Martin Caon

Lecture Notes, Worksheets, and Exercises for Basic Anatomy and Physiology

Springer

Lecture Notes, Worksheets, and Exercises for Basic Anatomy and Physiology

Martin Caon

Lecture Notes, Worksheets, and Exercises for Basic Anatomy and Physiology

Springer

Martin Caon
[Retired from Flinders University of South Australia]
Clarence Park, SA, Australia

ISBN 978-3-031-56295-2 ISBN 978-3-031-56296-9 (eBook)
https://doi.org/10.1007/978-3-031-56296-9

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Paper in this product is recyclable.

By the Same Author

Caon, M. (2020) *Examination Questions and Answers in Basic Anatomy and Physiology: 3rd ed. 2900 multiple choice questions and 64 essay topics*, Springer, 742p. ISBN: 978-3-030-47313-6, ISBN 978-3-030-47314-3 (eBook) https://doi.org/10.1007/978-3-030-47314-3

Caon, M. and Hickman, R. (2003) *Human Science: Matter and Energy in the Human Body 3rd ed*. Crawford Publishing House, Adelaide 472 p. ISBN 0 8633 3255 3

Abstract

A first-year university level course of introductory Human Anatomy and Physiology is presented as student's notes for 26 lectures that follow an organ-systems based approach. Some required basic chemistry and physics is also included. Many lectures have "additional material" which is provided for the student's interest but is excluded from the study course. Accompanying each lecture set are short-answer type revision questions that cover the important points of the lecture presentations. The answers may be constructed from the preceding lecture material. To ensure that the important points are not missed, extensive suggested answers to each of these 212 questions are provided and appear after the lecture material. Most of these questions have been used in end-of-course examinations. Also used in these examinations were the multiple-choice questions presented in a previous publication: Caon, M. (2020) *Examination Questions and Answers in Basic Anatomy and Physiology: 3rd ed., 2900 multiple choice questions and 64 essay topics*, Springer.

Contents

Lecture 1: Cells and Tissues 1

Lecture 2: Review of Chemistry 11

Lecture 3: The Integument 25

Lecture 4: Thermoregulation and Homeostasis 31

Lectures 5 and 6: Musculo-Skeletal System 37

Lectures 7 and 8: Digestive System 51

Lectures 9 and 10: Endocrine System & Hormones 65

Lectures 11 and 12: Urinary (Renal) System 77

Lectures 13–16: Nervous System 89

Lecture 17: Special Senses 109

Lecture 18: Blood 115

Lecture 19: Cardiovascular System: Anatomy of the Heart 127

Lecture 20: Anatomy, Structure and Function of Blood Vessels 135

Lecture 21: Pressure and Fluid Dynamics 141

Lecture 22: Control of Blood Pressure 149

Lectures 23 and 24: Anatomy and Physiology of Respiration 159

Lectures 25 and 26: Reproductive System 171

Suggested Answers to the Lecture Revision Homework Exercises 181

Lecture 1: Cells and Tissues

1 Cell Theory

The cell is the basic structural and functional unit of the body.

Procaryotes – bacteria (no nucleus or organelles except ribosomes)

Eucaryotes – plant and animal cells

2 Components of (Animal) Cells

1. **Plasma membrane**
2. **Cytoplasm** is the content of the cell, excluding the nucleus. **Cytosol** is the viscous gel-like fluid in which the organelles and inclusions are suspended and in which proteins, enzymes, ions and many other small molecules are dissolved. Many metabolic reactions occur in the cytosol.
3. **Organelles** – specialised structures of a characteristic shape that carry out specific roles in the cell.

   - **Mitochondria**: inner membrane folded into **cristae** (large surface area); they produce ATP (adenosine triphosphate); Krebs cycle occurs inside. They are able to replicate themselves.
   - **Lysosomes**: membrane-enclosed vesicles (formed in the Golgi) containing an acidic environment with enzymes capable of digesting (lysing) a wide variety of molecules.
   - **Centrosome**: contains two **centrioles** that function in a cell division.
   - **Ribosomes**: contain large amounts of RNA (ribonucleic acid); they synthesise proteins from amino acids.

M. Caon, *Lecture Notes, Worksheets, and Exercises for Basic Anatomy and Physiology*, https://doi.org/10.1007/978-3-031-56296-9_1

- **Nucleus**: largest organelle; a nuclear membrane with pores, which contains (one or more) **nucleolus** and **chromatin** (deoxyribonucleic acid (DNA) and associated proteins).
- (Multi-nucleate cells: muscle fibres, osteoclasts
- Cells without a nucleus: erythrocytes)
  - **Endoplasmic reticulum**: a system of membrane-enclosed channels continuous with the nuclear membrane (providing a large surface area); the **rough ER** is studded with ribosomes and stores newly synthesised molecules (by ribosomes); the **smooth ER** is the site of fatty acids, phospholipids and steroid synthesis;
  - **Golgi complex** (apparatus): four to six flattened sacs (cisterns) stacked on top of each other; it processes and delivers (via Golgi vesicles) lipids and proteins to the plasma membrane for secretion.
  - **Flagella and Cilia**: motile structures – sperm has a flagellum; the respiratory tract, the brain ventricles, some ducts in the testes and the fallopian tubes have ciliate cells.
  - **Cytoskeleton**: responsible for the movement of cells (e.g. phagocytes) and the movement of organelles and molecules within the cell and support and shape of the cell. **Microfilaments** – e.g. in muscle cells; **microtubules** – e.g. in the cilia.

3 Cell Membrane (Plasma Membrane)

It is a thin (6–10 nm) barrier separating the internal components of the cell from the exterior environment. It regulates the passage of substances into and out of the cell.

<u>Fluid mosaic model of membrane structure</u>: the membrane is a bilayer of lipids and has a mosaic of proteins “floating” (like icebergs) in a “sea” of lipids.

Lipids are **phospholipids** (75%), which form a *bilayer*, and **cholesterol** (20%). Proteins are **integral** (one end in the cell and the other end out of the cell) or **peripheral**.

<u>Membrane proteins act as:</u>

- Enzymes (catalyse reactions)
- Receptors (for signalling chemicals, e.g. hormones)
- Transporters (selectively allow entry to some solutes via channels (ATP-ases))
- Joiners (allow cells to adhere to each other)
- Recognisers (glycoproteins = identification tags)
- Attachment (to the cell’s internal cytoskeleton and to extracellular structures)

4 Diffusion

All molecules and ions are in constant motion. In fluids, these particles move quite separately; the higher the temperature is, the faster is the motion. As particles approach each other, electrostatic forces cause them to repel. That is, particles are continually "bouncing off" each other as they move. Particles suffer millions of collisions per second. This continual *random* movement of particles amongst each other is called diffusion. It is the way particles move about inside and around cells (in the absence of specific transport mechanisms).

5 Transport of Ions and Molecules Through the Plasma Membrane

1. Diffusion of ions and molecules occurs along a concentration gradient (from Hi concentration to Lo concentration):
   (a) Lipid-soluble molecules (O_2, CO_2, NH_3, urea, alcohol, N_2, steroids, some vitamins) pass through the lipid bilayer.
   (b) Water-soluble molecules pass through pores formed by integral proteins (e.g. K^+, Ca^{2+}, Cl^-, HCO_3^-).
   (c) H_2O molecules pass rapidly through channels called aquaporins.
   Facilitated diffusion (of e.g. glucose) along a concentration gradient is assisted by specific protein carrier molecules in the membrane.
2. Osmosis: the net movement (diffusion) of **water** through pores (aquaporins) in a **selectively permeable membrane** along its concentration gradient.
3. Active transport: **requires energy** (from ATP) to move ions, amino acids and monosaccharides **against** their concentration gradient or charge gradient, e.g. the "Na^+-K^+ pump".
   (Secondary active transport: some substances, e.g. monosaccharides and amino acids, pass through the membrane using energy expended producing the Na^+/K^+ gradient.)
4. Bulk transport: a plasma membrane engulfs the substance, and the membrane-enclosed vesicle moves through the membrane. **Endocytosis** brings large substances (e.g. red blood cells (RBC), bacteria, proteins, polysaccharides) into the cell, and **exocytosis** takes large substances out of the cell *(e.g. at synapses, neurotransmitters are released from their vesicles by exocytosis).*

6 Tissues

Tissue: a group of similar cells (usually of common embryonic origin) that function together to carry out specialised activities
Biopsy: the removal of the sample of living tissue for staining and examination under the microscope
Histology: the microscopic study of tissues

Four Primary Types of Body Tissue

1. **Epithelial tissue**: (3% of the body) covers body surfaces; lines hollow organs, body cavities and ducts; and forms glands.
   - Cells closely packed (little extracellular material) and tightly bound together
   - One end of the cell is attached to the basement membrane (basal lamina) and the other end is the internal surface of the cavity or duct to a space
   - No blood supply (diffusion or absorption)
   - High rate of cell division
2. **Connective tissue (CT)**: (45% of the body) widely distributed tissue; basement membranes, bone, fat, blood, tendons, cartilage. It protects and supports the body and organs, binds organs together, stores energy as fat and provides immunity.
   - It consists of cells surrounded by an intercellular **matrix** (= ground substance and fibres).
   - The matrix may be fluid, semi-fluid, gelatinous, fibrous or calcified.
   - It has few cells and much matrix (extracellular material).
   - It is highly vascular (except cartilage)

   1. **Muscle tissue**: it consists of 50% of the body.
   2. **Neural tissue**: it forms 2% of the body.
3. **Epithelial Tissue (Epithelium)**
   (Layers of cells or glands)
   - **Simple squamous**: it consists of a <u>single layer</u> of flat (*squa*shed) cells, so diffusion through the layer takes place easily. It lines the heart, lymph and blood vessels (known as **endo**thelium). It is called **meso**thelium when in serous membranes.
   - **Simple cuboidal**: it forms a <u>single layer</u> of *cube*-shaped cells. The cells secrete or absorb, e.g. kidney tubules or the retina.
   - **Simple columnar**: it is a <u>single layer</u> of rectangular cells (*column* like). The cells secrete or absorb, e.g. line the GI tract, where some are goblet cells and some have microvilli.

- **Stratified transitional**: this consists of variable-shaped cells that are several layers thick and are able to stretch. The cells line the urinary bladder.
- **Stratified squamous**: it consists of several layers of cells for protection in areas of high wear. It is cuboidal to columnar in deep layers and squamous in superficial layers. Keratinised cells form the outer layer of the skin. Non-keratinised cells line the mouth, oesophagus, tongue, vagina and anus.
- **Pseudostratified columnar**: this forms a single "layer". All cells are attached to the basement membrane, but some do not reach the surface of the layer. The cells line the male urethra and upper respiratory tract. Some are ciliated, and some are goblet cells.
- **Glandular epithelium**: Exocrine glands secrete oil, wax, milk, sweat, tears, saliva and digestive enzymes into ducts. Endocrine glands secrete hormones, which diffuse into extracellular fluid and into the blood.

7 Connective Tissue

(*-blast* = an immature cell; it secretes the matrix *-cyte* = a mature cell.)

Nine (or So) Cell Types

- **Fibroblasts** (form fibres): they are always present in CT. They secrete hyaluronan and protein (= proteoglycans) and also secrete collagen, elastin and glycoprotein, which make up collagen fibres, elastic fibres and reticular fibres (respectively) in the matrix. Some become fibrocytes.
- **Chondroblasts**: in the cartilage, they secrete matrix and become chondrocytes.
- **Osteoblasts**: in the bone, they produce the organic matrix of bone and become osteocytes.
- **Haemocytoblasts**: in the bone marrow, they become red blood cells and white blood cells (WBC).
- **Adipocytes**: fat storage cells.
- **Leucocytes** (white blood cells): these function for defence. They include neutrophils and eosinophils (= microphages), basophils, monocytes and lymphocytes.
- **Macrophages** (develop from monocytes – a WBC): these are large cells that can engulf bacteria and cellular debris (perform phagocytosis).
- **Mast cells**: they produce histamine and heparin, which stimulate inflammation.
- **Plasmocytes** (develop from B lymphocytes – a WBC): they secrete antibodies and hence provide immunity.

Intercellular matrix composition – it has two components: **protein fibres** (collagen, elastin and reticulin) embedded in liquid and gel or solid **ground substance** (which contains a diversity of large molecules). The ground substance is amorphous and surrounds cells. It binds, lubricates, supports and provides a medium through which substances can diffuse.

8 Classification: Four Types of Connective Tissue

(In terms of the nature of the ground substance and the types and organisation of fibres)

1. Loose CT: packing material in space between organs
   - (a) **Areolar**: widely distributed; contains many cells; mostly collagenous fibres; contains hyaluronic acid; around vessels, nerves and muscles; forms the synovial membrane, subserous fascia and superficial fascia (= hypodermis) layer under the skin
   - (b) **Adipose**: fat cells (adipocytes) in loose CT; stores fat (triglyceride) and, hence energy; supports and protects organs
   - (c) **Reticular**: with mainly reticular fibres; in the spleen, liver and lymph nodes
2. Dense CT: fibres occupy most of the volume.
   - (a) **Dense regular**: shiny white appearance, tough and mainly collagen fibres arranged in a regular pattern; form tendons, ligaments, deep fascia and aponeuroses
   - (b) **Dense irregular**: irregularly arranged collagen fibres; found in the dermis, heart valves, around cartilage (perichondrium), periosteum, fibrous capsules around kidney, liver, spleen, dura mater
   - (c) **Elastic**: strong and stretchy; elastic fibres allow the tissue to stretch and snap back. Occur in lung, artery walls, vocal cords, vertebral ligaments, suspensory ligament of penis.
3. Supportive CT
   - (a) **Cartilage**: very tough; it has no blood vessels or nerves. Cells are chondrocytes, which occur in spaces called lacunae. Perichondrium surrounds cartilage. e.g. Collagen and elastin fibres. It contains chondroitin sulphate in the ground substance.
     - *Hyaline cartilage* (gristle): the most common; bluish white; the ends of long bones, the nose, the trachea, and bronchi; flexible
     - *Fibrocartilage*: rigid; vertebral discs; menisci in the knee
     - *Elastic cartilage*: is elastic; found in ear lobe, epiglottis, eustachian tube.
   - (b) **Bone**: it is rigid but not brittle. Osteocytes are in the lacunae and connected by canaliculi. Bone consists of: Inorganic calcium hydroxyapatite, collagen fibres and water matrix.
4. Liquid CT – has no fibres
   - (a) **Blood**: erythrocytes (RBC), leucocytes (WBC) and platelets in a liquid matrix called plasma
   - (b) **Lymph** = lymphocytes + interstitial fluid

9 Serous Membranes and Mucous Membranes

Serous membranes (serosa) consist of thin layers of areolar CT and are covered by mesothelium. They line internal body "cavities" and organs within the cavity. They secrete serous fluid, a lubricating fluid. Has parietal and visceral portions. e.g. **Pleura**, **peritoneum**, **pericardium**.

Mucous membranes (mucosa) consist of epithelium on top of CT (**lamina propria**) and are often surrounded by smooth muscle (**muscularis mucosae**). They line body cavities that open to the exterior (mouth, oesophagus, stomach, intestine). They secrete mucous to lubricate and prevent drying.

<u>Location of Systems Within Cavities</u>

The **dorsal cavity** contains the brain and spinal cord.
The **thoracic cavity** contains the heart and great blood vessels in the mediastinum, the lungs and some air passages.
The abdominal cavity contains the renal system and most of the digestive system.
The pelvic cavity contains the bladder, female reproductive organs and part of the large intestine.
Viscera = body organs of the abdomino-pelvic cavity
Abdomino-pelvic cavity = ventral cavity

<u>Structures Outside Body Cavities</u>

Skeletal system, integumentary system, skeletal muscle, kidneys (and adrenals), pancreas, duodenum, testes, sense organs, peripheral nerves and blood vessels

10 Additional Information

Mitochondria

In addition to energy production, mitochondria play a role in several other cellular activities. For example, mitochondria help regulate the self-destruction of cells (apoptosis). They are also necessary for the production of substances such as cholesterol and heme (a component of haemoglobin, the molecule that carries oxygen in the blood).

Mitochondrial DNA contains 37 genes, all of which are essential for normal mitochondrial function. Thirteen of these genes provide instructions for making enzymes involved in oxidative phosphorylation. The remaining genes provide instructions for making molecules called transfer RNAs (tRNAs) and ribosomal RNAs (rRNAs), which are chemical cousins of DNA. These types of RNA help assemble protein building blocks (amino acids) into functioning proteins.

The Human Body Described

The human organism is a complex arrangement of many different cells arranged into four types of tissues. These are epithelial, muscular, nervous and connective. Two or more tissue types that perform specific functions form a structure called an organ. A group of organs that act together to perform a particular body function is an organ system, of which there are 11. Together, all these organ systems maintain a living organism, such as a human being.

Organisational units (from smallest to largest): chemicals/molecules, organelles, cells, tissues, organs, organ systems, and human organisms.

Body Cavities

The body is made up of a number of "cavities" that are filled with organs and enclosed by a membrane. The body has two main cavities: the ventral cavity (which includes thoracic, abdominal and pelvic cavities) and the dorsal cavity (comprising the cerebral and spinal cavities).

Cavity Membranes

Organs within a cavity are surrounded by a serous membrane. The outer membrane is called the parietal membrane, and the layer in contact with the organs is known as the visceral membrane. The cerebrospinal membranes are called meninges.

Anatomical Directional Terms

It is necessary to be able to describe the location of any body structure in relation to another, in a language that everyone can understand (especially other health professionals). For this reason, a number of scientific DIRECTIONAL TERMS are used that refer to any area of the body.

For a body standing in the "**anatomical position**", the following pairs of opposing directional terms are used: anterior/posterior, superior/inferior, medial/lateral, proximal/distal and superficial/deep.

Abdominal Regions

The nine abdominal regions are named: left hypochondriac, epigastric, right hypochondriac, left lumbar, umbilical, right lumbar, left inguinal, hypogastric and right inguinal.

Body Planes

The body may be (theoretically) "sliced" in order to look at cross-sectional views and be able to recognise internal structures. Such views, produced by imaging machines, are used for diagnostic purposes. The terminology used to describe these body planes are frontal (or coronal), sagittal and transverse planes.

Regional Anatomical Terminology

It is useful to learn names of anatomical body regions as they form the stem words of many medical terms: cephalic, cranial, frontal, buccal, mental, facial, orbital, oral, acromial, axillary, brachial, carpal, palmar, mammary, umbilical, inguinal, pubic, phalangeal, lumbar, sacral, coxal, gluteal, femoral, popliteal, patellar, sural, crural, calcaneal, tarsal, pedal and plantar.

11 Cells and Tissues Homework Exercise 1

1. Name four of the organelles in a cell and describe their function.
2. Describe the structure of the plasma membrane (cell membrane).
3. Define the processes of "diffusion" and "osmosis".
4. What roles do proteins play in a cell's plasma membrane?
5. What is active transport?
6. Name and briefly describe the four types of tissue.
7. What are the functions of the epithelial tissue?
8. What is the difference between "loose" connective tissue and "dense" connective tissue?
9. From which of the four types of tissue are the following seven structures made:

   bone, lymph, tendon, cartilage, adipose tissue, glands and epidermis?

10. What structure separates the thoracic and abdominal cavities, and what is it made of?
11. What is the collective name for the contents of the ventral cavity?
12. What are the main functions of these membranes and the potential space they form?
13. What is the clinical condition that develops when air is able to enter the potential space of the pleural membrane?
14. What is the clinical condition called when the membrane of the abdominal cavity is inflamed?
15. How does an organ differ from a tissue?
16. Using the gastrointestinal tract as an example, list the cavity/cavities in which organs of this system are found.
17. Do all organs of the body lie within a body cavity? If not, give examples.
18. Using directional terms, describe the appearance of the body when it is standing in the "anatomical position".
19. Describe the position of each of the following using anatomical, directional terms: ear (compared to the nose and chin), elbow (compared to the wrist and shoulder) and vertebrae (compared to the sternum and kidneys).

Lecture 2: Review of Chemistry

(Text ref: Caon & Hickman 3rd ed pp 9–10, 53–54, 80–81 (sec 3.), 158–164, 170–180 and 224–2s26.)

1 Some Terms Defined

Most matter is usually "impure", being a mixture of variable amounts of several different substances.

Iron ore (is a mixture), iron (Fe) (an element), iron oxide (a compound of 2 elements), steel (an alloy), haemoglobin (a molecule with four atoms of Fe)

Element: refers to 90 naturally occurring simplest substances (listed in the "periodic table" – have *chemical symbols*)
http://www.chemicalelements.com/index.html
(or http://www.periodicvideos.com/)
Atom: the smallest particle of an element (contains protons, neutrons and electrons)
Proton: +vely charged subatomic particle in the nucleus of an atom (atoms of different elements have different numbers of protons)
Neutron: subatomic particle in the nucleus of an atom
Electron: −vely charged subatomic particle outside of the nucleus; tiny yet occupies the bulk of space in an atom
Chemical bond: occurs when the outer electron(s) of an atom participate with those of another atom in joining two or more atoms together to form a new substance (a "compound")
Metal elements (left-hand side (LHS) of the periodic table): always lose (donate) electrons in chemical reactions
Non-metal elements (right-hand side (RHS) of the periodic table): always gain electrons in chemical reactions
Compound: a substance formed when atoms from two or more elements are chemically combined in fixed proportions (have a formula, e.g. H_2O, $C_6H_{12}O_6$)
Molecular compounds: atoms forming the molecule are from non-metal elements, covalently bonded

M. Caon, *Lecture Notes, Worksheets, and Exercises for Basic Anatomy and Physiology*, https://doi.org/10.1007/978-3-031-56296-9_2

Covalent bond: the bond between two *non-metal* atoms in a molecule (the atoms share electrons, so BOTH *gain* electrons)

Molecule: the smallest particle of a molecular compound; consists of two or more atoms joined by covalent bonds

Ionic (non-molecular) compounds: formed when metal atoms (ionically) bond to six to eight surrounding non-metal atoms (and vice versa) – continuous crystal lattice structure.

Ionic bond: the attraction between a metal atom and **all** the surrounding non-metal atoms in the lattice (the non-metal atoms gain electron(s), while the metal atoms lose electron(s)

Ion: an atom that has gained (if a non-metal) or lost (if a metal) one (or more) electron(s) (when an ionic substance dissolves in water, ions separate and move about freely as **electrolytes**).

Molecules can be ions too!

Organic molecules: contain long chains of carbon atoms bonded to each other.

2 Suspensions and Solutions

These are mixtures in which one or more substances are dispersed throughout another.

Mechanical suspensions: the dispersed substance consists of relatively large particles that settle to the bottom quite quickly (e.g. medicines labelled "shake well before use", like Mylanta and injectable insulin).

Colloidal suspensions: particles are not large enough to settle quickly but are too large to pass through semi-permeable membranes (e.g. kaolin, proteins in the blood – produce **colloid osmotic pressure**)

Solutions: particles are so small that they never settle out and can often pass through S-PM

Solutions consist of:

(a) **Solvent** – usually liquid (water); the major component of the mixture
(b) **Solute(s)**: the minor component of the mixture; may be electrolytes, large ions or molecules of solid, liquid or gas (O_2, CO_2)

(**electrolyte** – a solid substance that will conduct electricity when dissolved in water. An electrolyte dissociates into ions, e.g. Na^+, Cl^-, K^+, Ca^{++}, NO_3^-, HCO_3^-, NH_4^+ PO_4^{--}, H_3O^+)

3 Solution Concentration

The concentration of a solution is a statement about the relative amounts of the solvent and solute present in the solution.

Per cent concentration: a common way of expressing solution concentration (e.g. on intravenous (IV) bags):

$$\%\text{Conc} = \frac{\text{Mass }(\text{g})}{\text{Volume }(\text{ml})} \times 100$$

Percentage concentration tells the number of grams of solute present in each 100 ml of solution.

For example, normal saline is 0.9% Na^+Cl^-, which is 0.9 g of sodium chloride per 100 ml of solution.

4 Density & Specific Gravity

$$\text{Density} = \frac{\text{Mass }(\text{g})}{\text{Volume }(\text{ml})}$$

Density has units of grams per millilitre.

As a solution becomes more concentrated, its density increases (because adding solute increases the mass much more than it increases the volume).

Specific gravity – density written *without* the units

(If urine SG = 1.009 ⇒ density = 1.009 g/ml.)

Urine specific gravity is a measure of urine's (an aqueous solution) concentration and may be measured with a clinical refractometer.

5 Working with Moles

The SI unit for the "amount of substance" (number of particles) is **mole** (symbol mol, 1/1000 of a mole = millimole = mmol)

To measure out the mass of a mole, you must:

(a) Know or find out the chemical formula of the substance; for example, glucose has the formula

$$C_6H_{12}O_6$$

(b) Know or find out (*from the periodic table*) the relative atomic mass (RAM) (= atomic weight) value for each type of atom present in the formula

$$\left(\text{Glucose}\,C_6H_{12}O_6\right)\text{RAMs are}\,C = 12, H = 1, O = 16.$$

(c) Multiply the RAM values by the number of atoms of each element appearing in the formula

$$12\times 6 \text{ atoms} = 72$$
$$1\times 12 \text{ atoms} = 12$$
$$16\times 6 \text{ atoms} = 96$$
$$\text{Total} = 180 = \text{relative formula mass}$$

A mole of any substance is a sample of the substance having a mass, in grams, equal to its relative formula mass.

Hence, a mole of glucose is an amount having a mass of 180 g.

For example, 1 mole of ammonia (NH_3) is:

(1 ×   ) + (3 ×   ) =   g.

1 mole of water (H_2O) is:

(2 ×   ) + (1 ×   ) =   g.

(RAM values: N = 14, O = 16, H = 1.)

A **mole** of any substance will always contain a fixed number of particles, and this is what makes the mole the most suitable unit for the measurement of the *amount* of any chemical.

1 mole is 6×10^{23} particles.

Molarity is solution concentration expressed in moles/L.

6 Osmosis

Osmosis is the diffusion of water molecules (H_2O) across a cell membrane from the side where the solution concentration is more dilute (i.e. where there are more water molecules) to the side where the solution concentration is greater (i.e. where there are fewer water molecules).

Osmosis always results in the more concentrated solution becoming more dilute.

This means that water molecules diffuse from where their concentration is high to where their concentration is low (NOTE: *concentration* of molecules ≠ number of molecules).

Water molecules cross the membrane by passing through pores (aquaporins).

If a solution is placed on one side of a semi-permeable membrane and pure solvent on the other, pure solvent will tend to move across the membrane into the solution. This movement can be prevented by applying hydrostatic pressure to the solution. The amount of pressure required to prevent a net movement of water molecules is the **osmotic pressure** of that solution.

Osmotic pressure (stated in mmHg or Pa) is a measure of the tendency of water to move into an aqueous solution. It is also another measure of solution concentration.

7 Tonicity

Isotonic solution: a solution with an osmolarity within the range of blood's osmolarity (280–300 mmol/l). When added to blood, an isotonic solution causes no net movement of water into or out of red blood cells.

Examples: 5% glucose, 0.9% sodium chloride and 9.5% sucrose (0.3% NaCl + 3.3% glucose)

Hypotonic solution: a solution with an osmolarity less than that of blood. It causes the movement of water into RB cells (causing them to swell and perhaps lyse).

Hypertonic solution: a solution with an osmolarity greater than that of blood. It causes the movement of water out of RB cells (causing them to shrink and crenate).

8 A Question!

What do 5% glucose, 9.5% sucrose and 0.9% sodium chloride solutions have in common that makes them all isotonic?

Let us compare 5% glucose with 9.5% sucrose.

$$5\% \text{ glucose} \rightarrow 5 \text{ g}/100 \text{ ml} \rightarrow 50 \text{ g}/\text{l}.$$

A mole of glucose is 180 g.

Therefore, 5% glucose contains

50 g ÷ 180 g = 0.28 mole of glucose in each litre of solution.

$$9.5\% \text{ sucrose} \rightarrow 9.5 \text{ g}/100 \text{ ml} \rightarrow 95 \text{ g}/\text{l}.$$

Sucrose has the formula $C_{12}H_{22}O_{11}$, and a mole of sucrose is 342 g (check this yourself!); therefore, 9.5% sucrose contains $\frac{95}{342} = 0.28$ mole of sucrose in each litre.

So, 5% glucose and 9.5% sucrose both contain the same number of moles per volume and therefore *the same number of particles per volume*.

Let us now look at sodium chloride.

$$0.9\% \ \text{NaCl} \rightarrow 0.9 \ \text{g}/100 \ \text{ml} \rightarrow 9 \ \text{g}/\text{l}.$$

One mole of Na^+Cl^- is 58.5 g; therefore, 0.9% NaCl contains 9 ÷ 58.5 = 0.15 mole of Na^+Cl^- in each litre of solution.

But remember! Na^+Cl^- is an ionic compound, and when it dissolves, it forms separate Na^+ ions and Cl^- ions!

Therefore, the number of moles of particles in each litre of solution is 0.30, which is close to that for 5% glucose and 9.5% sucrose.

So, isotonic solutions contain the same concentration of dissolved (non-penetrating) *particles*.

To note, 5% glucose, 9.5% sucrose and 0.9% Na^+Cl^- solutions are all *isotonic*.

9 The Osmole

Osmole: this is the amount of substance that must be dissolved in order to produce 6×10^{23} solute particles (be they ions or molecules) of whatever size.

For most covalent-molecular substances

No. of moles = no. of osmoles (e.g. glucose, sucrose).

For ionic substances

No. of osmoles = no. of moles × **no. of ions in the formula** (e.g. Na^+Cl^- has two ions
∴ osmolarity = 2 × molarity).

(Osmolality – the number of osmoles dissolved in each kilogram of water
Osmolarity – the number of osmoles dissolved in each litre of solution)

10 Definitions of Acid

Acid: substance that reacts with water producing H_3O^+ (hydronium) ions
Strong acid: reacts *completely* with water producing *large concentration* of H_3O^+, for example: