction

Proteins are large molecules (macromolecules) that are indispensable to us. They are our body building blocks and have an enormous array of functions, playing a major role in all our body activities, including:

- Structural roles (e.g. muscle and nails contain the proteins collagen and keratin respectively)
- Protective roles (e.g. interleukins and immunoglobulins are released to help our body fight infection)
- Transport roles (e.g. oxygen and carbon dioxide can be transported in haemoglobin)
- Regulatory roles (e.g. most enzymes, which act as catalysts for the biochemical reactions in our bodies, are proteins)
- Signalling roles (e.g. hormones such as anti-diuretic hormone, which helps to conserve body water when it is released into the blood stream)

With so many functions, it's not surprising to find that there are thousands of different proteins with distinct structures. However, all proteins are made from chains of amino acids that are strongly held together by covalent peptide bonds. Hundreds of amino acids exist but only 20 are found in the body. All of these amino acids have different chemical structure. When combined in a chain, the structural variety of the amino acids gives proteins and almost endless range of structural (and therefore functional) diversity. Just think of how many words you could make out of 20 different letters, using each letter as many times as you liked, and what their meanings would be…

The names of the 20 amino acids are abbreviated using two systems; a three-letter system where the amino acid glycine is denoted Gly and a single-letter system where glycine is denoted G.

QUESTION 7.1: COMPLETE THE TABLE ON THE NEXT PAGE TO SHOW THE 20 AMINO ACIDS (AND THEIR ABBREVIATIONS) THAT MAKE UP OUR BODY PROTEINS.

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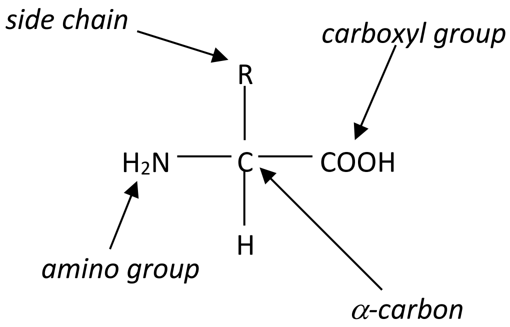
Amino acid	Three-letter abbreviation	Single letter Abbreviation
Alanine		
	Cys	
		D
		E
	Phe	
Glycine	Gly	G
Histidine		
	Ile	
		K
	Leu	
		M
Asparagine		
	Pro	
		Q
Arginine		
	Thr	
Valine		
		W
	Tyr	

Amino acid structure

All amino acids have four common parts (Figure 6.1):

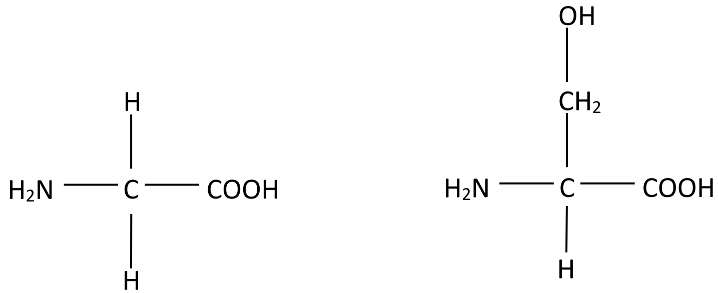
- an α-carbon atom
- an **amino** group (-NH_2)
- a **carboxyl** group (-COOH)
- a side chain, specific to each amino acid, denoted 'R'

Figure 7-1 General structure of amino acids



The side chain is the part of the molecule that varies between amino acids. For example, in glycine 'R' is a hydrogen atom but in serine 'R' is CH_2OH (Figure 6.2).

Figure 7-2 Structures of glycine and serine



Glycine Serine

In this video, amino acid's structure, which include an amine group, a carboxylic acid group, and a unique side chain (R-group) attached to the alpha carbon is explained.

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QUESTION 7.2: DRAW THE CHEMICAL STRUCTURE OF THE AMINO ACID OF YOUR CHOICE AND DISTINGUISH BETWEEN THESE VARIOUS GROUPS.

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The various side chains of the amino acids have different properties. Some are small (e.g. in glycine) whereas others are bulky (e.g. in tryptophan). Some side chains are charged, and others are uncharged, some acidic and some basic (see topic 8). These variations in the physico-chemical characteristics of the side chains mean that proteins can have almost endlessly variable shapes.

Note that in all the amino acids except for glycine, the α-carbon atom has four different chemical groups attached. This means that it is the **chiral centre** of the molecule.

QUESTION 7.3: WHAT IS A CHIRAL CENTRE?

ANSWER:

Peptide bonding

When a protein is being synthesised on a ribosome (see topic 5), the amino acids being carried on transfer RNA (tRNA) join in a sequential manner (the order of amino acids being determined by the codons on the messenger RNA (mRNA). A peptide bond is formed between the carbon of the carboxyl group of one amino acid and the nitrogen of the amino group of the next amino acid. This is a form of dehydration synthesis, involving the loss of a water molecule. This ensures that there is always an amino group at one end of the protein (the first amino acid of the sequence) and a carboxyl group at the other; addition to the carboxyl group extends the chain further. Proteins can therefore exist as dipeptides (two amino acids joined) or more commonly polypeptide chains of hundreds of amino acids in length. The more amino acids, the greater the weight of the molecule and the more complex the peptide is in terms of structure.

Protein organisation

Proteins are organised on 4 levels:

1. Primary structure

This is the unique sequence of the amino acids bonded together by the covalent bonds in a polypeptide chain and it makes each protein structurally and functionally distinct as there are so many possibilities. Mutations in DNA can cause alterations in this sequence, which has implications for function (see topic 6).

2. Secondary structure

This refers to the twisting or folding of the polypeptide chain because of hydrogen bonding (see topic 3) at regular intervals along the polypeptide back bone. Commonly, bonding between the amino acid residues in the same chain cause the peptide to twist clockwise (an α-helix). Some polypeptide chains, such as keratin, can also form sheets when chains that run side by side bond (β-pleated sheets), or even, as in the case of collagen, twist strongly like entwined ropes (triple helices). The secondary structure can therefore be informative about possible protein functional integrity.

QUESTION 7.4: WHAT IS THE QUATERNARY STRUCTURE OF AN IMMUNOGLOBULIN G (IGG) ANTIBODY?

ANSWER:

3. Tertiary structure

This refers to the 3-dimensional shape of all functional proteins and is the result of side chain interactions that cause each protein chain to fold up into a crystalline structure. Weak hydrogen, ionic or hydrophobic bonds or strong covalent disulphide bridges (linking adjacent cysteines) cause the proteins to have distinctive irregular shapes. The unique tertiary structure helps to determine how the protein will function. Thus, the amino acid sequence and folding of the protein give it a distinctive shape and it is this shape that is essential in determining function.

4. Quaternary structure

This occurs when 2 or more polypeptide chains are bonded together weakly or strongly, as before, so that they function together as a single unit. For instance, the respiratory pigment haemoglobin consists of 4 polypeptide globin chains (2α and 2β), which have related amino acids and similar tertiary structures. This means that haemoglobin can carry four molecules of oxygen (O_2), one on the haem group in each of its four globin chains.

Denaturation of proteins

Proteins can be denatured. This is a process whereby the protein unravels, and the specific secondary, tertiary or quaternary structure is lost, rendering the protein useless. Denaturation occurs when the protein is exposed to an excessive large change in its expected environment such as changes in temperature, **pH** or electrolyte concentration. Think of an egg when it is cooked! The protein albumen in the egg becomes white and hardens up permanently. For this reason, homeostatic regulation of temperature, pH and electrolyte concentration is vital to our normal body function.

Proteins as enzymes

Many proteins act as enzymes. Enzymes are **catalysts** (i.e. they speed up a chemical reaction) for biochemical reactions in the body. Enzymes are specific for the reactions that they catalyse; the shape of the protein confers this ability to catalyse a given reaction. The protein may be folded in such a way that it forms a 'binding pocket' for the **substrate** of the reaction and another area of the protein nearby may then chemically alter the substrate to form the **products** of the reaction. The action of enzymes is sometimes said to mimic a '**lock-and-key**' where the shape of the enzyme is ideally suited to the chemical structure of the substrate for the reaction, but not the products. In this way a substrate can be bound and chemically altered, but the products of the reaction are readily released.

Enzymes catalyse many different types of reactions and the type of reaction that a given enzyme catalyses places the enzyme in a particular class. For example, enzymes that split adenosine triphosphate (ATP) are known as **ATPases** (the –ase suffix denoting the enzymatic nature of the reaction. Another example is **lipases**, which digest triglycerides.

QUESTION 7.5: COMPLETE THE TABLE BELOW ON ENZYME CLASSES AND THEIR ACTIONS.

Enzyme class	Action
Amylases	
	Remove carboxyl groups from molecules
DNA polymerases	
	Convert esters to the constituent acid and alcohol
Kinases	
Lipases	Digest triglycerides
	Remove phosphate groups from molecules
Proteases	
RNA polymerases	

Altering the activity of enzymes and other proteins

Enzymes work best (have optimal activity) at a certain temperature, pH and in certain electrolyte concentrations. With some exceptions (e.g., **proteases** in the stomach), most enzymes in our bodies work best at around 37°C and close to physiological pH of 7.4.

Additionally, the activity of proteins (e.g., increasing or decreasing the activity of an enzyme) can be altered by several control mechanisms. One of the most important is **phosphorylation** of certain amino acid residues in the protein. These reactions are catalysed by **kinases**. Phosphorylation involves the addition of a phosphate group (often using ATP as the phosphate donor) to the protein. This is a form of **covalent modification**. The amino acids that are most commonly phosphorylated are serine, threonine and tyrosine residues. Phosphorylation can either increase or decrease the activity of the protein. Phosphorylation is reversed by **phosphatases**. You will be introduced to examples of reactions that are regulated by phosphorylation / **dephosphorylation** when you arrive on GEM.

Clinical Relevance

Several different factors affect protein structure. These factors may be genetic; mutations in the genes encoding a protein may alter its primary structure so that its overall structure is abnormal in affected individuals. One example is the disease cystic fibrosis in which affected individuals have mutations or deletions in the gene encoding a membrane transport protein, which results in abnormal amino acid sequence and therefore abnormal function of the protein. People with cystic fibrosis do not digest and absorb their food well, are prone to lung infections and have reduced life expectancy.

The factors may also be metabolic; electrolyte imbalance or altered body pH can have detrimental effects on protein function. Therefore, it is important to maintain acid-base balance in the body, a topic you will be introduced to as the last one in this workbook (topic 8).

TOPIC 8: SI UNITS, PREFIXES, SIZE AND CONCENTRATION

Introduction

In a medical setting, you will be surrounded by many different units and ways of expressing length, mass, concentration, temperature, pressure, etc. In most cases there are several different ways of expressing the same thing. For example, concentration may be expressed in grams per litre or in moles per litre. In the last 50 years or so, the way in which such parameters are expressed has become more standardised. It's important that you know something about the ways in which a parameter might be expressed so that you are less likely to make a mistake when administering the correct dose of a drug to a patient, for example.

In 1960 a standardised system of measurement, **Le Système International D'unités** (or SI system), was launched. **SI units** are now used in most countries of the world.

SI units are based on 7 standardised units of measurement. Each SI unit has a standard abbreviation, given here in brackets.

Unit	Parameter measured
metre (m)	Length
kilogram (kg)	Mass
mole (mol)	Amount of substance
second (s)	Time
ampere (A)	Electrical current
kelvin (K)	Thermodynamic temperature
candela (cd)	Luminous intensity

The last three SI units (A, K and cd) are rarely, if ever, used in medicine, so concentrate on the first four.

SI units can be combined to give other units of measurement. For example, speed is measured in metres per second (m/s) and volume in cubic metres (m3); these are **SI-derived units**.

QUESTION 8.1: USING THE INFORMATION ABOVE, WHICH OF THE FOLLOWING (A-E) IS STRICTLY THE CORRECT SI-DERIVED UNIT TO EXPRESS THE CONCENTRATION OF A SUBSTANCE IN SOLUTION?

A. g/L
B. g/m^3
C. mol/L
D. mol/m
E. mol/m^3

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Prefixes

In chemistry, physics, biology, and medicine we rarely come across unitary values. For example, red blood cells have a diameter of approximately 0.000007 m and there are approximately 5,000,000,000,000 red blood cells in a litre of normal blood. If this were the only way of expressing such large or small numbers, scientific and medical textbooks would be much larger than they are today.

Thankfully, SI units can have prefixes or special symbols that precede the unit. These prefixes allow us to make multiples of the original units.

Here are some commonly used prefixes (with their symbols in brackets)

Prefix	Meaning	Scientific notation
femto (f)	one thousand million millionth (0.000000000000001)	1 x 10^{-15}
pico (p)	one million millionth (0.000000000001)	1 x 10^{-12}
nano (n)	one thousand millionth (0.000000001)	1 x 10^{-9}
micro (µ)	one millionth (0.000001)	1 x 10^{-6}
milli (m)	one thousandth (0.001)	1 x 10^{-3}
centi (c)	one hundredth (0.01)	1 x 10^{-2}
deci (d)	one tenth (0.1)	1 x 10^{-1}
deca (da)	ten (10)	1 x 10^{1}
hecto (h)	one hundred (100)	1 x 10^{2}
kilo (k)	one thousand (1,000)	1 x 10^{3}
mega (M)	one million (1,000,000)	1 x 10^{6}
giga (G)	one thousand million (1,000,000,000)	1 x 10^{9}

It is important to remember that milli stands for one thousandth and not for one millionth. The prefix milli comes from the French word 'mille' or 1,000.

Using these prefixes obviates the need to write long numbers (and count zeros). For example, red blood cells, which have a diameter of seven one millionths of a metre are said to have a diameter of 7 µm (sometimes called 7 microns). There are approximately 5 million million red blood cells in a litre of normal blood, but this is usually expressed a 5×10^{12} cells/L.

QUESTION 8.2: HOW IS 10 µM EXPRESSED IN *SCIENTIFIC NOTATION*?

ANSWER:

Size of cells and organisms

A human hair is about 0.1 mm wide. If this is modelled using a 10-meter (m) tape then the size of cells and organisms can be compared and measured in cm and mm.

QUESTION 8.3: COMPLETE THE TABLE OPPOSITE AND COMPARE THE SIZES.

Structure / organism	Actual size	Model size
Human hair	0.1 mm	10 m
Monocyte	0.02 mm	
Red blood cell	7 µm	
Mycobacterium tuberculosis	3 µm	
Escherichia coli	2 µm	
Adenovirus	90 nm	
HIV	80 nm	

Concentration

Concentration is a measurement of how much of a substance is mixed with another substance, this usually refers to the amount of **solute** that is dissolved in a **solvent**. Although we usually think of a solute as a solid that is added to a solvent, the solute could be a dissolved gas.

A **solution** becomes more concentrated if more solute is added or the solvent is reduced. If more solvent is added or the solute is reduced a solution becomes more dilute.

A mole of a substance is the quantity of the substance whose mass in grams is the same as its formula weight. Thus, a mole of ^{12}C (see topic 2) will weigh 12 g. A mole of sodium chloride weighs approximately 58 g (as the atomic mass of sodium and chlorine are 23 and 35 approximately). One mole of a substance will contain approximately 602,214,150,000,000,000,000,000 'particles' of the substance.

QUESTION 8.4: HOW WOULD

602,214,150,000,000,000,000,000 BE EXPRESSED IN SCIENTIFIC NOTATION?

ANSWER:

Molarity is one method of expressing concentration. The molarity of a solution refers to the numbers of moles of a given substance per litre (L) of solution and is expressed as mol/L or M. Be careful not to confuse mega with molarity since both (unhelpfully) are represented by a capital 'M'.

Clinical relevance

Here are two examples of the importance of units in medicine:

A doctor who asks for a full blood count will receive information on the number of red blood cells per litre of the sample but will also be presented with data like packed cell volume (the haematocrit or Hct), mean cell volume (MCV), mean cell haemoglobin content (MCH) and mean cell haemoglobin concentration (MCHC). Although these measurements are clearly related to one another, they can be affected differently by different disease states. The doctor must know what each one means and be aware of the different units.

As another example, imagine the case of a doctor who is given a vial containing 20 mL of a drug at a concentration of 5 mg/mL and is asked to administer the drug at a dose of 50 µg/kg to a patient weighing 70 kg over a 2-hour period.

To do this safely and correctly, the doctor would first have to work out how much drug to administer. In this case, the doctor would have to administer 3.5 mg of the drug (50 µg/kg × 70 kg = 3,500 µg = 3.5 mg). This much drug is present in 0.7 mL (700 µL) of the solution in the vial (0.7 mL of 5 mg/mL = 3.5 mg), so the doctor might have to add 0.7 mL of the stock to an intravenous drip and administer the whole amount over a period of 2 hours.

It is complicated, isn't it? But we hope you will agree that it is worth getting it right. Ensure that you are familiar with these concepts before you come on GEM.

Additional resources

These websites may present some of the information in a way that you find more accessible.

http://www.nottingham.ac.uk/nursing/sonet/rlos/ebp/si_units/

http://www.bipm.org/en/si/

Self-test for topic 8

8.6 A patient's fluid intake could be measured using what unit?	
A	joule (J)
B	kilogram (kg)
C	litre (L)
D	volt (V)
E	watt (W)

8.7 The prefix milli can be abbreviated to	
A	m
B	M
C	mi
D	mL
E	µ

8.8 A patient is prescribed 1 thousandth of a gram of a drug. Which of the following options is a correct alternative way of writing the dose?	
A	10×10^{-2} g
B	1 mg
C	1 Mg
D	1 µg
E	10 µg

8.5 Match the (numbered) measurement to the (lettered) unit. Each unit can only be used once 1. Hct (haematocrit) 2. MCV (mean cell volume) 3. MCH (mean cell haemoglobin) 4. MCHC (mean cell haemoglobin concentration)	
A	fL
B	pg/cell
C	g/dL
D	%

Choose the single best answer from the five options (a-e) for the next four questions.

8.9 A patient is prescribed 0.005 litre of a liquid medication. Which of the following options is a correct alternative way of writing the dose?	
A	5 decilitres
B	5 microlitres
C	0.05 mL
D	5 mL
E	50 mL

TOPIC 9: MEDICAL LINGUISTICS

Introduction

You are entering a profession which although not having a recognized discipline we could call medical linguistics, perhaps should have one!

The language of medicine dates to the Hippocratic writings from the 5th and 4th centuries BC, which cover all aspects of medicine at that time and contain numerous medical terms.

This was the beginning of the Greek era of the language of medicine, which lasted even after the Roman conquests of Greece and Spain, the North African coast, much of the Middle East, modern-day France, and even the remote island of Britain. The Romans had no history of Roman medicine so directly imported Greek medicine into their culture. Most of the doctors practicing in the Roman Empire were Greek and our medical language has a great Greek legacy continuing to this day. Numerous names of diseases and symptoms have a Greek origin, such as catarrh (downflow), diarrhoea (throughflow), dyspnoea (bad breathing), melancholic (pertaining to black bile) and podagra (a foot trap).

At the beginning of the first century AD, when Greek was still the only language of medicine in the Roman world Aulus Cornelius Celsus wrote **De Medicina**, an encyclopaedic overview of medical knowledge based on Greek sources but written in Latin. He is sometimes called Cicero medicorum (the Cicero of doctors) on account of his elegant Latin.

Celsus faced the difficulty that most Greek medical terms had no Latin equivalents, he therefore imported a few Greek terms directly, even preserving their Greek grammatical endings into his text. He included, for instance, the Greek words pyloros (now pylorus) and eileos (now ileus), written with Greek letters in his Latin text. Secondly, he latinized Greek words, writing them with Latin letters and replacing Greek endings by Latin ones e.g., stomachus and brachium. Thirdly, and most importantly, he retained the vivid imagery of the Greek anatomical terminology by translating Greek terms into Latin, such as dentes canini from Greek kynodontes (dog teeth) and caecum from Greek to typhlon (the blind [gut]).

Because of this work we today can still enjoy the old Greek tradition of likening the shape of anatomical structures to, for instance, musical instruments (e.g. tuba=trumpet, tibia= flute), armour (thorax=breastplate, galea=helmet), tools (fibula=needle, falx=sickle), plants (uvea=grape, glans= acorn) and animals (helix=snail, concha=mussel, musculus= mouse, tragus=goat so named because that part of the external ear may be covered with hair, resembling the tuft on a goat's chin). Some of these words are the original Greek ones, while others are Latin equivalents introduced by Celsus and his successors.

Medical Latin persisted into the 1850s with patient notes still written in Latin until 1853 in some European countries.

Now, modern medical languages have replaced this practice, but medical scientists continued to develop new concepts that had to be named, and our classically schooled predecessors coined a multitude of new terms, most of which were composed of Greek rather than Latin roots, since Latin does not to the same extent permit the formation of composite words. They introduced, for instance, the terms nephrectomy, ophthalmoscopy, and erythrocyte, which in medical Latin would have been the rather more cumbersome excisio renis, inspectio oculorum and cellula rubra. This huge neoclassical word stock with Greek roots, which is still being used, also presents other characteristics of linguistic interest such as the special meaning attached to certain suffixes of a Greek origin (e.g. -itis and -oma) and the fact that some prefixes and suffixes are more productive than others. Greek hyper-, for instance, is more productive than Latin super-, although originally, they had the same meaning. Therefore, we say hypertension, which is a Greek-Latin hybrid, rather than supertension, which would have been the correct Latin term

The use of these prefixes and suffixes in modern medical linguistics is often key to understanding what the new words and terms in medicine mean and in decoding and understanding the Latin and Greek origins of many of our anatomical terms.

When we look at words which have prefixes and suffixes we start with a base word. The base word or Root is the central part of a word.

prefix	base word = root	suffix
A group of letters added to the BEGINNING of a word to make a new word.	The root or base word is the word you are adding a prefix or a suffix to.	A group of letters added to the END of the word to make a new word.
un	help	ful

A prefix is placed at the beginning of a word to modify or change its meaning. For example, Pre means "before." Prefixes may also indicate a location, number, or time. A suffix is the ending part of a word that modifies the meaning of the word.

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Self-test for topic 9

Can you think of a good example using each prefix to help you remember its meaning, you can use this to then decode any unknown terms you encounter in the course?

9.1 Cyto means	
A	Fat
B	Smooth
C	Blue
D	Cell

9.2 *Myo* refers to your	
A	Brain
B	Myopic nerve
C	Feet
D	Muscle

9.3 Neuro means	
A	Nerve
B	New
C	Digestive system
D	Endocrine system

9.4 Kary means	
A	Illness
B	Cell
C	Nucleus
D	Digestive system

9.5 *Leuk* means	
A	White
B	Black

C	Sickle shaped
D	Heart shaped

9.6. Erythro means	
A	Membrane
B	Heart shaped
C	Brown
D	Red

9.7 Histo means	
A	White
B	Yellow
C	Tissue
D	Film

9.8 Melano means	
A	White
B	Black
C	Cancer
D	Heart shaped

9.9 Patho means	
A	Disease
B	Red
C	Purple
D	Malignant

9.10. Somato means	
A	Body
B	Tissue

C	Yellow
D	Nerve

Words with the following prefix tell you a lot about the base word or roots action

9.11. *A, an* in front of a root word means	
A	Without
B	Within
C	Through
D	Against

9.12. Ab in front of a root word means	
A	Toward
B	Within
C	Pain
D	Away from

9.13. Ad in front of a root word means	
A	Away from
B	Binding
C	Together
D	Toward

9.14. Algia in front of a root word means	
A	Pressure
B	Pain
C	Point
D	Away

9.15. Anti	
A	Against, instead of
B	Down or away from
C	Binding, fixation

D	Outside, beyond

9.16. Bi	
A	Three, triple
B	Two, double
C	Four, quad
D	Five, quint

9.17. Brady	
A	Fast
B	Pain
C	Water
D	Slow

9.18. Circum	
A	Square
B	Toward
C	Around
D	Through

9.19. Co, con	
A	Together
B	Against
C	Toward
D	Without

9.20. De	
A	Up and towards
B	Against, instead of
C	Two, double

D	Down or away from

9.21. Desis	
A	Binding, fixation of
B	Against, instead of
C	Through
D	Shape of

9.22. Dia	
A	Excision
B	Around
C	Within
D	Through

9.23. Dys	
A	Difficult, abnormal
B	Binding, fixation of
C	Against, instead of
D	Slow

9.24. Ecto	
A	Outside of
B	Below, under
C	Half
D	Toward

9.25 Ectomy	
A	Binding
B	Binding, fixation
C	Without

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D	Excision

9.26. Endo	
A	Outward
B	Toward
C	Within
D	Together

9.27. Epi	
A	Iron
B	Pain
C	Slow
D	Outer, on top of, over

9.28. Exo	
A	Excision
B	Away from
C	Within
D	Toward

9.29. Extra	
A	Outside, beyond
B	Abnormal
C	Binding, fixation
D	Down or away

9.30. Ferro	
A	Zinc
B	Water
C	Writings, records

D	Half

9.31. Fore	
A	Always
B	Never
C	After
D	Before

9.32. Form	
A	Paste
B	Cut into
C	Excision
D	Shape of

9.33. Graphy	
A	Writing, record
B	Shape of
C	Binding
D	Away from

9.34. Hemi	
A	Full
B	Empty
C	Half
D	Above

9.35. Hydra, hydro	
A	Wastes
B	Water
C	Writings, records

D	Half

TOPIC 10: ACIDS, BASES & PH

Introduction

Enzymes and chemical reactions in the body work best in particular environments. This is particularly true with respect to the acidity of the body fluids. Acidity is a measure of the concentration of free hydrogen ions (H+) in the solution.

It is vitally important for the body to try to maintain the hydrogen ion status to avoid detrimental, potentially life-threatening effects. You will discover how during your studies on GEM.

Acids

Acids are chemical substances that ionise in water to donate H^+ ions. Weak acids do not dissociate easily but strong acids ionise nearly completely in solution. For instance, hydrochloric acid (HCl) ionises nearly completely to release one H^+ and one Cl^- ion:

$HCl \leftrightarrow H^+ + Cl^-$

The ability of the acid to dissociate can be quantified. The measure of this ability is the dissociation constant (K_a) of the acid. Strong acids have larger K_a values than weak acids.

Bases (alkalis)

Bases are substances that accept free H^+ ions and remove them from the solution. Like acids, there are strong and weak bases. Bicarbonate ion (HCO_3^-) and dihydrogen phosphate ($H_2PO_4^-$) are examples of weak bases that do not readily accept protons. In medicine you may find that the terms ***alkalis*** and bases are used interchangeably.

An alkali mainly refers to the salt form of a base that produces one or more hydroxyl ions (OH^-) upon ionization when it dissolves in water. For instance, sodium hydroxide (NaOH, or caustic soda) is a strong alkali. It completely dissociates in solution and can be harmful.

Acidic and alkaline solutions

Acidic and alkaline solutions can be produced when certain oxides are dissolved in water. When non-metal oxides such as sulphur dioxide dissolve in water, they form an acidic solution:

Sulphur dioxide + Water ↔ Sulphurous acid

$SO_2 + H_2O \leftrightarrow H_2SO_3 \leftrightarrow H^+ + HSO_3^-$

This is the reason why acid rain can be formed when sulphur dioxide is discharged into the atmosphere.

In terms of human biology, the most important non-metal oxide that forms an acidic solution when dissolved in water is **carbon dioxide**:

Carbon dioxide + Water ↔ Carbonic acid

$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$

In the body, the formation of **carbonic acid** from carbon dioxide and water is catalysed by the enzyme carbonic anhydrase, which is present in red blood cells and some other cell types. Having high levels of carbon dioxide in the blood can therefore lead to acidification of the blood. This can happen if someone develops any form of respiratory failure where insufficient amounts of carbon dioxide are being exhaled.

When metal oxides such as sodium oxide dissolve in water, they form an alkaline solution:

Sodium Oxide + Water ↔ Sodium Hydroxide

$Na_2O + H_2O \leftrightarrow 2NaOH \leftrightarrow 2Na^+ + 2OH^-$

Therefore, some metal elements are termed the 'alkali metals', since their oxides readily dissolve in water to form alkaline solutions.

Logarithms and logarithmic scales

The number 100 (10 x 10) can be written 10^2. Thus, the logarithm to base 10 of 100 (10^2) is 2 and the antilogarithm of 2 is 100. The number 1,000 (10 x 10 x 10) can be written 10^3. Thus, the logarithm to base 10 of 1,000 (10^3) is 3 and the antilogarithm of 3 is 1,000.

The number 1 can be expressed as $\mathbf{n}^0$ (n to the power 0), where **n** is any positive or negative number. Thus 1 can be expressed as 10^0, 2^0, 5^0, 26^0, 177.6^0 or even -36.6^0. Thus, the logarithm to base 10 of 1 is 0.

Acidic solutions and alkaline solutions differ in their relative concentration of free H^+. The acids in acidic solutions will tend to liberate H^+ ions whereas the bases in alkaline solutions (such as OH^- ions) will tend to mop up H^+ ions.

When describing the acidity of a solution, **pH** ('power of hydrogen') is used more commonly to express the concentration of free H^+ ions in a solution rather that stating the actual molar concentration of H^+ ions. The pH scale runs from 0 to 14 and pH is the negative logarithm to base 10 of the concentration of free H^+ ions in mol/L (termed $[H^+]$).

$$pH = -\log_{10} [H^+]$$

or:

$$pH = \log_{10} (1 / [H^+])$$

or even:

$$[H^+] = 10^{-pH}$$

This means that for every H^+ ion concentration between 1 mol/L and 1 x 10^{-14} mol/L, a pH value can be calculated. For example, rather than stating that a solution has a free H^+ ion concentration of 0.00000001 mol/L (1 x 10^{-8} mol/L), it is much simpler to state that it has a pH of 8.0.

QUESTION 10.1: IF THE FREE H^+ ION CONCENTRATION OF THE SOLUTION ABOVE (PH 8.0) INCREASED 10-FOLD, WHAT WOULD ITS PH THEN BE?

ANSWER:

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The pH scale

The pH scale (Figure 8.1) is a series of numbers from 0 to 14 to help quantify the concentration of free H^+ ions in a solution. Pure water dissociates into 10^{-7} mol/L H^+ ions and an equivalent concentration of OH^- ions at 25°C. It is regarded as neutral and so pH 7.0 lies in the middle of the scale. Acidic solutions have a pH < 7.0 and a higher concentration of free H^+ ions than pure water. Alkaline solutions have a pH > 7.0 and have a lower concentration of free H^+ ions than pure water.

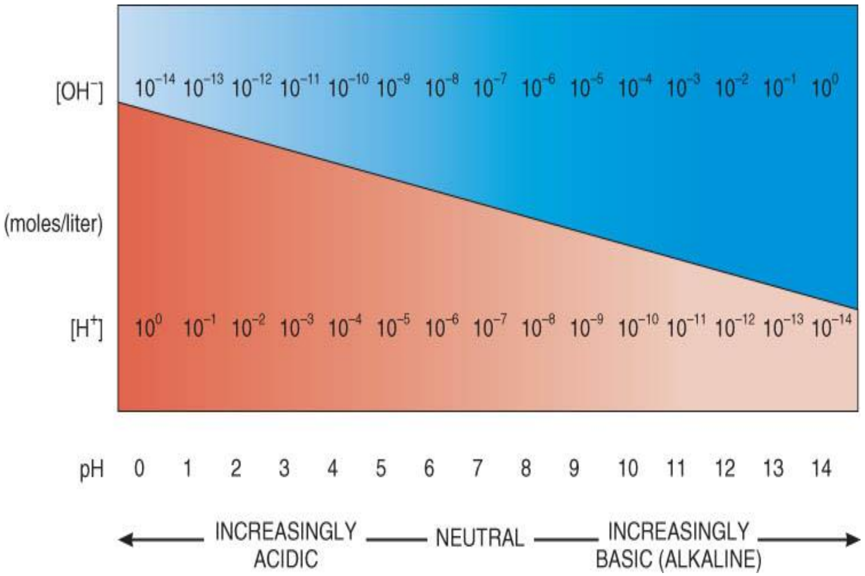

Figure 10-1 The pH scale

As the pH scale is a **logarithmic scale**, a 10-fold increase or 10-fold decrease in free H^+ ion concentration is required for a 1 unit change in pH. For instance, if the free H^+ ion concentration of a 1 nmol/L (1 x 10^{-9} mol/L) solution increased 10 fold to 10 nmol/L (1 ⍰ 10^{-8} mol/L), its pH would be 8.0 and would have moved towards the acidic range of the scale. On the other hand, if the same solution (pH 8.0) was diluted by adding water, this would make it less alkaline, and decrease the pH of the solution towards 7.0.

Struggling with pH… watch this simple video where pH as the power of hydrogen is explained. How increases in the hydronium ion (or hydrogen ion) concentration can lower the pH and create acids. Also, how the reverse is true. An analysis of a strong acid and strong base is also included

Different body fluids may have a different pH

Each body fluid usually has a very narrow range of acceptable levels of pH because most biological processes work best at a given pH (see Topic 7 for the importance of pH for enzyme function).

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QUESTION 10.2: THE TABLE BELOW SHOWS THE PH VALUES OR FREE H^+ ION CONCENTRATION OF SOME SAMPLES OF A MAN'S BODY FLUIDS. FILL IN THE BLANKS.

Fluid	Free H^+ concentration	**pH**
Vomit	7.94 mmol/L	
Urine		6.40
Saliva	281.8 nmol/L	
Blood		7.42
Semen	63.1 nmol/L	
Bile		7.60

The pH range that is compatible with life is 7.0 to 7.7 (a 5-fold difference in [H+]). Our bodies are continuously producing acids; for instance, the carbon dioxide we produce during respiration contributes to generation of carbonic acid:

$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$

Carbon dioxide + water ↔ carbonic acid ↔ hydrogen ion + bicarbonate ion

During exercise lactic acid is produced by our cells. It is obviously important that the [H+] is regulated to prevent deleterious effects on function. In fact if any pH change caused by a clinical condition is not corrected, this can have serious consequences and can lead to coma and even death.

Fortunately, our body uses various mechanisms including chemical buffers (such as bicarbonate ions (HCO_3^-)) and the respiratory and renal systems to try to protect against such changes in pH. However, despite the efforts of our homeostatic mechanisms, some clinical conditions can lead to changes in pH that could be detrimental to health.

CLINICAL RELEVANCE

In some clinical conditions, the pH of the blood changes so that it falls outside the normal range of 7.35-7.45. In uncontrolled diabetes mellitus, in which blood glucose levels are higher than normal, a lack of insulin (the hormone that helps transport glucose into cells) or a lack of response of the cells to insulin can mean that diabetic patients start to produce ketone bodies to meet the metabolic demands of their tissues. The ketone bodies are acids (acetoacetic acid and 3-hydroxybutyric acid) that, if produced in large amounts, can cause **acidosis** (ketoacidosis) and can lead to confusion and behavioural changes. When the pH of the blood falls below 7.35, the body tries to compensate for the acid-base imbalance by increasing breathing (hyperventilation) so that more carbon dioxide is exhaled (remember that carbonic acid can be produced from carbon dioxide and water so that removing carbon dioxide helps remove some acid and therefore some H^+ ions from the system). If the ketoacidosis continues, the kidneys can try to excrete more H^+ ions. However, if the cause of the acidosis is not corrected, this can eventually lead to coma and even death.

If blood pH rises above 7.45, the person is said to be in **alkalosis**, which can sometimes be more dangerous than being in acidosis.

You will learn about such conditions and the physiological compensation and correction for acid-base imbalance during the GEM course.

Determining the logarithm to base 10

You should familiarise yourself with the most used logarithm, $\log_{10}$.

You can easily use a calculator to determine logs (if you do not have log tables) The key for logs to base 10 is the **log** key. Although calculators differ (check how yours does this) the log of a number is generally performed by pressing the **log** key and then the number.

For instance, try getting the $\log_{10}$ of 1.5 on the calculator. Rounded up to the third decimal place, you should get 0.176 on the screen. What about $\log_{10}$ of 2.8? You should get 0.447.

What about working the other way about? In other words, finding out what the number is when you know its $\log_{10}$? This is finding the '**antilogarithm**'. Pressing the **inverse** key (or the **shift** key) and then the **log** key will show the antilog of the number. Trying this for the examples above (i.e. the antilog of 0.176 and 0.447) should display 1.5 and 2.8 on your calculator (actually you'll get 1.4997 and 2.799, but that's close enough).

One could multiply 1.5 and 2.8 by adding their logarithms and then displaying the antilog of that simple sum.

QUESTION 10.3: USING LOG_{10}, MULTIPLY 1.5 AND 2.8

ANSWER:

Self -test for topic 10

10.4 Which one of the following will produce an alkaline solution when dissolved in water?	
A	Carbon dioxide
B	Nitrogen Dioxide
C	Potassium Nitrate
D	Potassium Oxide
E	Sodium Chloride

10.5 If urine has a pH of 6.35, blood has a pH of 7.40 and bile has a pH of 7.60, which one of the following statements is **correct**?	
A	Blood is more acidic than urine
B	Blood is more acidic than water
C	Bile is more acidic than blood
D	Urine is more acidic than blood
E	Urine is more alkaline than bile

10.6 Look at the following table and match the pH to the concentration of free H^+ ions given below. Each concentration can only be used once.

pH	$[H^+]$
7.4	
3.5	
6.5	
7.1	
7.2	

A. 40 nmol/L
B. 63 nmol/L
C. 79 nmol/L
D. 316 nmol/L
E. 316µmol/L

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ANSWERS TO QUESTIONS INCLUDED IN THE WORKBOOK
ARE GIVEN ON THE NEXT PAGES…

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Topic 2

2.1 e

2.2 d

2.3 c

2.4 e

2.5 a

Topic 3

3.1

Element	Atomic number	Number of neutrons	Atomic mass
Nitrogen	7	7	14
Oxygen	8	8	16
Phosphorus	15	16	31
Sodium	11	12	23
Chorine	17	18	35

3.2 Carbon has 4 electrons in the outer energy shell. This could contain 8 electrons. Hence 4 other carbon atoms could share electrons with one carbon atom.

3.3 Both sodium and chlorine have 3 levels. The first level contains 2 electrons, the second 8 and the third level can hold up to 18 electrons. When sodium loses an electron to become a sodium ion it then only has 2 energy levels and a positive charge.

3.4 Iodine is found as iodide (an anion), magnesium, potassium and calcium are cations.

3.5 d

3.6 a

3.7 b

3.8 d

Topic 4

4.1 A molecule of water (H_2O) is released during this type of reaction, which is called dehydration synthesis.

4.2 Palmitic acid is a saturated fatty acid; there are no carbon-carbon double bonds in the molecule.

4.3 c

4.4 b

4.5 c

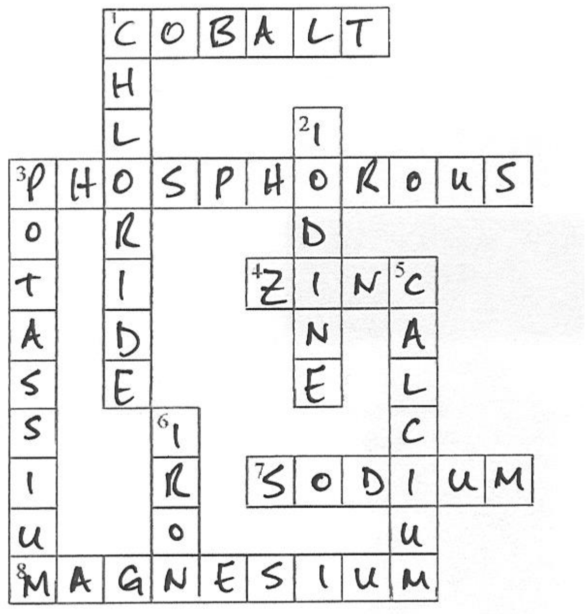
Topic 5

5.1 Compounds that have an affinity for water are known as **hydrophilic** and those which dislike water are known as **hydrophobic**. Fats and oils are hydrophobic and do not dissolve in water.

5.2 Iron is found in red meat, liver, beans and spinach. Iron is better absorbed from meat sources. Some foodstuffs can inhibit absorption, for example, high bran foods.

5.3 Iron is lost when blood is lost, so any situation where chronic blood loss occurs will deplete body iron stores. Examples are haemorrhage from peptic ulcers, haemorrhoids and intestinal parasites. Women can have low iron levels because of blood loss during menstruation or during pregnancy when the iron is transferred to the fetus.

Crossword answer:



Topic 6

6.1 There are six different combinations of three bases on mRNA (codons) that encode for the amino acid arginine: CGU, CGC, CGA, CGG, AGA and AGG.

6.2 a

6.3 c

6.4 d

6.5 b

Topic 7

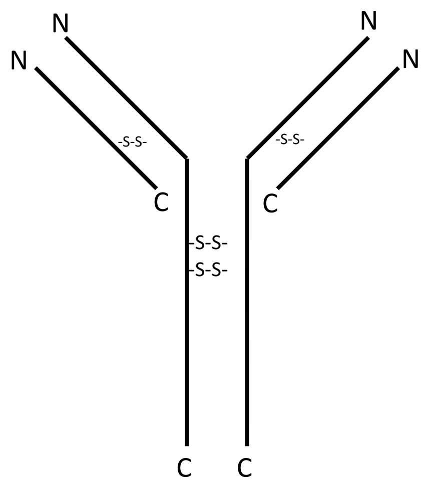
7.1

Amino acid	Three-letter abbreviation	Single-letter abbreviation
Alanine	Ala	A
Cysteine	Cys	C
Aspartic acid	Asp	D
Glutamic acid	Glu	E
Phenylalanine	Phe	F
Glycine	Gly	G
Histidine	His	H
Isoleucine	Ile	I
Lysine	Lys	K
Leucine	Leu	L
Methionine	Met	M
Asparagine	Asn	N
Proline	Pro	P
Glutamine	Gln	Q
Arginine	Arg	R
Serine	Ser	S
Threonine	Thr	T
Valine	Val	V
Tryptophan	Trp	W
Tyrosine	Tyr	Y

7.2 Hopefully you have a diagram that shows an α-carbon and the attached amino group, carboxyl group, hydrogen atom and side-chain.

7.3 If the carbon atom of an organic molecule is its chiral centre, this means that there are four different chemical groups covalently attached to the carbon. The groups can be arranged in two ways: to make a **laevo- (l)** form or a **dextro- (d)** form of the molecule, which will be mirror images of each other. These two forms are **stereoisomers**. In the case of the amino acids in our proteins, all of them are L-amino acids

7.4 IgG is composed of four polypeptide chains (two heavy chains of around 440 amino acids and two light chains of around 220 amino acids), joined together by **disulphide bridges**. The antigen is bound between the amino termini of the heavy and light chains:



7.5

Enzyme class	Action
Amylases	Digest polysaccharides such as starch
Carboxylases	Remove carboxyl groups from molecules
DNA polymerases	Make DNA from deoxyribonucleotides
Esterases	Convert esters to the constituent acid and alcohol
Kinases	Add phosphate groups to molecules
Lipases	Digest triglycerides
Phosphorylases	Remove phosphate groups from molecules
Proteases	Digest proteins
RNA polymerases	Make RNA from ribonucleotides

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Topic 8

8.1 The correct SI-derived unit for concentration is moles per cubic metre (mol/m^3). Were you expecting moles per litre? This is usually used instead of mol/m^3, especially when talking about aqueous solutions. The litre is a non-SI unit, but is internationally recognised nonetheless.

8.2 10 µm = 1×10^{-5} m. Scientific notation takes the form $y \times 10^z$, where y is a number between 1.0 and 9.99 (recurring) and z is any integer (a positive or negative whole number). So it would incorrect to say that the scientific notation for 10 µm is 10×10^{-6} m.

8.3 Model sizes: monocyte 2 m; red blood cell 70 cm; M. tuberculosis 30 cm; E. coli 20 cm; adenovirus 9 mm; HIV 8 mm. Notice how small a virus would appear, even if magnified 100,000 ×.

8.4 602,214,150,000,000,000,000,000 is expressed as 6×10^{23} in scientific notation. This number is also known as **Avogadro's number** or the Loschmidt number.

8.5

1. d. Hct is expressed as a relative figure or as a percentage (e.g. 0.45 or 45%, meaning that 450 mL of the blood sample is cells).

2. a. MCV is expressed in femtolitres (fL).

3. b. MCH is expressed in picograms (pg) per cell or in femtomoles (fmol) per cell.

4. c. MCHC is expressed in grams per decilitre (g/dL). It can also be expressed in millimoles per litre (mmol/L or mM).

8.6 c

8.7 a

8.8 b

8.9 d

Topic 9 (prefix/suffix)

Topic 10

10.1

If the free [H+] increased by 10-fold to 100 nmol/L (1×10^{-7} mol/L), the pH of the solution would then be $-\log_{10}10^{-7}$, or 7.0

10.2

Fluid	Free H^+ concentration	**pH**
Vomit	7.94 mmol/L	2.1
Urine	398.1 nmol/L	6.40
Saliva	281.8 nmol/L	6.55
Blood	38.0 nmol/L	7.42
Semen	63.1 nmol/L	7.20

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Bile	25.1 nmol/L	7.60

10.3

1.5 x 2.8 = n

n = 1.5 x 2.8

$\log_{10} n = \log_{10} 1.5 + \log_{10} 2.8 = 0.62324929$

n = antilog 0.62324929 = $10^{0.62324929}$ = **4.2**

10.4 d

10.5 d

10.6

pH	$[H^+]$
7.4	40 nmol/L
3.5	316 μmol/L
6.5	316 nmol/L
7.1	79 nmol/L
7.2	63 nmol/L

Key Words

Throughout this workbook we have highlighted key words that we will expect you to know the meaning of when you start on the course. Take the opportunity now to read this list and ensure that you understand what these terms mean. You should be able to find definitions for most of these in this workbook or in any scientific / medical dictionary. See you in September!

acid

acidosis

adenine

adenosine triphosphate (ATP)

alkali

alkalosis

amino

amino acid

aminoacyl tRNA

anion

anticodon

atomic mass

atomic number

atom

ATPase

Avogadro's number

base

carbohydrate

carbon dioxide

carbonic acid

carboxyl

catalyst

cation

centi (c)

chiral centre

cilia

codon

concentration

covalent bond

covalent modification

cytoplasm

cytosine

deci (d)

deoxyribonucleic acid (DNA)

deoxyribose

dephosphorylation

dextro- (D)

dipeptide

disaccharide

disulphide bridge

double helix

electrolyte

electron acceptor

electron donor

electron

element

endoplasmic reticulum

energy level

enzyme

extracellular fluid

fatty acid

femto (f)

gene

genetic code

genome

giga (G)

glucose

glycerol

glycogen

Golgi apparatus

guanine

hexose

hydrogen bond

hydrophilic

hydrophobic

inorganic

intracellular fluid

ionic bond

isotope

kilo (k)

kilogram (kg)

kinase

laevo- (L)

lipase

lipid

lock-and-key hypothesis

logarithmic scale

mega (M)

messenger RNA (mRNA)

metre (m)

micro (μ)

milli (m)

mineral

mitochondrial DNA

mitochondrion

molarity

mole (mol)

monosaccharide

mutation

nano (n)

neutron

nonpolar covalent bond

nuclear membrane

nucleic acid

nucleotide

nucleus (atomic)

nucleus (cellular)

organelle

organic

pentose

peptide bond

pH

phosphatase

phosphate

phospholipid

phosphorylation

pico (p)

plasmalemma

polar covalent bond

polynucleotide

polypeptide

polysaccharide

primary structure

product

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prostaglandins

protease

protein synthesis

protein

proton

pyrimidine

quaternary structure

ribonucleic acid (RNA)

ribose

ribosomal RNA (rRNA)

ribosome

saturated fatty acid

scientific notation

second (s)

secondary structure

SI units

SI-derived units

solute

solution

solvent

stereoisomer

stop codon

substrate

sucrose

tertiary structure

thymine

transcription

transfer RNA (tRNA)

translation

triglyceride

tripeptide

unsaturated fatty acid

uracil

vesicle

- END OF BASIC SCIENCE WORKBOOK FOR NEW GEM STUDENTS –