External Respiration:

1. Outline the uses of energy in the body of humans
   - Key understanding: organisms need usable energy to maintain cells and carry out their activities and functions
   - Uses of Energy: muscle contraction, protein synthesis, cell division, active transport, growth, passage of nerve impulses and the maintenance of a constant body temperature

2. Explain that energy is stored in the ATP molecule in the human body
   - Key understanding: Respiration is an energy releasing process

Adenosine Tri-Phosphate:

- Known as the "energy currency" since it is produced during respiration and energy is stored in the bonds between the phosphate groups
- ATP is produced by combining ADP and Pi, through photophosphorylation, oxidative phosphorylation or substrate-level phosphorylation
- ADP + Pi -> ATP + H2O
    - The forward process is endergonic
    - Energy released from ATP hydrolysis into ADP (exergonic) is used by many other endergonic metabolic reactions
- **Delivery of energy in small amounts**
- Respiration is the major source of energy input for ADP phosphorylation to ATP
- Aerobic respiration produces more energy than anaerobic respiration (36 molecules vs 2 molecules)

3. Describe the two types of respiration namely aerobic and anaerobic. Quote the full equation on energy output

Aerobic Respiration:

- Breakdown of glucose in the presence of oxygen with the release of energy
- Glucose is completely oxidized to its products (carbon dioxide and water) which are waste products
- Occurs in presence of oxygen (but not all the time)
- Takes place in the mitochondria (singular: mitochondrion)
- The process is a slow, step by step oxidation controlled by many enzymes
    - Prevents wastage of energy released in the form of heat energy
- Glucose + Oxygen -> Carbon dioxide + Water + large amounts of energy (NOT ATP)
- $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + large amounts of energy

Anaerobic Respiration:

- Takes place in the absence of oxygen
- Produces ethanol and carbon dioxide as waste products in yeast (alcohol fermentation)
    - Accumulation of lactic acid will kill yeast cells
    - $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$ + small amount of energy
- Produces lactic acid as waste product in muscle cells (animals)
    - Reason: oxygen cannot reach our muscles fast enough during exercise
    - Accumulation of lactic acid (mildly poisonous) in muscle cells cause muscle fatigue
    - Site of lactic acid breakdown: liver
    - $C_6H_{12}O_6 \rightarrow 2C_3H_6O_3$ + small amount of energy
- Oxygen debt: explains panting after exercise
    - The amount of oxygen required to oxidize the lactic acid produced in muscles producing during anaerobic respiration
    - Oxidation of the lactic acid produces energy used to convert remaining lactic acid into glucose: transported back to muscle cells
    - Oxidized for energy or stored as glycogen (oxygen debt is paid)
    - $2C_3H_6O_3 + 6O_2 \rightarrow 6H_2O + 6CO_2$ + small amount of energy

4. Compare aerobic respiration in which energy is released, to photosynthesis in which energy is stored.

Anaerobic Respiration	***Aerobic Respiration***	***Photosynthesis***
Small amounts of energy is liberated	Energy is liberated in large quantities	Energy is stored in carbohydrate molecules
By-products are lactic acid (muslces) or carbon and ethanol in yeast	Oxygen is used. Carbon dioxide and water are released as by products	Carbon dioxide and water are used; oxygen is given off
	Catabolic process in which glucose is broken down	Anabolic process in which glucose is formed
Occurs when there is no oxygen	Occurs all the time when oxygen is available	Occurs only in cells with chlorophyll and in presence of sunlight
	Results in loss of dry mass	Results in gain of dry mass

5. Gas exchange in cells occurs by diffusion
    - Diffuses across a barrier (cell membrane)
    - Diffusion across the cells in the alveoli into the blood capillaries

6. The rate of diffusion depends on the surface area of the respiratory surface, the concentration gradient and the length of the diffusion path

Factors affecting rate of diffusion:

- Concentration gradient (should be high)
- Surface area (higher=more diffusion)
- Distance of diffusion (smaller distance=more diffusion)

7. Larger animals have specialized respiratory as the rate of diffusion of substances from the exterior into and out of the body of the animal is too slow to sustain life
    - Larger animals like humans have specialized respiratory system for gaseous exchange compared to unicellular organisms

Explanation:

- Cells must remain small if CO2 and O2 are to diffuse across cytoplasm fast enough to maintain life
    - The volume of Amoeba which is about 0.1mm^3 is adequately served by cell membrane area of approximately 2.5mm^2
    - Cells must have a large surface area to volume ratio in order to have sufficient diffusion to support the life of the organism
- If not, a specialized respiratory system is necessary to carry out the function of diffusion

8. Relate the structures of the respiratory system (nose, larynx, trachea, bronchus, bronchioles, alveoli, ribs, diaphragm and intercostal muscles) to their functions

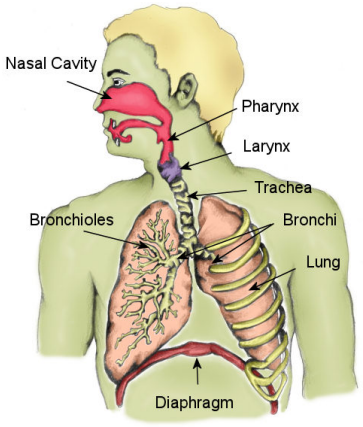
Respiratory Pathway:

- Summary: Nose – Nasal Cavity – Pharynx – Larynx – Trachea – Bronchi – Bronchioles – Alveoli
- Air enters through the two external nostrils and from nostrils to the nasal passage
    - Hair in nostrils and mucus in mucous membrane trap dust and foreign particles
    - Harmful chemicals are detected by sensory cells in mucous membrane
    - Air is warmed and moistened before entering the lungs
- From nasal passage, air passes into the pharynx
- Larynx:
    - In mammals, it can be adapted as a voice box
    - Vocal cords: voluntary muscles in the voice box, are tensed so they vibrate when air passes over them

- Trachea:
  - Windpipe maintained by C shaped rings of cartilage, forks into bronchi at the end
  - C shaped cartilage: allows for movement of trachea when epiglottis directs food into gullet
  - Prevent the trachea from collapsing and keeps the airway open for survival (even if a person is in a coma, his trachea remains open for air to pass through)
  - Epithelium lining bears ciliated cells and gland cells that secrete mucus
    - Mucus that traps dust particles and pathogens, ciliated cells sweep mucus into pharynx
    - Mucus swallowed into oesophagus, preventing infection of lung
- Lungs:
  - Organ dedicated to the exchange of gases between man and the environment
  - Two lungs present (two lobes on left, three lobes on right)
  - Located in the chest cavity
- Bronchi: 2 tubes branching from the trachea, one leads to each lung
- Bronchioles: finer tubes that branch and rebranch from the bronchi inside the lungs, dead end into the alveoli
  - 3 bronchial tubes in the right lung, while only 2 bronchial tubes in the left lung (based on the number of lobes in each lung)
  - C-shaped cartilage can be found in the bronchial tubes to prevent collapse
- Alveoli: air sacs (site of gaseous exchange)
  - The total area of the air sac is the equivalent of a tennis court
  - Supplied with continuous flow of blood from the capillaries

Other Definitions:

- Ribs: pairs of bones that support the chest wall
  - 12 pairs of ribs, first 10 pairs attached to the sternum (at the chest)
  - All 12 pairs attached to the vertebral column (backbone)
  - Moves sternum away or nearer to the backbone in changing the thoracic cavity volume
- Diaphragm: a sheet of skeletal muscle that forms the bottom wall of the chest cavity
  - Separate the abdominal cavity and rib cavity (thorax and abdomen)
  - With orifices to allow oesophagus and major blood vessels to pass through
  - Attached to a central tendon (as leverage to flatten during inhalation)
  - Causes hiccups: involuntary action involving a reflex arc
  - When diaphragm contracts, it flattens downwards
  - When diaphragm relaxes, it arches upwards
  - Movement of the diaphragm changes the volume of thoracic cavity, changing pressure in thoracic cavity, movement of air
- Intercostal muscles:
  - 2 sets of muscles that are antagonistic in action
  - When one set of muscle contracts, the other relaxes
  - External intercostal muscles contract, causing ribs to swing upwards and outwards to increase volume of thoracic cavity
  - When ribs move up and down, they change the volume of thoracic cavity
- Pleura: membranes that cover the lungs and line the pleural cavity
- Tidal Volume: the volume of air inhaled or exhaled at each normal breath



9. <u>Explain that the ribs, diaphragm and intercostal muscles work together to enable ventilation to take place</u>

Definitions:

- Gas Exchange: exchanging oxygen for carbon dioxide in the lung alveoli
- Pulmonary Ventilation: moves gases between atmosphere and respiratory surface

- External Respiration: occurs when gases diffuse across the respiratory surface
- Internal Respiration: occurs when gases diffuse between circulating blood and respiring cells
- Tissue/cellular respiration: occurs when oxygen is used and carbon dioxide is produced during the oxidation of foods to release energy for metabolism
- Ventilation: the movement of the respiratory medium to and from the respiratory surface to help to maintain adequate concentration gradient of O2 and CO2 so that diffusion can take place across the respiratory surface

Negative Pressure Breathing:

- It works as a suction pump, pulling air into the lungs instead of pushing
- When you breathe in your rib muscles contract lifting your ribs (to expand the rib cage) and the diaphragm contracts (at rest it bows upward, contracted it is nearly flat) which moves the floor of the chest cavity down increasing the volume, thus forcing lung tissue to expand and air rushes into the lungs

Positive Pressure Breathing:

- Ventilator breathing is positive pressure (for patients)
- Frog is positive pressure (air is pumped into the lungs)
    - Gulps air and lowers floor of mouth
    - Closes nostrils and raises floor of mouth to allow air to be pushed into alveoli

Breathing Control Centres:

- Located in the medulla oblongata and the pons of the brain (brain stem and brain base)
- Receive signals from receptors throughout the body (and act with a negative feedback loop)
- Regulate the unconscious control of respiration and circulation

Inspiration and Expiration:

- Inspiration: air is taken into body
- Expiration: air is taken out from the body
- Breathing movements: to change dorso-ventral diameter and the breadth of thorax
- Breathing is simply rhythmic inspirations and expirations
    - 10-14 times per minute
    - Automatic process with control centers in the brain

Inspiration:

- Diaphragm contracts and flattens downwards while external intercostal muscles contract and internal intercostal muscles relax
- Ribs swing upwards and outwards
- Sternum moved up and further from backbone
- Increases the dorso-ventral diameter and breadth of thorax
- Thoracic cavity volume increases, air pressure in thorax decreases, air rushes into lungs

Expiration:

- Diaphragm relaxes and arches upwards, external intercostal muscles relax
    - Note: Internal intercostal muscles and abdominals only contract for active expiration only: during intense exercise whereby more air is required in the lungs for gaseous exchange
- Ribs swing downwards and inwards
- Sternum returns to original position nearer the backbone
- Thoracic cavity volume decreases, air pressure in thorax increases, air rushes out of the lungs

10. <u>Describe the adaptations of the alveoli for efficient gaseous exchange</u>

A. Two-cell thick distance for diffusion
    - The diffusion distance is only 0.5 micrometers in humans
    - Increases the rate of diffusion due to the shorter distance of diffusion path
B. Thin film of moisture surrounding the alveoli

- To allow oxygen and carbon dioxide to dissolve and diffuse into and out of the alveolar capillaries

C. Maximization of surface area with the structure of the air sacs
- 700 million alveoli found in lungs, providing total area of 80m^2 to service volume of about 80dm^3
- Man has 95000km of capillaries to provide an area of about 700m^2 to exchange gases with cells
- Large surface area for rapid diffusion of gases

D. Abundance of capillaries which allows for greater diffusion of gases
- Well supplied: maintains the concentration gradient for diffusion to occur
- Allowing for rapid and efficient diffusion of gases
- Surrounded by capillaries from pulmonary artery to pulmonary vein
- Oxygenated: pulmonary vein, deoxygenated: pulmonary artery

Extra:
- The rate of supply of O2 and removal of CO2 can be increased during exercise
    - In Man the breathing rate goes up four-fold, volume inhaled per breath increases sevenfold
    - Heart rate doubles and the volume of blood pumped doubles (athletes do much better)

11. State that the respiratory system is protected by the nasal hair, mucus, cilia and immune system

Introduction:
- The major branches have motile cilia and mucus linings that catch dust, pollen and other particles
- The cilia sweeps the mucus and debris up to the pharynx where it can be swallowed into the digestive tract through the oesophagus and broken down by the digestive system
- Epithelium cells lining the bronchi and trachea bears gland cells that secrete mucus to help trap particles and bacteria

Advantages of Breathing Through Nose:
- Nasal hair can trap dust, foreign particles and pathogens (first line of defence)
- Mucus on the mucous membrane produces fluid that traps particles (and is secreted through the nostrils out of the body)
- Warmed and moistened before it enters the lungs
    - Especially important for dry and non-humid places (prevents water loss)
    - Warms up to prevent heat loss from the body
- Harmful chemicals detected by sensory cells
    - Prevent infection of the lungs (bronchitis/tuberculosis) from air-borne diseases
    - Prevents tar particles and other irritants found in the air from entering the lungs (which can damage the alveoli)

Immune System:
- Upon the detection of harmful particles in the air breathed in, the body's immune system increases the secretion of mucus in the epithelial cells to trap the particles and prevents lung infection
- Chemical receptors in the nose are able to alert the body to presence to particles

12. State that the respiration rate is determined by the level of carbon dioxide in the blood

Detection of Stimulus:
- Control center in the medulla sets the basic rhythm, and a control center in the pons moderates it, smoothing out the transitions between inhalations and exhalations
- Nerve impulses trigger muscle contraction
    - Nerves from breathing control center in medulla oblongata of the brain send impulses to the diaphragm and rib muscles, stimulating contraction and causing inhalation
- Medulla control center also helps regulate blood CO2 level
    - Sensors in the medulla detect changes in pH (reflecting CO2 concentration) of the blood and cerebrospinal fluid bathing the surface of the brain
- The level of carbon dioxide indicates to the sensory receptors (in the carotid arteries) that the body needs to breathe to remove the carbon dioxide from the blood

    - There are also sensors for O2 levels in the carotid arteries and aorta
    - The blood pH is affected as more carbonic acid is formed through the reaction between the plasma and the carbon dioxide
- Concentration of CO2 in the blood (pH change) is the main (not the only) stimulus for breathing

Detailed pathway of signals:

- Chemoreceptors on aorta and carotid sinus send information about chemical changes in blood to respiratory centres in the pons and medulla
- Respiratory centres in the brain monitor CO2 and pH and control motor neurons to intercostal muscles and diaphragm
- Motor neurons in the intercostal muscles and diaphragm react to speed up or slow down external respiration (explains the negative feedback loop)

Pure Oxygen Inhalation:

- Very large concentration gradient for diffusion reducing need to breathe at present rate
- Extremely dangerous, since the CO2 levels in the body will be very low
- This means a reduced urge to breathe (controlled by pons): leading to a collapse of the respiratory system (no impetus to breathe since the brains does not send signals with little detection of CO2 in the blood)

13. State and account for the difference between inspired and expired air

Comparison of inspired and expired air:

Gas	Inspired Air	Expired air	Reason for Difference
Oxygen	21%	16%	Oxygen absorbed into blood and used in respiration
Carbon Dioxide	0.03%	4% (100x more)	Carbon dioxide is a waste product of respiration
Nitrogen	78%	78%	Not used by cells
Argon and noble gases	1%	1%	Not used by cells
Water vapour	Variable	Always higher	Water evaporates from the walls of alveoli (from thin film of moisture)
Temperature	Variable	Always higher (close to human temperature)	Heat also escapes from blood into alveolar air
Dust Particles	Present	Little/none	Dust particles removed by mucous lining in nose and epithelial cells of trachea

14. Describe how the respiratory and circulatory systems work closely together to supply the body with adequate amounts of oxygen according to the level of activity of the person
    - Circulatory and respiratory systems work together to maintain a concentration gradient for diffusion of gases at the alveolus
        - Movement of ribs and diaphragm contraction and relaxation results in inspiration bringing air rich in oxygen into the lungs and expiration that brings air rich in CO2 out of the lungs
        - Circulatory system (or blood capillaries) lie close to the alveolus to bring in deoxygenated blood rich in CO2 and transport away oxygenated blood
    - Circulatory systems help to transport gases between the lungs and the body cells
        - Transport of oxygen:
            - Oxygen dissolves in moisture lining inner surface of alveolus
            - Dissolved oxygen diffuses into blood where it binds to hemoglobin to form oxyhemoglobin in red blood cells (to Fe2+)
            - Hb+4O2 -> HbO8
            - Note: in natural settings, there is enough time for oxygen diffusion to fill up all Hb

        - Note: in thin air with reduced oxygen, not all Hb are filled up (only ½ are filled) thus increasing the need for acclimatization (might feel light-headed)
    - Transport of carbon dioxide:
        - Dissolved in plasma
        - Bound to the amino groups of hemoglobin (15-20%) but not to Fe2+
        - Bicarbonate ions in the plasma (70-80%) with carbonic anhydrase as catalyst
            - $H_2O + CO_2 \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$
            - H^+ can be detected in the pH levels (more acidic blood)
        - When blood flows past the alveoli where CO_2 concentration is low, carbonic anhydrase catalyzes the converse of bicarbonate ions to carbon dioxide and water
        - Carbon dioxide diffuses into alveolus

Exercise:

- The pulse and heart rate increases as more blood needs to travel more frequently to the cells to supply materials for respiration, which is required to produce energy for movement
- An increase in the rate of respiration also increases the demand for oxygen, and more carbon dioxide must be removed from the body
- The rate of external respiration will increase, since the concentration gradient must be maintained (when the heart rate increases, more blood is supplied to the lungs as well, where diffusion continues to take place)

15. Describe the advantages and disadvantages of water as a respiratory medium

Advantages and disadvantages of air

Factor	Advantage:	Disadvantage:
Rate of Diffusion		Slower than in air
Maintaining moist respiratory surface	Already in aqueous medium, no danger of drying out	
Solubility of O_2		Lower than air (0.8% compared to 21%, thus concentrations of oxygen in water is lower (especially in salty water)
Factors affecting O_2 solubility	Dissolved solutes (eg. Salinity) or increased temperatures will decrease oxygen solubility further	
Density of medium	Denser than air so can support heavy respiratory surfaces like gills	Denser than air so more energy is needed to ventilate respiratory surface

Effects of solubility of O_2:

- Much less oxygen is available to aquatic organisms per unit volume of medium compared to land
- Large aquatic plants such as seaweeds have a very large surface area/volume ratio
- Aquatic animals that are highly mobile have high respiration rate to maintain continuous flow of water over their gills (trouts or herring)
- Efficient exchange mechanism between blood and water at gill surface

16. Describe counter current exchange in the gills of the fish and explain why it is more efficient than concurrent flow of water and blood

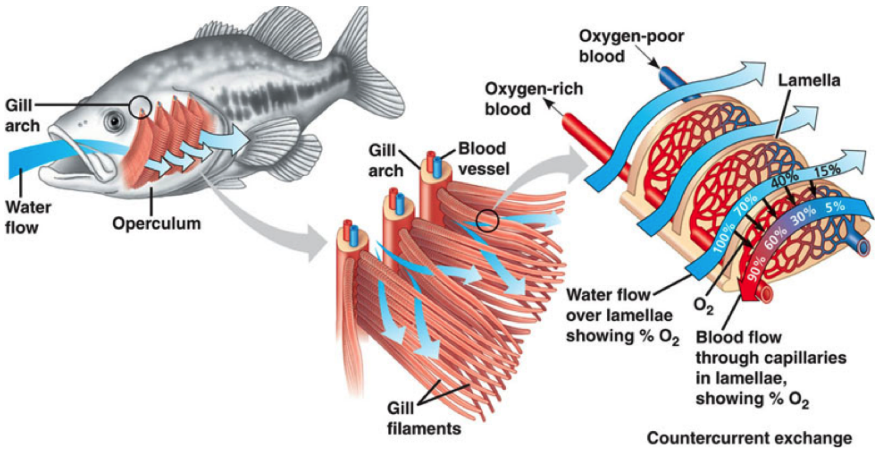
Gas Exchange of Fish:

- The gill bar supports the gill filaments and carries the blood supply
- The gill raker stops food from being lost through the operculum and filters the water supply to the gills to ensure that it does not get clogged up

- The gill filaments are paired and lie close together, while maximizing the surface area for reaction
    - Each gill has two rows of filaments arranged in V shape
- The gill filaments are surrounded by blood capillaries which increase the diffusion and provide a greater supply of oxygenated blood back to the systemic circulation
- Operculum: flap of muscle which protects the gills of fishes from external surroundings
- Positive pressure in buccal cavity through raising on base of mouth: pushes water into gills

Countercurrent Mechanism:

- Water flows over the gill filaments in the opposite direction of blood flow in the capillaries
- Resulting in the water always having a higher concentration of oxygen than the blood
- Maintains the diffusion gradient (over almost the entire length of respiratory surface)



- As blood moves through a gill capillary it becomes more and more loaded with O2 but simultaneously encounters water with even higher concentrations of CO2
- Enhances gas exchange (more oxygen diffuses into blood) and reduces the energy cost of ventilation

Concurrent Exchange:

- Water flows over the gill filaments in the same direction of blood flow in the capillaries
- Resulting in fast equilibrium of oxygen concentration gradient
- Uptake of only 50% of the oxygen in water as diffusion stops at this oxygen concentration

Structure to function	Human Lungs	Adaptation found in fish gills
1.Large surface area for gaseous exchange	Large number of alveoli contribute to large surface area to volume ratio	Large number of finely divided gill lamellae contribute to large surface area to volume ratio
2.Thin walls ensure faster rate of diffusion	Alveoli and blood capillaries are both one cell thick	Gill lamellae is very thin
3.Richly supplied with blood capillaries (continuous blood flow maintains diffusion gradient)	Alveoli are surrounded with or supplied by numerous blood capillaries that lie close	Gill lamellae are richly supplied with blood capillaries
4.Moist surface for oxygen to dissolve in order to diffuse across respiratory surface	Layer of moisture found on the inner surface of the alveoli.	Oxygen already dissolved since respiratory medium is water

17. State that with the breathing in of cigarette smoke as well as other irritants causes respiratory tract diseases (lung cancer, emphysema, bronchitis)

Components of Tobacco Smoke:

i. Nicotine
- Physically addictive substance

ii. Carbon Monoxide
- Carbon dioxide is odourless and colourless
- CO in smoke promotes atherosclerosis (the deposition of fatty acids in arteries)
- Insufficient CO2 reaching the heart via coronary arteries may result in a heart attack

- Carbon Monoxide poisoning
    - Carbon dioxide binds irreversibly to haemoglobin to form carbaminohemoglobin and prevents it from carrying oxygen molecules to cells
    - Reduction of athletic ability
    - Insufficient oxygen may lead to amputation owing to gangrene
    - Results in a serious risk of fetal underdevelopment and deformity

iii. Tar

- Tar from the smoke paralyzes ciliated cells which reduces its motility
- Causes emphysema: breakdown of the partitions between alveoli, reducing the surface area for O2 absorption and gaseous exchange
- Cancer-causing: it kills 36 000 a year in UK (tar and lead are carcinogens)
    - Cigarettes contain 50 types of carcinogens
    - In US, smokers account for 90% of all lung cancer cases (more than proportion of smokers)

Chronic Bronchitis:

- Inflammation of the epithelium of airways by toxins in tobacco smoke (hyper production of mucus by gland cells that accumulate and obstruct the bronchial pathway
- As a result, the cilia is unable to sweep germs upwards in mucus resulting in its accumulation and germs and bacteria can reproduce more easily, leading to a greater risk of respiratory infections (such as bronchitis)
- Airway also becomes blocked and more difficult to breathe
- Symptom: persistent coughing with green or yellowish mucus to clear airway, wheezing, breathlessness

Emphysema:

- Toxins in tobacco smoke and coughing cause partition walls between air sacs to disintegrate
- Lowered surface area to volume ratio for efficient exchange of gases
- Lung loses elasticity, leading to breathlessness and wheezing
- Permanent effect (alveolar walls cannot be repaired)
- Deep and loud coughs can also damage alveoli by disintegrating partition walls