HSC Biology
Module 1 – Maintaining A Balance

Focus 2:

- *Plants and animals transport dissolved nutrients and gases in a fluid medium.*

Identify the form(s) in which each of the following is carried in mammalian blood:

- **Carbon dioxide.**
- **Oxygen.**
- **Water.**
- **Salts.**
- **Lipids.**
- **Nitrogenous waste.**
- **Other products of digestion.**

Substance	From	To	Form	Carried By
O_2	Lungs	Cells	Oxyhaemoglobin	RBCs
CO_2	Cells	Lungs	HCO_3^- ions	RBCs, plasma
Nitrogenous waste	Liver, body cells	Kidneys	Mostly urea	Plasma
H_2O	Digestive system, body cells	Body cells	H_2O molecules	Plasma
Salts	Digestive system, body cells	Body cells	Ions in plasma	Plasma
Other digestion products	Digestive system & liver	Body cells	Separate molecules (AAs, glucose...)	Plasma

Oxygen Transport:

- Mammals require a continuous supply of O_2 for respiration.
  - O_2 diffuses from the external environment into the blood; through alveoli.
    - Diffuses from air into blood due to concentration gradient.
      - Less in blood than in the air ∴ moves into the blood.
  - Circulates throughout body to cells via circulatory system.

- O_2 highly insoluble in H_2O.
  - 100mL of blood can carry just 0.2mL of O_2 if only dissolved in plasma.
  - Blood of mammals contains haemoglobin (Hb), increasing the blood's capacity to carry O_2 by 100 times.
    - Each Hb molecule contains 4 sites in which O_2 can bind to.

- In the lungs:
  - When O_2 concentration is high;

    $Hb + 4O_2 \rightarrow Hb(O_2)_4$

    Haemoglobin + Oxygen → Oxyhaemoglobin
- In body tissues:
  - O_2 concentration is low;

    $Hb(O_2)_4 \rightarrow Hb + 4O_2$

- The concentration of O_2 in the atmosphere decreases with altitude.
  - Mammals can adapt to the changes physiologically & behaviourally.
    - Breathe deeper.
    - Produce more RBCs.
    - Larger heart.

<u>Carbon Dioxide Transport</u>:

- In high concentrations in body tissues.
  - Diffuses into the circulatory system.
    - 70% of CO_2 dissolves in water to form HCO_3^- in RBCs.

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

    Carbonic acid → Hydrogen ions + Hydrogen carbonate ions

    - 23% combines with Hb to form carbaminohaemoglobin (does not prevent the reaction between Hb & O_2).
    - Remaining 7% dissolved in plasma.

- Respiratory surfaces:
  - CO_2 levels low.
  - CO_2 diffuses out of the blood, across respiratory surface, into external environment.

Explain the adaptive advantage of haemoglobin.

Red Blood Cells (erythrocytes):

- Disc shaped, biconcave cells.
- Contain the respiratory pigment haemoglobin (Hb).
- Each RBC contains 200-300 million Hb molecules.

Haemoglobin:

- Gives blood red colour.
- Each Hb molecule consists of 4 sub units.
  - Subunits comprised of the polypeptide chain; globin & haem.
- There are 2 types of globins;
  - Alpha chains.
  - Beta chains.
- Haem contains an iron atom that is able to combine with an oxygen molecule.
  - Each Hb molecule has the ability to carry 4 oxygen molecules.
    - Oxyhaemoglobin.

Adaptive Advantage:

- The ability of Hb to carry oxygen.
  - Oxygen is not readily soluble in water.
    - Not carried efficiently by plasma.
- Structure of Hb allows it to dissociate O_2 readily to tissues.
  - Loosely combines with O_2 (oxyhaemoglobin).

  $\mathbf{Hb + 4O_2 \rightleftharpoons Hb(O_2)_4}$
- Takes O_2 from lungs & CO_2 to lungs.
- Increases the blood's capacity to carry O_2.
- Hb is enclosed in RBCs.
  - Many mammals have Hb molecules in plasma, upsetting osmotic balance of their blood.

Perform a first-hand investigation to demonstrate the effect of dissolved carbon dioxide on the pH of water.

Aim: To investigate the effect of dissolved carbon dioxide on the pH of water.

Hypothesis: As more breaths are added to the water the pH will decrease. This will cause the pH to decrease, increasing its acidity.

Equipment:
- Test tubes.
- Drinking straw.
- Universal indicator.
- Distilled water.

Procedure:
- Set up a control experiment consisting of 15mL of distilled water & 5 drops of universal indicator in a test tube (A).
- Add 15mL of distilled water & 5 drops of universal indicator to 4 test tubes (B, C, D & E).
- In test tube B, breathe once through the drinking straw.
- In test tube C, breathe twice.
- In test tube D, breathe 3 times.
- Breathe 4 times into test tube E.
- Record the pH of each solution.

Results:

1st Trial

Number of Breaths	pH
0	7
1	6
2	5
3	4.5
4	4

2nd Trial

Number of Breaths	pH
0	7
1	6
2	5
3	4.5
4	4

Discussion:
The results of the experiment show that the water becomes more acidic as the number of breaths is increased, supporting the hypothesis. This is due to carbonic acid forming when CO_2 is dissolved in water. As the number of breaths is increased, the concentration of CO_2 increases & the pH decreases. The results cannot be considered reliable due to a number of variables being beyond control. The duration of the breath decreases each time & the concentration of CO_2 varies as the number of breaths are increased. The intensity of each breath also varies.

In the body CO_2 is created by respiration, creating an acidic environment in body tissues. This leads to the denaturation of enzymes & cells being poisoned. Removal of CO_2 through the blood is essential to maintain homeostasis.

Conclusion:
The pH of H_2O decreases as the number of breaths increases.

Compare the structure of arteries, capillaries & veins in relation to their function.

Arteries:

- Carry blood away from the heart.
- Under high pressure.
  - Thick elastic walls enable vessels to withstand pressure.
- Structure:
  - 3 layers.
    - Endothelium (lining).
    - Smooth muscle (contract vessel).
      - Gives strength to arteries.
      - Controlled by sympathetic nervous fibres.
      - Allows stretch & recoil as heart beats.
      - Contain 40-10% elastic tissue.
    - Connective tissue.
      - Non elastic
      - Anchors arteries in place.
  - Muscular arteries branch into smaller & smaller arteries, creating arterioles.
    - Lead into capillaries.
    - Control rate of flow into capillaries through muscle contractions.

Veins:

- Carry blood to the heart.
  - Same quantity as arteries.
- Low pressure.
  - Thin walls with valves to prevent backflow.
- Structure:
  - 3 layers.
    - Endothelium (lining).
    - Smooth muscle.
      - Thinner than arteries.
    - Connective tissue.
      - Thinner than arteries.
  - Thinner layers make veins more flexible.
  - Blood enters veins from capillaries through venules.
  - Contraction of muscles surrounding veins helps to push blood through.

Capillaries:

- Thin walled vessels between 5-8um in diameter.

- Materials pass through cells or between cells.
- Structure:
  - 1 cell thick (endothelium).
- Function:
  - Thin walls allow substances to diffuse across.
    - *eg.* O_2 & CO_2, H_2O, water soluble molecules (glucose, ions).
    - Phagocytic cells also move out through endothelial cells.

Describe the main changes in the chemical composition of the blood as it moves around the body to identify tissues in which these changes occur.

Chemical Composition of Blood	Tissue Where Change Occurs
Blood receives O_2, CO_2 released.	Lungs
Blood receives CO_2, O_2 released.	Body tissues
H_2O diffuses into blood. Other substances pass into blood.	Stomach tissue
Digested foods (AAs, glucose) diffuse into blood, carried to liver.	Small intestinal tissue
Vitamins, Fe, fats removed from stored. $C_6H_{12}O_6$ added/removed. Poisonous substances removed. Excess AAs absorbed, converted to urea.	Liver tissue
H_2O, salts & vitamins absorbed into blood.	Large intestinal tissue
Excess H_2O & salts removed from blood.	Kidney tissue
Hormones secreted directly into blood stream.	Endocrine tissue

Circulation:

- Blood circulates through 2 systems.
  - Pulmonary system.
  - Systemic system.
- Pulmonary system:
  - Blood flows to the heart → lungs → heart.
    - Right ventricle (pulmonary artery) to lungs.
      - CO_2 released into alveoli.
      - O_2 released from alveoli, diffuses into RBCs.
    - Pulmonary vein carries oxygenated blood back to the heart.
  - Blood under higher pressure than systemic system.
    - Flows faster.
- Systemic system:
  - Blood flows from the heart to the rest of the system.
    - Out of the left ventricle, through the aorta.
    - Flows through capillaries where O_2 diffuses out & CO_2 diffuses in.
      - Other waste products picked up from the liver & taken to kidneys.
      - Glucose transported (picked up at liver, dropper off at cells).
    - Deoxygenated blood returns to right ventricle via super vena cava.

Transport of Nutrients:

- Nutrients are transported in the plasma.
- Simple sugars (monosaccharides):
  - Cross the membranes of cells lining the gut & enter blood through capillaries.
  - Carried in hepatic portal vein to capillaries in the liver.
    - Some removed for storage (converted to glycogen, about 100g), excess moved to skeletal muscles for storage.
- Amino Acids:
  - Produced by the digestion of protein.
  - Absorbed into the hepatic portal vein in the gut.
  - Transported to the liver & to all parts of the body to be used.
- Lipids:
  - Digestion of fat produces fatty acids & glycerol.
  - Some fatty acids & glycerol diffuse through cells lining the small intestine into the hepatic portal vein & carried to the liver.

Outline the need for oxygen in living cells & Explain why removal of carbon dioxide from cells is essential.

Oxygen:

- Needed for the process of aerobic respiration.
  $C_6H_{12}O_6 + O_2 \rightarrow 6CO_2 + 6H_2O$ + Energy (ATP) + Heat

Carbon Dioxide:

- CO_2 is produced during respiration.
  - Causes pH to drop from normal 7.4 which provides optimal function of nerve cells & enzymes.
- CO_2 needs to be removed to keep a constant pH (maintain homeostasis).
  - Removed via blood in plasma & combined with Hb.

Concentration Changed of CO_2:

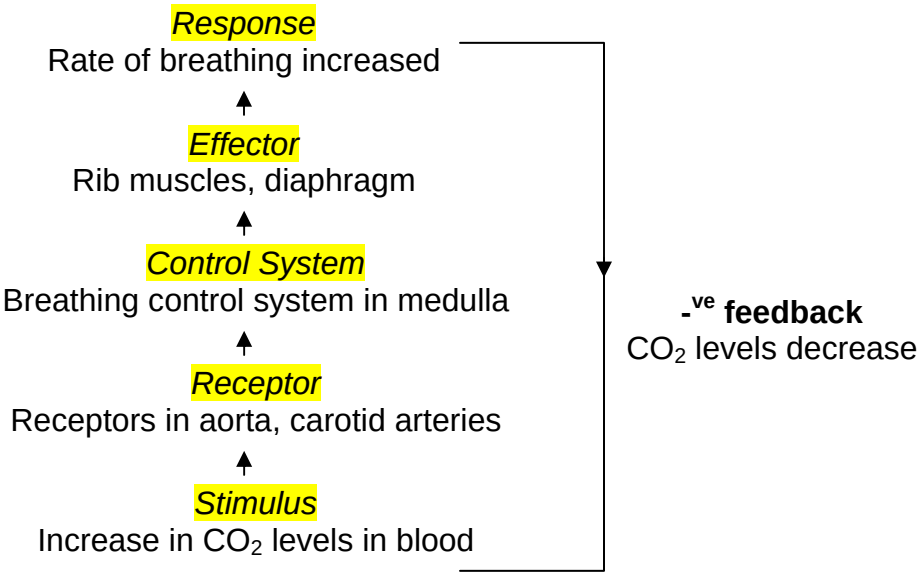
- CO_2 diffuses down a concentration gradient; like O_2.
- Diffuses out of cell, into interstitial fluid. Then diffuses into capillary.
- Moves into the right chamber of the heart through veins.
  - Enters lung capillaries & diffuses out through alveoli.
  - Pco_2 leaving lungs is 40mmHg.

Transport of CO_2:

- Little CO_2 can be carried in the blood compared to the amount of O_2.
  - CO_2 has low solubility in H_2O.
  - Reactions take place in blood to convert it to a more soluble form.
    - Dissolves in plasma to form $H_2CO_3 \rightarrow HCO_3^-$ (very soluble).
    - Equilibrium between CO_2 & HCO_3^- important for buffering & maintaining pH7.4.
  - Some binds to Hb to form carbaminohaemoglobin.

Mammals:

- pH of blood monitored by the receptors in the medulla, walls of the aorta & the carotid arteries.
- Nerves send messages to the breathing control centre in the medulla to alter the rate & depth of breathing.


Response
Rate of breathing increased
Effector
Rib muscles, diaphragm
Control System
Breathing control system in medulla
Receptor
Receptors in aorta, carotid arteries
Stimulus
Increase in CO_2 levels in blood
-ve feedback
CO_2 levels decrease

Describe current theories about processes responsible for the movement of materials through plants in xylem & phloem tissue.

Xylem:

- Transport of H_2O & mineral ions.
- Move from roots to leaves **(up only)**.

Transport in the Xylem:

- The **transpiration, tension, cohesion theory**.
- Transpiration:
  - Water evaporates off mesophyll cells. Vapour exits through stomata.
    - Water then moves out of mesophyll cells, onto mesophyll cell walls (keeping them moist).
  - Roots of the plant draw water in through osmosis (passively).
    - Concentration gradient created as water moves up the xylem to replace water lost off mesophyll cells.
- Tension:
  - Water moving out of stomata creates tension in the xylem.
    - Xylem shrinks slightly.
  - Negative pressure created within xylem.
- Cohesion:
  - Tensile strength (created by cohesive forces of water) allows a continuous column of water to move up the xylem.
    - Diameter of xylem increases / decreases tensile strength of water.
- This process was discovered by conducting various experiments & observing the movement of water.
  - Accurate measurements of xylem.
  - Cutting off roots & observing water movement.
- If water relied on air pressure to move it would not exceed 10m. Many trees are up to 100m tall.

Phloem:

- Transport of organic material.
  - Hormones, sugar, AAs.
- **Up & down.**

Transport in the Phloem:

- **Pressure flow theory.**
  - Movement on phloem very rapid (1m/h).

- Translocation:
  - The movement of sugars, AAs & hormones.
  - Enables the plant to distribute resources to wherever they are needed.
  - The process ceases when the phloem cell dies.
  - Translocation is an active process (energy required).
- The process:
  - Sugar is loaded into the phloem tube at the source (*eg.* a leaf).
  - Water follows through osmosis (follows concentration gradient).
    - This creates an increase in pressure at the source & a decrease in pressure at the sink.
  - Solute flows from source to sink.
- At the sink:
  - Sugar leaves phloem tube where it is used or stored.
  - Water also leaves phloem, water pressure in tube decreases.

Analyse information from secondary sources to identify the products extracted from donated blood & discuss the uses of these products.

Donated Blood:

- Used to treat severe haemorrhage (accidents & child birth).
- Apheresis:
  - Blood extracted from donor.
  - Platelets, leukocytes & plasma retained.
  - Blood retransfused into donor.
  - Donor can donate more frequently.

- Plasma:
  - Red & white cells suspended in plasma.
  - 70% H_2O, minerals, CHOs, from digestion, hormones, waste products & antibodies.
  - Most versatile blood component.
  - Stored up to 12 months.

Analyse and present information from secondary sources to report on progress in the production of artificial blood and use available evidence to propose reasons why such research is needed.

***Artificial Blood*:**

- The military has actively pursued Hb based blood substitutes.
  - Use as an oxygen carrying plasma expander for use in the battle field.
- The 1st generation of artificial blood could hit the market within 2 years, greatly reducing the pressure on donated blood supplies.

- Advantages:
  - May prevent shock.
  - Stored at room temperature.
  - Stored for more than a year.
  - No need to match patent's blood type.
    - Doesn't contain blood type antigens.
  - Unlikely to be infected.
    - Pasteurisation used to remove any pathogens.

- Disadvantages:
  - Not capable of replacing the real thing.
  - Only substitutes RBCs (carries O_2).
  - Potential safety problems.
    - Some cause hypertension → stroke → cardiac arrest.
  - Decomposes rapidly.

Analyse Information from secondary sources to Identify current technologies that allow measurement of oxygen saturation and carbon dioxide concentrations in blood and Describe and Explain the conditions under which these technologies are used.

Pulse Oximeter:

- Function:
  - Senses a change in the colour of blood as it circulates through the skin.
  - Red & infrared light emitted from the tip of the peg.
  - Amount of light passing through the skin determined by an electric sensor.
  - Amount of O_2 in blood in arterial capillaries calculated.
  - Normally 95-100%.

- Uses:
  - Monitor level of O_2 in blood during heavy sedation or anaesthesia.
  - Used during stress testing (heart function).
  - Monitor response to medication.

Arterial Blood Gas Analysis:

- Function:
  - Measurement of O_2 & CO_2 in a sample of blood.
  - Uses the diffusion of gases through an artificial permeable membrane.
  - Movement of O_2 molecules produces an electrical current.
    - Current converted to a digital reading.
  - Diffusion of CO_2 through a separate membrane changes the pH of a solution.

- Uses:
  - Monitoring of a patient during therapy.
  - Diagnosis of respiratory disease.
  - Function of kidneys.

Perform a first-hand investigation using the light microscope and prepared slides to Gather information to estimate the size of red and white blood cells and draw scaled diagrams of each.

Aim:
Using to light microscope & prepared slides, estimate the size of red & white blood cells.

Materials:
- Monocular light microscope.
- Microslide grid.
- Red blood smear.

Method:
* Only rack up to prevent breaking slides.
* Wear covered footwear to prevent injury from laboratory equipment.
- Prepare microscope by adjusting light source & focus.
- Place microslide grid on stage, focus at 100x magnification.
- Calculate size of field of view.
- Refocus at 400x.
- Calculate size of field of view.
- Estimate field of view using microslide grid.
- Place red blood smear on microscope & focus at 100x.
- Refocus at 400x.
- Draw image in field of view.
- Count number of RBCs across field of view.
- Calculate size.
- Count number of WBCs across field of view.
- Calculate size.

Calculations:
RBC:
$350_{um} \div 50$
$= 7_{um}$

WBC:
$350 \div 17$
$= 20_{um}$