

1a The circulatory system

Mass transport and water

Can you explain why many animals need a heart and circulation, in terms of mass transport overcoming the limitations of diffusion?



Can you explain the importance of water as a solvent in transport, including its dipole nature?



Blood vessels and the heart

Can you explain how the structures of capillaries, arteries and veins relate to their functions?



Can you describe the cardiac cycle (atrial systole, ventricular systole and diastole)?



Can you relate the structure and operation of the mammalian heart, including the major blood vessels, to its function?



Can you explain how the relationship between heart structure and function can be investigated practically?



1b Cardiovascular disease and risk

Atherosclerosis and blood clotting

Can you describe the sequence of events leading to atherosclerosis, including endothelial dysfunction, inflammation, plaque formation and raised blood pressure?



Can you describe the blood clotting process (including thromboplastin, prothrombin, thrombin, fibrinogen and fibrin) and explain its role in cardiovascular disease (CVD)?



Risk factors and evidence

Can you explain how genetics, diet, age, gender, high blood pressure, smoking and inactivity increase the risk of CVD?



Can you analyse and interpret data on illness and mortality to determine health risks, distinguishing between correlation and causation?



Can you recognise conflicting evidence in data about health risks?



Can you evaluate the design of studies used to identify health risk factors, including sample selection and sample size, in terms of validity and reliability?



Can you explain why people's perceptions of risk are often different from the actual risk, including for diet and other lifestyle factors in heart disease?



Energy balance

Can you analyse data on energy budgets and diet?



Can you explain the consequences of energy imbalance, including weight loss, weight gain and the development of obesity?

**Carbohydrates**

Can you describe the differences between monosaccharides, disaccharides and polysaccharides, including glycogen and starch (amylose and amylopectin)?



Can you relate the structures of monosaccharides, disaccharides and polysaccharides to their roles in providing and storing energy?



Can you describe how monosaccharides join by condensation reactions to form glycosidic bonds in disaccharides (sucrose, lactose, maltose) and polysaccharides (glycogen, amylose)?



Can you describe how glycosidic bonds are broken by hydrolysis reactions?

**Lipids and cholesterol**

Can you describe the synthesis of a triglyceride by the formation of ester bonds in condensation reactions between glycerol and three fatty acids?



Can you explain the differences between saturated and unsaturated lipids?



Can you analyse and interpret data on blood cholesterol levels, HDL and LDL levels and their significance for health?



Can you discuss the evidence for a causal relationship between blood cholesterol levels (total cholesterol and LDL) and CVD?

**Reducing risk and treatments**

Can you discuss how people use scientific knowledge about diet (including energy budgets), obesity indicators (BMI and waist-to-hip ratio), exercise and smoking to reduce their risk of coronary heart disease?



Can you discuss the possible ethical issues of using invertebrates in research?



Can you describe the benefits and risks of treatments for CVD, including antihypertensives, statins, anticoagulants and platelet inhibitors?



2a

Gas exchange and membranes

Gas exchange

Can you explain the properties of gas exchange surfaces in living organisms (large surface area to volume ratio, thin surface, steep concentration gradient)?



Can you explain how the rate of diffusion depends on these properties and use Fick's law of diffusion in calculations?



Can you explain how the structure of the mammalian lung is adapted for rapid gaseous exchange?



Cell membranes and transport

Can you describe the structure and properties of cell membranes?



Can you explain how models such as the fluid mosaic model of cell membranes are interpretations of data used to develop scientific explanations?



Can you explain osmosis as the movement of free water molecules from a lower to a higher solute concentration across a partially permeable membrane?



Can you explain passive transport (diffusion and facilitated diffusion), active transport (including ATP as an immediate energy source), endocytosis and exocytosis?



Can you explain the involvement of carrier and channel proteins in membrane transport?



2b

Nucleic acids and protein synthesis

DNA and RNA

Can you describe the basic structure of mononucleotides (deoxyribose or ribose, phosphate group, nitrogenous base)?



Can you describe how DNA and RNA are polynucleotides formed by condensation reactions?



Can you describe the structure of DNA, including complementary base pairing and hydrogen bonding between the two strands of the double helix?



Protein synthesis and the genetic code

Can you describe the process of protein synthesis (transcription and translation), including the roles of RNA polymerase, mRNA, tRNA, ribosomes and start and stop codons?



Can you explain the roles of the template (antisense) DNA strand in transcription, codons on mRNA and anticodons on tRNA?



Can you explain the nature of the genetic code (triplet, non-overlapping and degenerate)?



Can you explain that a gene is a sequence of bases on a DNA molecule that codes for a sequence of amino acids in a polypeptide chain?



DNA replication

Can you describe the process of semi-conservative DNA replication, including the role of DNA polymerase?



Can you explain how Meselson and Stahl's classic experiment provided new data that supported the accepted theory of replication and refuted competing theories?



2c

Proteins and enzymes

Protein structure

Can you describe the basic structure of an amino acid (amine group, carboxylic acid group and variable R group)?



Can you describe the formation of polypeptides and proteins by peptide bonds in condensation reactions?



Can you explain the significance of a protein's primary structure in determining its three-dimensional structure and properties, including the types of bond involved?



Can you compare globular and fibrous proteins and relate the structures of haemoglobin and collagen to their functions?



Enzymes

Can you explain the mechanism of enzyme action, including the active site, enzyme-substrate complex and specificity, in terms of three-dimensional structure?



Can you explain that enzymes are biological catalysts that reduce activation energy?



Can you describe the difference between intracellular and extracellular enzymes?



2d

Inheritance and cystic fibrosis

Mutation and inheritance

Can you explain how errors in DNA replication can give rise to mutations?



Can you explain how cystic fibrosis results from one of a number of possible gene mutations?



Can you define gene, allele, genotype, phenotype, recessive, dominant, incomplete dominance, homozygote and heterozygote?



Can you explain monohybrid inheritance, including interpreting genetic pedigree diagrams?



Can you explain how the expression of the cystic fibrosis mutation impacts on the functioning of the gas exchange, digestive and reproductive systems?



Genetic screening

Can you describe the uses of genetic screening, including identifying carriers, pre-implantation genetic diagnosis (PGD) and prenatal testing (amniocentesis and chorionic villus sampling)?



Can you discuss the implications of prenatal genetic screening?



Can you identify and discuss the social and ethical issues related to genetic screening from a range of ethical viewpoints?



3a

Cell structure

Eukaryotic and prokaryotic cells

Can you explain that all living organisms are made of cells that share some common features?



Can you describe the ultrastructure of an animal (eukaryotic) cell, including the nucleus, nucleolus, ribosomes, rough and smooth endoplasmic reticulum, mitochondria, centrioles, lysosomes and Golgi apparatus, and state their functions?



Can you explain the role of the rough endoplasmic reticulum and the Golgi apparatus in protein transport within cells, including their role in the formation of extracellular enzymes?



Can you describe the ultrastructure of a prokaryotic cell, including the cell wall, capsule, plasmid, flagellum, pili, ribosomes, mesosomes and circular DNA, and state their functions?



Can you recognise the organelles of eukaryotic cells in electron micrographs?



3b

Reproduction and inheritance

Gametes and fertilisation

Can you explain how mammalian gametes are specialised for their functions, including the acrosome in sperm and the zona pellucida in the egg?



Can you describe the process of fertilisation in mammals, including the acrosome reaction, the cortical reaction and the fusion of nuclei?



Linkage and meiosis

Can you explain that a locus is the location of a gene on a chromosome?



Can you explain the linkage of genes on a chromosome and sex linkage, including interpreting inheritance of sex-linked characteristics?



Can you explain how meiosis results in haploid gametes and produces genetic variation by independent assortment and crossing over?



3c

Cell division, stem cells and gene expression

Mitosis and the cell cycle

Can you describe the cell cycle and the stages of mitosis?



Can you explain the role of mitosis in producing genetically identical daughter cells for growth and asexual reproduction?



Stem cells and specialisation

Can you explain what is meant by the terms stem cell, pluripotency and totipotency?



Can you discuss the way society uses scientific knowledge to make decisions about the use of stem cells in medical therapies?



Can you explain how cells become specialised through differential gene expression, producing active mRNA that leads to synthesis of proteins that determine cell structure and function?



Can you explain the lac operon as an example of differential gene expression?



Can you explain how cells are organised into tissues, tissues into organs and organs into organ systems?



Genes and the environment

Can you explain how phenotype is the result of an interaction between genotype and the environment?



Can you explain how epigenetic modification, including DNA methylation and histone modification, can alter the activation of certain genes?



Can you explain how epigenetic modifications can be passed on following cell division?



Can you explain how some phenotypes are affected by multiple alleles for the same gene at many loci (polygenic inheritance), as well as by the environment, and how this gives rise to continuous variation and normal distribution?



4a

Biodiversity and evolution

Measuring biodiversity

Can you explain that over time the variety of life has become extensive but is now being threatened by human activity?



Can you define the terms biodiversity and endemism?



Can you describe how biodiversity can be measured within a habitat using species richness and within a species using genetic diversity, including calculating the heterozygosity index ($H = \text{number of heterozygotes} / \text{number of individuals}$)?



Can you compare the biodiversity of different habitats using the index of diversity $D = N(N - 1) / \sum n(n - 1)$?



Adaptation and natural selection

Can you explain the concept of niche and give examples of behavioural, physiological and anatomical adaptations?



Can you explain how natural selection can lead to adaptation and evolution?



Can you use the Hardy-Weinberg equation to calculate allele frequencies and to see if the frequency of alleles in a population changes over time?



Can you explain how reproductive isolation can lead to the formation of new species?



Classification

Can you explain how classification is built around the species concept, using similarities and differences in phenotypes and genotypes?



Can you explain how critical evaluation of new data by the scientific community leads to new taxonomic groupings, including the three domains (Bacteria, Archaea, Eukaryota) based on molecular phylogeny?



4b

Plant structure and minerals

Plant cells

Can you describe the ultrastructure of plant cells (cell wall, chloroplasts, amyloplasts, vacuole, tonoplast, plasmodesmata, pits and middle lamella) and state their functions?



Can you compare the structure of plant cells with animal cells?



Can you recognise the organelles of plant cells in electron micrographs?



Starch, cellulose and plant tissues

Can you compare the structures, positions in the cell and functions of starch and cellulose, including how hydrogen bonds between beta-glucose molecules form cellulose microfibrils?



Can you explain how the arrangement of cellulose microfibrils and secondary thickening in plant cell walls contributes to the physical properties of xylem vessels and sclerenchyma fibres?



Can you compare the structure, position in the stem and function of sclerenchyma fibres, xylem vessels and phloem sieve tubes?

**Water and mineral ions**

Can you explain the importance of water and inorganic ions (nitrate, calcium and magnesium) to plants?

**4c****Drugs, microorganisms and sustainability****Drug testing and bacterial growth**

Can you compare historic drug testing, such as William Withering's digitalis soup, with contemporary drug testing protocols, including double-blind trials, placebos and three-phase testing?



Can you describe the conditions required for bacterial growth?

**Sustainability and conservation**

Can you explain how the uses of plant fibres and starch may contribute to sustainability, including plant-based products replacing oil-based plastics?



Can you evaluate the methods used by zoos and seed banks in the conservation of endangered species and their genetic diversity, including scientific research, captive breeding, reintroduction programmes and education?



5a

Ecosystems

Ecosystems and distribution

Can you define the terms ecosystem, community, population and habitat?



Can you explain how the numbers and distribution of organisms in a habitat are controlled by biotic and abiotic factors?



Can you explain how the concept of niche accounts for the distribution and abundance of organisms in a habitat?



Can you describe the stages of succession from colonisation to a climax community?



5b

Photosynthesis and energy transfer

Photosynthesis

Can you describe the overall reaction of photosynthesis, in which energy from light splits water, hydrogen is combined with CO_2 and stored in glucose, and oxygen is released?



Can you explain that energy is required to phosphorylate ADP to ATP and that ATP hydrolysis provides an immediate supply of energy for biological processes?



Can you describe the light-dependent reactions, including the excitation of electrons in chlorophyll, the generation of ATP and reduced NADP, and the photolysis of water releasing oxygen?



Can you describe the light-independent reactions (Calvin cycle), including the roles of RuBP, RuBisCO, GP and GALP, and the use of ATP and reduced NADP?



Can you explain that the products of photosynthesis are used for respiration and to synthesise other biological molecules, including polysaccharides, amino acids, lipids and nucleic acids?



Can you relate the structure of the chloroplast to its role in photosynthesis?



Productivity and energy transfer

Can you calculate net primary productivity?



Can you explain the relationship between gross primary productivity, net primary productivity and plant respiration ($\text{NPP} = \text{GPP} - \text{R}$)?



Can you calculate the efficiency of biomass and energy transfers between trophic levels?



Evidence and causes

Can you discuss the evidence for climate change and its causes, including records of CO₂ levels, temperature records, pollen in peat bogs and dendrochronology, recognising correlations and causal relationships?



Can you explain the causes of anthropogenic climate change, including the role of greenhouse gases (CO₂ and methane) in the greenhouse effect?



Can you explain how data can be extrapolated to make predictions about future climate change?



Can you explain the limitations of the models used to predict climate change?

**Effects on organisms**

Can you explain the effects of climate change (changing rainfall patterns and seasonal cycles) on plants and animals, including distribution of species, development and life cycles?



Can you explain the effect of temperature on the rate of enzyme activity and its impact on plants, animals and microorganisms, including calculating the temperature coefficient Q₁₀?

**Evolution and speciation**

Can you explain how evolution, as a change in allele frequency, can come about through gene mutation and natural selection?



Can you explain the role of the scientific community (scientific journals, peer review and conferences) in validating new evidence supporting the theory of evolution, including molecular evidence from proteomics and genomics?



Can you explain how isolation reduces gene flow between populations, leading to allopatric or sympatric speciation?

**Controversy and managing carbon**

Can you discuss how conclusions about controversial issues such as climate change may depend on who is reaching them?



Can you explain how knowledge of the carbon cycle can be applied to methods of reducing atmospheric levels of CO₂?



Can you discuss how reforestation and the use of sustainable resources, including biofuels, can help manage the conflict between human needs and conservation?



Time of death and decomposition

Can you explain how to determine the time of death of a mammal by examining the extent of decomposition, stage of succession, forensic entomology, body temperature and degree of muscle contraction (rigor mortis)?



Can you explain the role of microorganisms in the decomposition of organic matter and the recycling of carbon?

**DNA profiling and PCR**

Can you describe how DNA profiling is used to identify individuals and determine genetic relationships between organisms (plants and animals)?



Can you describe how DNA can be amplified using the polymerase chain reaction (PCR)?

**Bacteria and viruses**

Can you compare the structure of bacteria and viruses (including DNA and RNA viruses)?



Can you explain how *Mycobacterium tuberculosis* (TB) and the human immunodeficiency virus (HIV) infect human cells, causing a sequence of symptoms that may result in death?

**Immune responses**

Can you describe the non-specific responses of the body to infection, including inflammation, lysozyme action, interferon and phagocytosis?



Can you explain the roles of antigens and antibodies, plasma cells, macrophages and antigen-presenting cells in the body's response to infection?



Can you distinguish between the roles of B cells (memory and effector B cells) and T cells (T helper, T killer and T memory cells) in the immune response?



Can you explain how one gene can give rise to more than one protein through post-transcriptional changes to mRNA (splicing)?



Barriers and immunity

Can you describe the major routes pathogens may take when entering the body?



Can you explain the role of barriers in protecting the body from infection, including skin, stomach acid, and gut and skin flora?



Can you explain how individuals may develop immunity (natural, artificial, active and passive)?



Can you discuss how the theory of an evolutionary race between pathogens and their hosts is supported by the evasion mechanisms shown by pathogens?

**Antibiotics and hospital infections**

Can you explain the difference between bacteriostatic and bactericidal antibiotics?



Can you explain how an understanding of the contributory causes of hospital-acquired infections has led to codes of practice relating to antibiotic prescription and hospital practice?



Skeletal muscle

Can you explain the way in which muscles, tendons, the skeleton and ligaments interact to enable movement, including antagonistic muscle pairs, extensors and flexors?



Can you describe the sliding filament theory of muscle contraction, including the roles of actin, myosin, troponin, tropomyosin, calcium ions (Ca^{2+}), ATP and ATPase?

**Overview of respiration**

Can you describe the overall reaction of aerobic respiration, splitting the respiratory substrate to release CO_2 and combining hydrogen with oxygen, releasing a large amount of energy?



Can you explain that respiration is a many-stepped process with each step controlled and catalysed by a specific intracellular enzyme?

**Stages of respiration**

Can you describe the roles of glycolysis in aerobic and anaerobic respiration, including the phosphorylation of hexoses, the production of ATP, reduced coenzyme and pyruvate, and the production of lactate?



Can you describe the link reaction and Krebs cycle, including the complete oxidation of glucose to CO_2 with production of ATP, reduced NAD and reduced FAD?



Can you explain why the link reaction and Krebs cycle take place in the mitochondria while glycolysis takes place in the cytoplasm?



Can you describe the synthesis of ATP by oxidative phosphorylation associated with the electron transport chain in mitochondria, including the role of chemiosmosis and ATP synthase?



Can you describe the fate of lactate after a period of anaerobic respiration in animals?

**Control of the heartbeat**

Can you explain that cardiac muscle is myogenic?



Can you describe the normal electrical activity of the heart, including the roles of the sinoatrial node (SAN), atrioventricular node (AVN), bundle of His and Purkyne fibres?



Can you explain how an ECG can be used to help diagnose CVD and other heart conditions?



Cardiac output and ventilation

Can you calculate cardiac output (cardiac output = stroke volume x heart rate)?



Can you explain how variations in ventilation and cardiac output enable rapid delivery of oxygen to tissues and removal of CO₂ from them?



Can you explain how heart rate and ventilation rate are controlled, including the roles of the cardiovascular control centre and the ventilation centre in the medulla oblongata?

**Muscle fibres**

Can you describe the structure of a muscle fibre, including sarcomeres, myofibrils and the sarcoplasmic reticulum?



Can you explain the structural and physiological differences between fast and slow twitch muscle fibres?

**7c Homeostasis and exercise****Feedback and homeostasis**

Can you explain the concept of negative feedback and positive feedback control?



Can you explain the role of negative feedback in maintaining systems within narrow limits?



Can you discuss the concept of homeostasis and its importance in maintaining the body in a state of dynamic equilibrium during exercise, including the role of the hypothalamus and the mechanisms of thermoregulation?

**Exercise, health and sport**

Can you analyse and interpret data on the possible disadvantages of exercising too much (wear and tear on joints, suppression of the immune system) and too little (obesity, CVD, diabetes), recognising correlation and causal relationships?



Can you explain how medical technology, including keyhole surgery and prostheses, is enabling those with injuries and disabilities to participate in sports?



Can you discuss different ethical positions relating to whether the use of performance-enhancing substances by athletes is acceptable?



Can you explain how genes can be switched on and off by DNA transcription factors, including hormones (such as steroid hormones binding to receptors in the cell)?



Neurones and reflexes

Can you describe the structure and function of sensory, relay and motor neurones, including the role of Schwann cells and myelination?



Can you explain how the nervous systems of organisms can cause effectors to respond to stimuli?



Can you explain how the pupil dilates and contracts in response to light intensity?

**Nerve impulses and synapses**

Can you explain how a nerve impulse (action potential) is conducted along an axon, including changes in membrane permeability to Na⁺ and K⁺?



Can you explain the role of myelination in saltatory conduction?



Can you describe the structure and function of synapses, including the role of neurotransmitters such as acetylcholine?



Can you explain how stimuli are detected by rod cells in the mammalian retina, including the roles of rhodopsin, opsin, retinal, sodium ions, cation channels and hyperpolarisation in forming action potentials in the optic neurones?

**Coordination in plants and animals**

Can you explain how phytochrome and IAA bring about responses in plants to environmental cues, including their effects on transcription?



Can you compare mechanisms of coordination by nervous and hormonal control in animals?

**Brain structure and imaging**

Can you locate and state the functions of the cerebral hemispheres, hypothalamus, cerebellum and medulla oblongata in the human brain?



Can you describe the use of MRI, fMRI, PET and CT scans in medical diagnosis and in investigating brain structure and function?

**Visual development and animal models**

Can you explain what happens during the critical period for the full development of visual capacity in mammals?



Can you discuss the role of animal models in research into brain function, including Hubel and Wiesel's experiments with monkeys and kittens?



Can you discuss the moral and ethical issues relating to the use of animals in medical research from two ethical standpoints?



Learning and nature versus nurture

Can you explain how animals, including humans, can learn by habituation?



Can you describe the methods used to investigate the contributions of nature and nurture to brain development, including newborn studies, animal experiments, studies of individuals with damaged brain areas, twin studies and cross-cultural studies?



8c

Brain chemicals, drugs and genetic technology

Brain chemicals and drugs

Can you explain how imbalances in naturally occurring brain chemicals can contribute to ill health, including dopamine in Parkinson's disease and serotonin in depression?



Can you explain how knowledge of brain chemical imbalances contributes to the development of new drugs?



Can you explain the effects of drugs on synaptic transmission, including L-Dopa in the treatment of Parkinson's disease and the action of MDMA (ecstasy)?



Genomics and genetic modification

Can you explain how the human genome sequence can be used to develop personalised medicine?



Can you discuss the social, moral and ethical issues related to the use of genome sequencing in personalised medicine?



Can you describe how drugs can be produced using genetically modified organisms (plants, animals and microorganisms)?



Can you discuss the risks and benefits associated with the use of genetically modified organisms?



Core practical activities

1 Can you investigate the effect of caffeine on heart rate in <i>Daphnia</i> ?	☐ ☐ ☐
2 Can you investigate the vitamin C content of food and drink?	☐ ☐ ☐
3 Can you investigate membrane structure, including the effect of alcohol concentration or temperature on membrane permeability?	☐ ☐ ☐
4 Can you investigate the effect of enzyme and substrate concentrations on the initial rates of reactions?	☐ ☐ ☐
5 Can you prepare and stain a root tip squash to observe the stages of mitosis?	☐ ☐ ☐
6 Can you use a light microscope to identify sclerenchyma fibres, phloem sieve tubes and xylem vessels and their location within stems?	☐ ☐ ☐
7 Can you investigate plant mineral deficiencies?	☐ ☐ ☐
8 Can you determine the tensile strength of plant fibres?	☐ ☐ ☐
9 Can you investigate the antimicrobial properties of plants, including aseptic techniques for the safe handling of bacteria?	☐ ☐ ☐
10 Can you carry out a study on the ecology of a habitat, such as using quadrats and transects to determine distribution and abundance of organisms, and measuring abiotic factors appropriate to the habitat?	☐ ☐ ☐
11 Can you investigate photosynthesis using isolated chloroplasts (the Hill reaction)?	☐ ☐ ☐
12 Can you investigate the effect of temperature on the initial rate of an enzyme-catalysed reaction, including calculation of the temperature coefficient (Q_{10})?	☐ ☐ ☐
13 Can you investigate the effects of temperature on the development of organisms, such as seedling growth rate or brine shrimp hatch rates?	☐ ☐ ☐
14 Can you use gel electrophoresis to separate DNA fragments of different length?	☐ ☐ ☐
15 Can you investigate the effect of different antibiotics on bacteria?	☐ ☐ ☐
16 Can you investigate the rate of respiration?	☐ ☐ ☐
17 Can you investigate the effects of exercise on tidal volume, breathing rate, respiratory minute ventilation and oxygen consumption using data from spirometer traces?	☐ ☐ ☐
18 Can you investigate habituation to a stimulus?	☐ ☐ ☐