**Mastery Matrix: Topic 3 – Exchange With the Environment**

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| **Topic Title** | **Topic Number** | **Sub-Topic Title** | **Sub-Topic Number** | **Paper** | **Learning Statement** | **Statement Type** |
| Exchange with the Environment | 3 | Exchange in Single-Celled Organisms & Insects | 3.1 | 1 | State the relationship between an object's size and its SA/Vol ratio. | K |
| Exchange with the Environment | 3 | Exchange in Single-Celled Organisms & Insects | 3.1 | 1 | Calculate the SA/Vol ratio for a regular 3D object. | M |
| Exchange with the Environment | 3 | Exchange in Animals | 3.2 | 1 | Describe the structures and adaptations of gas exchange surfaces in: single-celled organisms, insects, fish and leaves. | K |
| Exchange with the Environment | 3 | Exchange in Animals | 3.2 | 1 | Understand the antagonistic relationship between internal and external intercostal muscles. | K |
| Exchange with the Environment | 3 | Exchange in Animals | 3.2 | 1 | Explain how changes in thoracic pressure result in ventilation. | K |
| Exchange with the Environment | 3 | Exchange in Animals | 3.2 | 1 | Interpret data relating to the effect of smoking, pollution and disease on gas exchange. | M |
| Exchange with the Environment | 3 | Exchange in Animals | 3.2 | 1 | Analyse data associated with specific risk factors for lung disease. | M |
| Exchange with the Environment | 3 | Exchange in Animals | 3.2 | 1 | Recognise the difference between correlations & causal relationships. | M |
| Exchange with the Environment | 3 | Exchange in Animals | 3.2 | 1 | Calculate pulmonary ventilation rate (PVR), using tidal volume and breathing rate. | M |
| Exchange with the Environment | 3 | Exchange in Animals | 3.2 | 1 | Describe the gross structure of the human gas exchange system. | K |
| Exchange with the Environment | 3 | Exchange in Animals | 3.2 | 1 | State the roles of the diaphragm and intercostal muscles in breathing/ventilation. | K |
| Exchange with the Environment | 3 | Exchange in Plants | 3.3 | 1 | Understand the compromise between maximising gas exchange and minimising water loss in plants. | K |
| Exchange with the Environment | 3 | Enzymes & Digestion | 3.4 | 1 | Define digestion. | K |
| Exchange with the Environment | 3 | Enzymes & Digestion | 3.4 | 1 | State the products of, and enzymes involved in, digestion for the following species: carbohydrates, lipids, proteins. | K |
| Exchange with the Environment | 3 | Enzymes & Digestion | 3.4 | 1 | State the role played by bile salts in digestion. | K |
| Exchange with the Environment | 3 | Enzymes & Digestion | 3.4 | 1 | Explain co-transport mechanisms for the absorption of amino acids & monosaccharides. | K |
| Exchange with the Environment | 3 | Enzymes & Digestion | 3.4 | 1 | Describe the role played by micelles in lipid absorption. | K |
| Exchange with the Environment | 3 | Enzymes & Digestion | 3.4 | 1 | Understand how Visking tubing can be used to model absorption of the products of digestion. | AT |
| Exchange with the Environment | 3 | Heart, Circulation & The Blood | 3.5 | 1 | Describe the general quaternary structure of haemoglobin molecules. | K |
| Exchange with the Environment | 3 | Heart, Circulation & The Blood | 3.5 | 1 | Describe the role of haemoglobin in oxygen transport and relate this to oxyhaemoglobin dissociation curves. | K |
| Exchange with the Environment | 3 | Heart, Circulation & The Blood | 3.5 | 1 | Explain the cooperative nature of oxygen binding in haemoglobin molecules. | K |
| Exchange with the Environment | 3 | Heart, Circulation & The Blood | 3.5 | 1 | State the Bohr effect. | K |
| Exchange with the Environment | 3 | Heart, Circulation & The Blood | 3.5 | 1 | Explain why different species may possess different types of haemoglobin, based on their environment. | K |
| Exchange with the Environment | 3 | Heart, Circulation & The Blood | 3.5 | 1 | Name the main blood vessels of the mammalian circulatory system. | K |
| Exchange with the Environment | 3 | Heart, Circulation & The Blood | 3.5 | 1 | Describe the gross structure of the human heart and explain how it's adapted to ensure a unidirectional flow of blood. | K |
| Exchange with the Environment | 3 | Heart, Circulation & The Blood | 3.5 | 1 | Link the structures of the following blood vessels with their function: arteries, arterioles, veins, capillaries. | K |
| Exchange with the Environment | 3 | Heart, Circulation & The Blood | 3.5 | 1 | Explain how tissue fluid forms and is returned to the circulatory system. | K |
| Exchange with the Environment | 3 | Heart, Circulation & The Blood | 3.5 | 1 | Calculate cardiac output (CO), using stroke volume and heart rate. | M |
| Exchange with the Environment | 3 | Heart, Circulation & The Blood | 3.5 | 1 | Analyse data relating to pressure and volume changes during the cardiac cycle. | M |
| Exchange with the Environment | 3 | Heart, Circulation & The Blood | 3.5 | 1 | Carry out the dissection of a mass transport organ (the heart). | RP |
| Exchange with the Environment | 3 | Transport in Plants | 3.6 | 1 | State the roles of xylem and phloem tissues in mass transport in plants. | K |
| Exchange with the Environment | 3 | Transport in Plants | 3.6 | 1 | Describe the cohesion-tension theory of water transport in the xylem. | K |
| Exchange with the Environment | 3 | Transport in Plants | 3.6 | 1 | Describe the mass flow hypothesis of translocation in plants. | K |
| Exchange with the Environment | 3 | Transport in Plants | 3.6 | 1 | Understand how tracers, ringing experiments and potometers can be used to investigate transport in plants. | AT |
| Exchange with the Environment | 3 | Transport in Plants | 3.6 | 1 | Evaluate the evidence for and against a mass flow hypothesis of translocation in plants. | K |

**Topic 3.1 – Exchange in Single-Celled Organisms & Insects: Key Knowledge**

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| State the equations used to calculate the (i) S.A., (ii) Volume of a cube with side length 'x' | (i) 6x2, (ii) x3 |
| State the effect on S.A. : Vol ratio of increasing body size | S.A. : Vol ratio decreases |
| State the equation for estimating the S.A. of a cell | Surface area = 4πr2 |
| State the equation for estimating the volume of a cell | Volume = 4/3πr3 |
| Explain why prokaryotes haven’t evolved a dedicated exchange surface | Prokaryotes are small enough that their metabolic requirements are met by simple diffusion, alone |
| Describe the general adaptations of a gas exchange surface | Large surface area, thin, selectively permeable, dense network of capillaries, moist |
| State the name given to the tiny pores which cover the thorax of insects | Spiracles |
| State the route taken by oxygen from the air into the respiring tissues of insects | Spiracles --> tracheae --> tracheoles --> respiring tissues |
| Explain why insects do not possess a mass transport/circulatory system | They're sufficiently small for gases to diffuse to every cell, individually |
| Suggest why insects may close their spiracles during the middle of the day | Inhibit water loss |
| Explain why insects have evolved to possess small quantities of water at the end of each tracheole | Oxygen & carbon dioxide must be dissolved in water, in order to pass across the cell membrane |
| Name the substance produced in the respiring cells of insects, during periods of intense activity | Lactate |
| State the effect of lactate on the exchange systems of insects | Lowers water potential inside the cells, causing more water to be absorbed from the tips of the tracheoles |
| Explain why water absorption from the tracheoles is adaptively beneficial | Allows oxygen to diffuse down the tracheoles more rapidly (diffusion happens more quickly through gases than liquids). |
| Name the internal structures which allow insects to continue respiring, even with closed spiracles | Air sacs |

**Topic 3.2 – Exchange in Animals: Key Knowledge**

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| Name the individual structures which are found in their thousands attached to the gill bars of fish | Gill filaments |
| State two adaptations of the gill filaments | Thin to reduce diffusion distance, dense network of capillaries to maintain steep conc gradient |
| State the name and function of the projections which point outwards from the gill filaments in fish | Lamellae – Increase surface area for gas exchange |
| Describe the location of the gills in fish | Behind the head |
| State the name given to the system by which blood and water are moved through the gills in opposite directions | Countercurrent flow mechanism |
| Explain the benefit of fish evolving a countercurrent flow mechanism | Ensures that the maximum volume of oxygen is absorbed from the water |
| Name the tiny air sacs located at the end of each bronchiole in the mammalian lungs | Alveoli |
| Explain why expiration is a largely passive process | Collagen & elastic tissues in/surrounding the lungs recoil, forcing air out. |
| State four processes which occur during inspiration | External intercostal muscles contract, internal intercostal muscles relax, diaphragm contracts, ribs move up + out |
| State two reasons why the exchange surfaces of multicellular organisms are generally found internally. | Reduces water loss, protects delicate structures |
| Define pulmonary ventilation rate and state its units | The volume of air taken in and out of the lungs in 1 minute, measured in dm3min-1 |
| State the equation for calculating pulmonary ventilation rate | pulmonary ventilation rate = tidal volume x breathing rate |
| Identify the primary risk factors for pulmonary disease | Smoking, air pollution, genetic predisposition, infections and occupation  |
| Define 'tidal volume' | The volume of air which enters the lungs during inspiration |
| Describe two adaptations of the alveolar wall which increase the rate of gas exchange | 1) Moist - allows gases to dissolve for more rapid diffusion ; 2) One cell thick - short diffusion distance |

**Topic 3.3 – Exchange in Plants: Key Knowledge**

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| Explain why plants have evolved less complex exchange surfaces than other multicellular organisms | Plants produce a percentage of their own oxygen via photosynthesis, so don't need to absorb as much from their surroundings. |
| State three adaptations of the leaves for efficient gas exchange | Leaves have a flattened shape, contain air spaces and possess stomata. |
| Compare the rates of photosynthesis and respiration over a 24 hour period | Respiration = contestant, photosynthesis = variable (high in the day, low at night) |
| State the function of the wax cuticle | Inhibits water loss from the leaf |
| Identify the tissue within the leaf which contains the highest density of chloroplasts | Palisade mesophyll |
| Explain why stomata are almost exclusively found on the underside of the leaf | Lower light intensity, so reduces water loss |
| Name three gases which diffuse into/out of the leaf via the stomata. | Oxygen, carbon dioxide, water vapour |
| Explain why a small number of stomata will remain open throughout the night | Oxygen is still required for respiration and, as photosynthesis isn't taking place, this must be obtained from the air |
| Compare the thicknesses of the inner and outer cell walls of guard cells | Inner wall = thicker, outer wall = thinner |
| Describe the effect of high water availability on guard cell structure | The guard cell's vacuole expands, causing it to become turgid and opening the stoma |
| Identify two structural adaptations of leaves which help to inhibit water loss | Pits/grooves to trap air, 'rolling up' |
| State the name given to plants which inhabit very dry ecosystems  | Xerophytes |
| Identify two types of ecosystem with very little water availability | Desert & tundra |
| Explain why cacti and pines have developed needles, rather than broad leaves | Inhibits water loss |
| State the direction in which carbon dioxide moves through the stomata i) during the day ii) at night | i) CO2 moves into the leaf, ii) CO2 moves out of the leaf |

**Topic 3.4 – Enzymes & Digestion: Key Knowledge**

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| State the name given to the finger-like projections in the membrane of the epithelial cells | Microvilli |
| Describe the structure of the villi | Large projections in the surface of the ileum, itself |
| State the name given to the 'spaces' located between (i) microvilli, (ii) villi | (i) Invaginations, (ii) Crypts |
| Describe how microvilli act to increase the rate of absorption of digestive products | Provide a greater surface area for the insertion of transport proteins into the epithelial membrane |
| State four ways in which the villi are adapted for their function | High surface area, thin walls, dense network of capillaries, associated muscles to 'mix' the contents of the lumen |
| State and explain the number of protein carriers involved in co-transport of nutrient molecules | Three (one to actively transport the sodium out of the ileum, one to move the sodium + molecules back in, one to transport the molecules into the blood) |
| Describe the structure of a micelle | Tiny droplet (4-7 nm in diameter), comprising monoglycerides and fatty acids, associated with bile salts |
| Explain why the products of lipid digestion are able to diffuse simply through the plasma membrane | Monoglycerides & fatty acids are non-polar molecules |
| Describe what happens to monoglycerides & fatty acids, on entering the epithelial cells | Transported to the SER, where they're recombined to form triglycerides. These molecules then move to the Golgi apparatus, where they're combined with cholesterol & lipoproteins to form transport molecules called chylomicrons |
| Describe the route taken out of the epithelial cells by chylomicrons | Chylomicrons move into lymphatic capillaries, called lacteals, before passing into the blood |

**Topic 3.5 – Heart, Circulation & the Blood: Key Knowledge**

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| Name the two phases which comprise the cardiac cycle | Contraction (systole) & Relaxation (diastole). |
| Describe what happens during (i) diastole, (ii) systole | (i) Cardiac muscle relaxes, allowing the atria and ventricles to fill with blood, (ii) Cardiac muscle contracts, causing an increase in pressure which forces blood out of the heart |
| State the locations of the (i) tricuspid and (ii) bicuspid valves | (i) Between the right atrium & ventricle; (ii) Between the left atrium & ventricle |
| Describe when in the cardiac cycle the atrioventricular valves open | When atrial pressure is larger than ventricular pressure |
| Explain why the atrioventricular and semilunar valves remain closed during ventricular systole | Atrioventricular valves = prevents backflow from the ventricles to the atria ; semilunar valves = causes ventricular pressure to increase |
| Define cardiac output and state the equation used to calculate it | Cardiac output is the volume of blood pumped by one ventricle of the heart in one minute (dm3 min-1) ; Cardiac output = heart rate x stroke volume |
| State the function of (i) Arteries, (ii) Veins, (iii) Arterioles, (iv) Capillaries | (i) Carry blood away from the heart, (ii) Carry blood to the heart, (iii) Connect arteries to capillaries, (iv) Exchange respiratory gases/metabolic materials with the cells |
| Name the fluid which directly exchanges metabolic materials with the cells and state the two ways in which it is returned to the circulatory system | Tissue fluid ; returned directly into the capillaries, or travels through the lymphatic system |
| Name the process by which blood plasma & metabolic materials are forced out of the capillary and into the surrounding tissue | Ultrafiltration |
| Describe what is meant by two risk factors having an additive effect | When combined together, they produce a disproportionately greater risk. |
| Describe the structure of a haemoglobin molecule | Four separate polypeptide chains, each coordinated around its own Fe2+ (A.K.A. ferrous) ion. These prosthetic groups are referred to as ‘haem groups’. |
| Describe the process of (i) association, (ii) dissociation | (i) The binding of oxygen molecules to haem groups ; (ii) The unloading of oxygen molecules in respiring tissues |
| Describe and explain the rate of binding of oxygen molecules to haemoglobin | Binding of first molecule is slow, as haem groups are close together ; Binding of the second and third happens faster, due to changes in quaternary structure ; Binding of the fourth molecule is slow, due to the low probability that an oxygen molecule will come into contact with the final free site |
| State the name given to the idea that binding of the first oxygen molecule to haemoglobin speeds up binding of the second & third  | Positive cooperativity |
| Describe and explain the types of haemoglobin produced by (i) Organisms which are adapted to low-oxygen environments, (ii) Organisms with a high metabolic rate | (i) Haemoglobins with a high affinity for oxygen, allowing them to become fully saturated at low partial pressures ; (ii) Haemoglobins with a low affinity for oxygen, to allow for rapid unloading, to meet the respiratory needs of the cells |

**Topic 3.6 – Transport in Plants: Key Knowledge**

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| Define transpiration | The movement of water, by plants, from the roots to the leaves, for use during photosynthesis |
| Explain why the 'pull' of transpiration is passive, despite occurring against gravity | It uses hydrogen bonding between water molecules (cohesion) to pull ‘strings’ of water, under tension, as water evaporates through the stomata |
| Name the tissue through which transpiration takes place | Xylem |
| State and explain two adaptations of the xylem tissue | The cells are dead, preventing absorption of water into the xylem walls ; The cells have no end walls, creating an unbroken pathway |
| Explain why tree trunks tend to be narrowest at noon | Highest light intensity/temperature occurs at noon, increasing the rate of transpiration and generating a greater tension/negative pressure, which pulls the trunk inwards |
| Define translocation | The movement of organic substances (e.g. sugars) and dissolved ions between different regions of a plant |
| Name the tissue through which translocation takes place | Phloem |
| State and explain two adaptations of the phloem | The end walls of each phloem cell form perforated sieve plates, allowing substances to pass through easily ; Each sieve cell is coordinated to a companion cells, which controls the loading/unloading of organic molecules |
| State the direction in which substances are moved during translocation | From sources (sites of sugar production, such as the leaf) to sinks (tissues where these molecules are used/stored) |
| Name the primary hypothesis by which translocation is assumed to occur | The mass flow hypothesis |
| Explain why scientists have proposed a complex, multi-step process for how translocation works | Substances move too quickly to be accounted for by diffusion, alone |
| Explain how sucrose moves from the companion cells into the sieve cells | Sucrose is co-transported via the active movement of H+ ions into spaces within the cell wall |
| Explain why a high hydrostatic pressure is generated at the 'source end' of the phloem | A high sucrose concentration in the sieve cells causes their water potential to decrease. As a result, water moves from the xylem into the sieve cells |
| Explain why sucrose concentration inside the sink cells is low | It is used up or converted into insoluble starch |
| State and describe the two experiments which provide evidence for the xylem as the site of transpiration and the phloem, the site of translocation | (1) Ringing experiment - Ring of outer stem & phloem is removed from a plant. This leads to an accumulation of sucrose solution in the region above the ring ; (2) Tracer experiment - A radioactive isotope of carbon (14C) is used to track the movement of sugars through the plant |