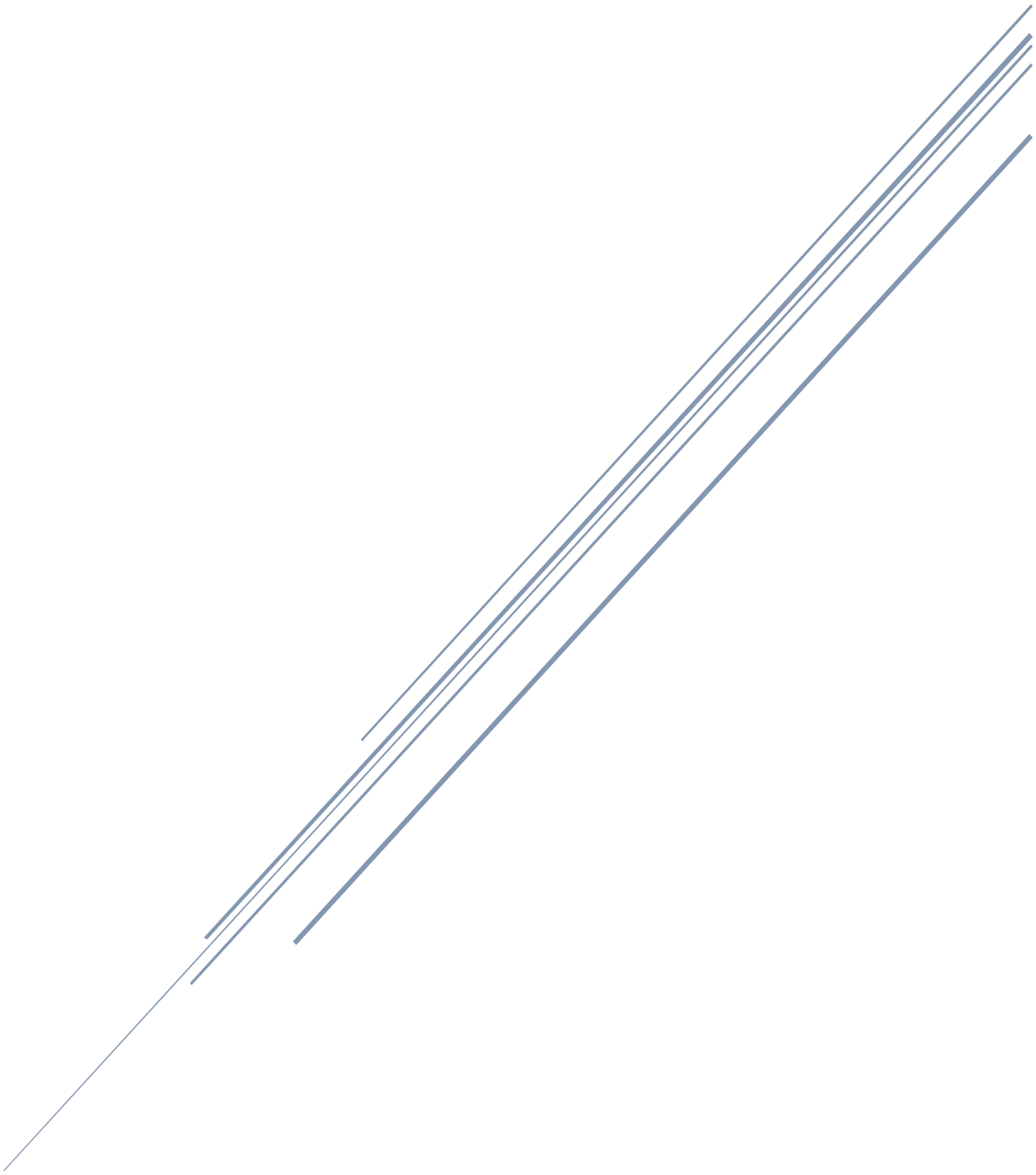
SJBO 2020

revision notes



structure and function of biological molecules

molecular formula: disaccharides $C_n(H_2O)_m$, monosaccharides $C_6H_{12}O_6$; contains carbonyl group [$C=O$] on C_6 and two or more hydroxyl groups [$-OH$] [$H-OH$ in α – glucose, $OH-H$ in β – glucose on anomeric C_1]. [*aldose* [aldehyde] [ribose, glucose], *ketose* [ketone] [fructose; 2 carbon sidechains] sugar]
monosaccharides are ready, easily accessible sources of energy for living cells; carbon skeleton used as raw material for synthesis of other organic molecules; monomers to build up into disaccharides and polysaccharides [maltose: glucose + glucose; sucrose: glucose + fructose; lactose: glucose + galactose] via dehydration.
storage polysaccharide: *starch* [*amylose* as long-term storage in stems/roots, as unbranched helix; *amylopectin* in seeds, branched], *glycogen*: horizontal chain from $\alpha-1,4-$ glycosidic bond; vertical chain $\alpha-1,6-$ glycosidic bond, helix shape due to intramolecular HB between hydroxyl groups of glucose residue within the same chain;
structural polysaccharide: cellulose, chitin [linear unbranched, not easily hydrolysed, bundling of cellulose for tensile strength]: alternating $\beta-1,4-$ glycosidic bond [β – linkage] does not form helix, intramolecular and intermolecular HB between hydroxyl groups of glucose residue of adjacent chains form cross linkage.

triglyceride [triacylglycerol] is a simple lipid [*ester* derived from glycerol and 3 fatty acids], that serves as a long – term, highly concentrated energy store, provide thermal insulation to maintain body temperature, and act as shock-absorbing cushion around vital organs to protect organs from traumatic injury.
phospholipid is a complex lipid [ester derived from glycerol, 2 fatty acids, and phosphate group [with small polar group choline]] that form phospholipid bilayer in cell membranes; engages in lateral movement and flip-flop, such that *membrane proteins can be inserted*, and *protein channels can change shape* [open and close].
steroids are four fused rings with chemical groups attached; cholesterol act as buffer, maintain stable fluidity [low fluidity, creates space, prevents contraction and freezing; high fluidity, takes up space, hold bilayer in place, decrease fluidity] of membrane; hormones travel throughout body as signalling molecules.

proteins are highly modified polymers [polypeptide chain] of monomers [amino acids]; includes *enzymes* [catalyze chemical reactions], *defensive proteins* [protect against disease], *storage proteins* [store amino acids], *transport proteins*, *hormones* [coordinate organismal responses], *receptor proteins* [receive signals from outside cell], *motor proteins* [function in cell movement], *structural proteins* [provide structural support].
primary structure: precise sequence of amino acids held by peptide bonds, N -Terminus NH_3^+, C-Terminus COO^-.
secondary structure: polypeptide chains coiled and folded into *alpha helices* and *beta pleated sheets* [parallel/ anti – parallel] via HB at polypeptide backbone [every 4th amino acid, every $C=O \mid N-H$].
tertiary structure: held together by hydrophobic interactions between non-polar R-groups [CH, CH_2, CH_3]; hydrogen bonds between polar uncharged R-groups [$OH, S=O, NH_2$]; ionic bonds between polar acidic R-groups [COO^-] and polar basic R-groups [NH^+, NH_2^+, NH_3^+]; disulfide bonds between sulphydryl groups [cysteine].
quaternary structure: interactions between protein subunits to form larger aggregate protein complex, results in 3D native configuration, enable amino acid residues at different position in polypeptide to form receptor site.
collagen: long fibrous protein of 3 α – chains arranged in a triple helix found in extracellular matrix in connective tissues to provide support to the surrounding cells and tissues; high tensile strength due to covalent bonds or crosslinks from $R-$ group interactions of lysine that point outwards of triple helix which holds molecule together and form bundles of collagen fibril/fiber; small R-group of glycine allows 3 chains to be compacted together; HB between chains [glycine/proline residues] enables 3 chains to be stabilized/held together.
haemoglobin: a globular protein of 4 subgroups of tertiary structures [2 α, β – chains] [and a heme group [Fe^{2+} ion that an O_2 molecule can bind to]; cooperative binding by oxygen concentration [facilitated diffusion].

deoxyribonucleic acid exists as a double helix of phosphate backbone and nitrogenous bases; length of DNA which wind around a histone octamer core forms nucleosome; chromatosome is nucleosome cores held together by double-stranded linker DNA with histone H1; nucleosomes coil to form solenoid 30 nm in diameter [chromatin fiber], condensed chromosome form from loops attached to a protein scaffold [looped domains];
nucleoside: [pentose] sugar and base; ***nucleotide***: phosphate group attached to sugar of nucleoside;
sugar-phosphate backbone forms from phosphodiester bonds linking adjacent nucleotides, nucleic acid sequences forms from addition of nucleotide at 3' carbon, condensation reaction at $-OH$ group on C_3.
complementary base pairing ensures specificity of DNA replication [ensures integrity of base sequence];
antiparallel DNA strands ensures that phosphate group [C_5] engage in hydrophilic interactions with external aqueous environment, hydrophobic base [C_1] face inwards for internal non-polar environment;
double helix [of two nucleic acid chains] facilitate replication process; hydrophobic interactions between stacked bases stabilizes the double helix of DNA.

transmembrane, peripheral, integral proteins; selective transport [hydrophilic channel protein, hydrophilic molecules], enzyme, cell surface receptor [ligand, receptor site, shift in shape to release product], cell surface identity marker, cell adhesion, attachment to cytoskeleton/ECM [maintain shape of cell].
cholesterol reduces membrane fluidity by *reducing phospholipids movement*; hinders solidification by *disrupting regular packing* of phospholipids [glycoprotein, glycolipid, oligosaccharide chain].

exocytosis; constitutive secretion [receptors], regulated secretion [Ca^{2+} triggered; signal].
endocytosis; phagocytosis [solid in pseudopodium, form phagosome, food vacuole], pinocytosis [vesicle containing fluid], receptor-mediated endocytosis [coated vesicle, coat protein with target ions; receptors].

G-protein-coupled receptors contain 7 transmembrane regions, N-terminus on exoplasmic face and C-terminus on cytosolic face – ligand specific and differ in extracellular surface; transmit signal to heterotrimeric G-protein;

glucose mobilization; binding of epinephrine, glucagon to receptors changes conformation of **G *protein***, causing exchange of GDP for GTP in the subunit, switching it to the activated state; with bound GTP G dissociates from the G complex and binds to its effector molecule, activating the effector enzyme adenyl cyclase *[*GTP *is hydrolysed [accelerated by interaction with* GAP *protein],* G *subunit rebinds to* G*, returning complex to inactivated state; deactivation by phosphorylation and binding of arrestin]*; cAMP is synthesized by adenylyl cyclase [integral membrane protein] using ATP as a substrate *[second messenger; non-specific, generates a variety of responses]*; 2 cAMP bind to regulatory subunit of protein kinase A causing release of catalytic subunit PKA, which phosphorylate, inhibit glycogen synthase, and activate phosphorylase kinase, which phosphorylates and activates phosphorylase [catalyse glycogen breakdown; glycogen synthase catalyses polymerization]; translocate to nucleus to phosphorylate transcription factor CREB; phosphorylated CREB binds to the CRE enhancer, activating genes involved in gluconeogenesis [production of glucose by non-carbohydrate sources].

termination: adenylyl cyclase inactivated [G dissociates], cAMP levels drop [continually degraded]; inactivates PKA and hence inhibitor-1, leading to activation of phosphatase-1 [removes phosphates groups from enzymes].

lipid-derived second messengers; phosphatidylinositol is phosphorylated to PIP and PIP2 by kinases [activated by GPCR, receptor tyrosine kinases]; PIP2 [cell membrane phospholipid] cleaved by phospholipase C [hydrolytic enzyme that split phospholipids, activated by GPCRs, RTKs], producing lipophilic DAG, and soluble IP3; IP3 binds to and opens IP3-gated Ca^{2+} channel in ER membrane, transiently let Ca^{2+} into cytosol; binding of Ca^{2+} to PKC recruits it to the membrane; phosphorylation at serine/threonine, tyrosine residues [kinase activity stimulated by interaction with DAG, opposed by phosphatases that remove phosphate groups]; calmodulin binds 4 Ca^{2+} ions, results in a large conformational change that increases affinity for effector proteins.

Receptor Tyrosine Kinase is a tetramer of two extracellular subunits and two transmembrane subunits with a single transmembrane region; one signalling molecule binds to each of sub-unit, resulting in dimerization of receptor subunits [induced dimerization [conformational change]], activating intracellular kinase domains [cytoplasmic kinase domain], leading to autophosphorylation [or cross phosphorylation] of tyrosine residues [cytosolic domains]; phosphorylated phosphotyrosine motifs have high affinity for SH_2 domains; interaction of phosphotyrosine motifs with SH_2 proteins cause conformational change to bind to other proteins or translocated to other parts of the cell [amplification and activation of transcription factors that cause specific genes for cell division to be transcribed]. *[*RTKs*: transfer of glucose transporter to plasma membrane; increase in protein synthesis; stimulation of glycogen synthases; activation of phosphatase-1]*.

relationships of signalling pathways; converging SP [G protein-coupled receptors, RTKs and integrins relay signals that result in the recruitment to the membrane of the adaptor protein Grb2, activation of Ras and MAP kinase cascade]; crosstalk between SP; hormone responses in glucose metabolism [liver and muscle cells].

cellular respiration, and fermentation

glycolysis: [energy investment phase] ***hexokinase*** transfer phosphate group from ATP to *glucose*, increase reactivity [charge on phosphate also traps sugar in cell]; ***phosphoglucoisomerase*** convert *glucose-6-phosphate* to *fructose-6-phosphate*; ***phosphofructokinase*** transfers phosphate group from ATP to opposite end of sugar [key step for regulation of glycolysis]; ***aldolase*** cleaves *fructose-1,6-biphosphate* into *glyceraldehyde-3-phosphate*, *dihydroxyacetone phosphate*; ***isomerase*** catalyse conversion between G3P and DHAP [3C isomers]; [energy payoff phase, *reactions occur in pairs*] G3P oxidised by NAD^+ [$H-C-OH + NAD^+ \rightarrow C=O + NADH + H^+$], energy released attach phosphate group, form high-energy *1,3-bisphosphoglycerate*; ***phosphoglycerokinase*** transfer P group to ADP [substrate-level phosphorylation] in exergonic redox reaction, carbonyl group [$C=O$] of G3P oxidised to carboxyl group [$-COO^-$] of organic acid *3-phosphoglycerate*; ***phosphoglyceromutase*** relocate remaining phosphate group, form *2-phosphoglycerate*; ***enolase*** extract H_2O to form double bond in substrate, yielding very high PE compound *phosphoenolpyruvate*; ***pyruvate kinase*** transfer phosphate group from PEP to ADP [SLP], forming *pyruvate*. [$C_6H_6O_6 + 2\ NAD^+ + 4e^- + 4\ H^+ \rightarrow 2\ CH_3COCOO^- + 2\ H_2O + 2\ ATP + 2\ NADH + 2\ H^+$]

pyruvate oxidation [transported into mitochondrion via active transport; reactions catalysed by ***pyruvate dehydrogenase complex***]: carboxyl group of pyruvate [partially oxidised, little chemical energy] fully oxidised, released as CO_2; remaining 2C fragment oxidised by NAD^+ [form NADH]; coenzyme A [derived from B vitamin] attached via sulfur to two-carbon intermediate, form acetyl CoA [high PE, to transfer acetyl group].

citric acid cycle [tricarboxylic acid cycle, Krebs cycle]: acetyl CoA transfers 2C acetyl group to oxaloacetate, producing *citrate* [enzyme ***citrate synthase*** from mitochondrial matrix]; ***aconitase*** convert citrate to isomer *isocitrate* by removal and addition of H_2O; isocitrate oxidized by NAD^+, resulting compound released CO_2 to form *α – ketoglutarate* by ***isocitrate dehydrogenase***; ***α – ketoglutarate dehydrogenase*** catalyse release of CO_2, oxidation by NAD^+, $CoA-SH$ attached via unstable bond to form *succinyl CoA*; CoA displaced by phosphate group, which is transferred to GDP forming GTP, by ***succinyl-CoA synthetase***; ***succinic dehydrogenase*** [inner mitochondrial membrane] catalyse oxidation of *succinate* to *fumarate* by transferring 2 H to FAD [form $FADH_2$]; addition of H_2O rearranges bonds in substrate to form *malate* with ***fumarase***; ***malate dehydrogenase*** oxidise substrate, reducing NAD^+ to NADH and regenerating *oxaloacetate*; 2 net GDP [ATP], 6 NADH, 2 $FADH_2$.

oxidative phosphorylation: [electron transport] e^- carriers accept, donate e^- between neighbours with lower, higher electron affinity, alternate between reduced, oxidized states; NADH, flavoprotein [complex I; prosthetic group: flavin mononucleotide], $Fe \cdot S$ protein, *ubiquinone* [Q, CoQ; small hydrophobic molecule, mobile within membrane, not residing in particular complex] [$FADH_2$ transfer e^- to $Fe \cdot S$ [then ubiquinone] within complex II at lower energy level than NADH; provide $^1/_3$ less energy for ATP synthesis]; cytochromes [heme prosthetic group], mobile carrier Cyt c ferry e^- between complex III and complex IV, final cytochrome [Cyt a_3] transfer e^- to O_2, reacts with H^+ from the aqueous solution, forming H_2O; as complexes shuttle e^-, they pump proton from mitochondrial matrix into intermembrane space; [chemiosmosis] H^+ flow down gradient across membrane via ATP synthase, harnesses proton-motive force [from chemical energy] to phosphorylate ADP, forming ATP.

direct phosphorylation: ***arginine***, ***glycine*** form **GAA** [enzyme AGAT] in liver; GAA, $\mathbf{CH_3}$ [from methionine] form ***creatine*** [GAMT]; in muscles, *creatine kinase* convert ***creatine phosphate*** to ***creatine***, produce ATP [excess CP broken down to creatinine in kidney];

anaerobic fermentation [substrate-level phosph.]: *[lactic acid]* NAD^+ regenerated for ***glycolysis*** as pyruvate serves as e^- acceptor for oxidizing NADH, forming lactate; *[alcohol]* pyruvate release CO_2 to form acetaldehyde.

photosynthesis

chloroplasts have an inner and outer membrane, with stroma [intermembrane space] that contains ribosomes, chloroplast DNA, starch granules and thylakoid [membranous flattened discs enclosed by thylakoid membrane, arranged in grana [stacks] connected by lamellae].

light reactions [photosystems; linear e^- flow]: a *photon of light* strikes a pigment molecules in light-harvesting complex of PS II, boosting an e^- to a higher energy level, as the e^- falls back to ground state, an e^- the next pigment molecule is simultaneously raised to an excited state, such that energy is relayed till the P680 pair of chlorophyll a molecule in the reaction-centre complex, and excites an e^- in this pair of chlorophylls to a higher energy state, ***e^- is transferred*** from the excited P680 to the primary electron acceptor [resulting form $P680^+$];

enzyme catalyses *splitting of a water molecule*, e^- supplied to $P680^+$ pair to replace e^- transferred to primary electron acceptor, ***H^+ released into thylakoid space***, 2 O atoms combine to form O_2; each photoexcited e^- pass from primary electron acceptor to PS I via *electron transport chain* [*electron carrier* plastoquinone Pq, *[4 protons translocated across membrane to thylakoid space]* cytochrome complex, *protein* plastocyanin Pc], redox reaction release free energy to pump H^+ into thylakoid space, create ***proton gradient across thylakoid membrane***;

potential energy used to make ATP [via chemiosmosis; diffusion of H^+], *light energy* transferred to PS I reaction centre complex [via light-harvesting complex pigments], exciting e^- of the P700 pair of chlorophyll a molecules, ***e^- transferred*** to PS I primary electron acceptor, $P700^+$ act acceptor for e^- that reach bottom of ETC from PS II;

cyclic electron flow: photoexcited e^- are passed in series of redox reactions from primary electron acceptor of PS I down a second ETC through protein ferredoxin Fd [chain does not create proton gradient, or produce ATP] [e^- occasionally shunted back from Fd to chlorophyll via cytochrome complex and Pc; supply ATP but not NADPH]; *enzyme* $NADP^+$ reductase catalyses ***transfer of $2e^-$ from Fd to $NADP^+$*** [removes H^+ from stroma; e^- in NADPH at a higher energy level than in H_2O, more available for Calvin cycle [as reducing power]].

Calvin cycle: ***carbon fixation***: incorporation of CO_2 into [5C] *ribulose bisphosphate* [*R*uBP] by RuBP *carboxylase-oxygenase* [rubisco], resulting 6C intermediate immediately forms two molecules of *3-phosphoglycerate*; ***reduction***: each molecule receives additional phosphate group from ATP to form *1,3-bisphosphoglycerate*, e^- from NADPH reduce a carboyxl group on *1,3-bisphosphoglycerate* to the aldehyde group of *glyceraldehyde 3-phosphate* [G3P] [stores more potential energy; loses phosphate group in the process]; regeneration of *R*uBP: 3 ATP used to rearrange carbon skeletons of 5 G3P [net gain of 1G3P for 3 CO_2; cycle takes place thrice].

photorespiration [stomata close, low CO_2 level]: rubisco adds O_2 to Calvin cycle in place of CO_2; peroxisomes and mitochondria split 2C compound formed into CO_2; ***C_4 photosynthesis***: [mesophyll cells] ***PEP carboxylase*** [much higher affinity for CO_2, no affinity for O_2] adds CO_2 to *phosphoenolpyruvate* [PEP], forming 4C *oxaloacetate*; [bundle-sheath cells] 4C compounds release CO_2, which is re-fixed into organic material by rubisco in Calvin cycle; regenerates pyruvate, which is transported to mesophyll cells, where ATP convert pyruvate to PEP [extra ATP generated from cyclic electron flow [no PS II]]; ***crassulacean acid metabolism*** [CAM]: CO_2 taken up at night incorporated into variety of organic acids [stored in mesophyll cells], Calvin cycle occurs in day [stomata closed].

mitosis and cell cycle

chromatids are the replicated form of same chromosome joined at centromere; **chromosomes** refer to the pair of sister chromatids in replicated chromosome or un-replicated DNA molecule; **microtubules** [form cytoskeleton in cytoplasm] are tubular polymers of tubulin [amino acid]; linear, single-stranded polypeptide chain; **centrioles** are cylindrical structures, consist of nine triplets of microtubule.

interphase [non-diving stage]:
G1 [Gap 1] phase: absorption of nutrients; duplication of protoplasm;
S [Synthesis] phase: duplication of chromosomes; replication of DNA;
G2 [Gap 2] phase: check duplicated chromosomes for error, making any needed repairs.

mitosis [nuclear division]:
prophase: chromatin fibers condense into compact discrete chromosomes [double structure]; centrosomes [centriole pairs] duplicate and migrate towards opposite poles in the cell; duplicated centrosomes assemble and organize microtubules to form mitotic spindle, where microtubules extend outwards from Mitotic Organizing Center [centrosome]; nucleolus gradually disappears; nuclear envelope disintegrates.
metaphase: microtubules from each pole attach to chromosomes at paired kinetochores; chromosomes align singly along, and centromeres lie at metaphase plate; polar microtubules from opposite pole overlap at plate.
anaphase: centromeres divide, allowing sister chromatids to split and separate as kinetochore microtubules shorten, pulling the daughter chromosomes towards opposite poles; polar microtubules from opposite poles elongate, overlap, and slide past one another, opposite poles are pushed further apart, and cell elongates.
telophase: identical, diploid set of daughter chromosome reach opposite pole of cell; daughter chromosome uncoils and decondense to form chromatin fibers; spindle fibers/microtubules disassemble; nucleolus reforms; nuclear envelope reform around chromosomes to form daughter nuclei.

cytokinesis [division of cytoplasm]:
division of cytoplasm of parent cell to form two genetically identical daughter cells, with equal distribution of organelles, cytoplasm, and chromosomes; **animal cell**: formation of cleavage furrow in cell surface by contractile ring of actin and myosin proteins pinches parent cell into two completely separated daughter cells;
plant cell: Golgi vesicle coalesce to form cell plate [form new cell wall and surface membrane] which enlarges and extends across parent cell to completely separate two daughter cells.

regulation: synthesis, accumulation of ***cyclin*** in S, G2 phase; combination with ***cyclin-dependent kinase*** [Cdk] produce ***maturation promoting factor*** [MPF]; sufficient accumulation allow cell to pass G2 checkpoint, begin mitosis; [M checkpoint] stop signal if any chromosome not attached to spindle fiber; MPF cause phosphorylation of protein of nuclear lamina, promote fragmentation of nuclear envelope [peak activity during metaphase]; in anaphase, cyclin degraded, terminating M phase, cell enters G1 phase, Cdk component recycled; [G1 checkpoint] cell enters G_o [non-dividing] phase without signal [chemical factor: *growth factor* [protein], physical factors: *density-dependent inhibition*, *anchorage dependence*]; cells with ability to divide infinitely [undergone transformation]: ***benign*** [single location], ***malignant*** [spread to other locations; ***metastasis***] tumor.

meiosis and sexual life cycles

significance of meiosis; form of nuclear division where ploidy/chromosome number is halved from $2n$ to n [reduction division], involving 1 round of DNA replication in parent cell, followed by 2 cycles of nuclear and cell divisions; formation of haploid gametes [from diploid spermatogonium/oogonium] to enable restoration of diploid condition upon fusion of gametes during fertilization; meiosis ensures that the chromosome number characteristic of the species is maintained after fertilization.

mitosis vs meiosis; during mitosis, two diploid daughter cells are produced per cycle, while four haploid daughter cells called gametes are produced per meiotic cycle; mitosis does not introduce genetic variability, while meiosis introduces genetic variability among gametes via genetic exchange between homologous chromosomes in Prophase I; dividing cells can be haploid or diploid in mitosis while dividing cells are diploid in meiosis; homologous chromosomes have the same number of genes [code for same characteristics] and the same loci [same position of genes on chromosome] but have different alleles [for each gene] and have different sequences of bases [especially non-coding DNA].

prophase **I**: chromatin begins to condense into chromosomes; homologous chromosomes pair up against their lengths, aligned gene by gene precisely, crossing over occurs; centrosomes move to poles; mitotic spindle starts to develop; nucleolus disappear, nuclear membrane break down; microtubule from poles attach to kinetochore at each centromere of each homolog, causing homologous pair [tetrad] to move towards the metaphase plate.
metaphase **I**: pair of homologous chromosomes [bivalents] arranged on metaphase plate; kinetochore microtubules attach to both sister chromatids of one of homologous chromosomes.
anaphase **I**: bivalents separate and move towards the poles, guided by kinetochore microtubules.
sister chromatids remain attached at the centromere and move as a single unit towards the same pole.
telophase **I**: homologous chromosomes reach opposite poles of the spindle; each half of cell contains complete haploid set of duplicated chromosomes, each comprising of two sister chromatids attached h centromere.
cytokinesis: formation of two haploid daughter cells, followed by de-condensation of chromosome and reformation of nuclear envelop and nucleoli in some species.
prophase **II**: spindle fibers form with axis at right angles to spindle axis of meiosis I.
cytokinesis: formation of four haploid and genetically different daughter cells.

genetic variation [differences in combination of alleles within a population]; crossing over is the equivalent exchange of genetic material between non-sister chromatids of homologs at the chiasma [point where two non-sister chromatids crisscrossed to exchange genetic material] following synapsis [pairing up], resulting in homologous recombination; independent assortment is the random and independent orientation of bivalents at metaphase plate; random fertilization depending on the gamete undergoing fertilization.

Mendel and chromosomal basis of inheritance

alleles [homozygous, heterozygous; controls single *trait, character*]: alternating versions of a gene that occupy the same locus on a pair of homologous chromosomes.

genotype is the genetic makeup of an organism; symbolic representation of pair of alleles; **phenotype** is the expressed physical traits; monohybrid [dihybrid] cross is the genetic mix between two individuals with one [two] distinct traits; homozygous or heterozygous genotypes.

cross-fertilization between two true breeding produces hybrids; examine phenotypic ratio of second filial generation [progeny] following inbreeding/selfing; pedigree analysis.

Mendel's 1st Law: principle of segregation; alleles of gene pair segregates during gamete formation [mitosis].
Mendel's 2nd Law; principle of independent assortment [meiosis].
cause of genetic variation: germline mutations; genes reshuffling [crossing over during Prophase I, independent assortment during Anaphase I, random fusion of gametes during fertilization].

degree of dominance [dominant, recessive, codominant, incomplete dominance] affects phenotype; **multiple alleles** [> 2 alleles per gene] increases possible genotypes/phenotypes; **pleiotropy** in a gene exhibits multiple [seemingly unrelated] phenotypic expressions, due to the underlying mechanism that the gene codes for a product that is either used by various cells or has a cascade-like signaling function that affects various targets; **lethal genes** affects genotypic/phenotypic ratio; in the case of two or more genes, **epistasis** causes interactions between genes; **polygenic inheritance** occurs when one characteristic is controlled by multiple genes [continuous variation; discontinuous for monogenic inheritance].

epistasis: [two-way recessive epistasis] both genes [dominant allele] encode for [parts of] enzyme/pigments that will affect [phenotype]; both parts are necessary for conversion, thus if 1 enzyme/pigment is not functioning, no colouration will be produced.
epistatic gene masks [controls, affects] hypostatic gene [effect is masked].

nature [heredity] vs nurture [environment]; norm of reaction is the phenotypic range of a genotype influenced by the environment; multifactorial.

sex determination from Y-linked sex-determining region Y [SRY] gene; **X-linked disorders**; **X-inactivation** from Barr bodies in females; **complete/partial linkage** depending on crossing over between non-sister chromatids, deviation from expected ratio [independent assortment] to show $50/50$ split between parental phenotype, or with smaller percentage of recombinant phenotypes.

chi-squared analysis: since the calculated χ^2 value [n] is smaller/larger than the critical χ^2 value [n], the probability that the observed results differ from the expected results occurring by chance along is more [less] than 0.05. The observed results do not/do differ significantly from the expected [$n{:}\,n{:}\,n$] ratio, and the differences are likely due to chance. Hence, do not [do] reject $\mathrm{H_o}$ in favour of $\mathrm{H_A}$.

molecular basis of inheritance

history of DNA: [1] T.H. Morgan's group showed that genes are located on chromosomes, DNA and proteins became candidates for genetic material; [3] Griffith's Transformation Experiment [1928] shows mixture of heat – killed S cells [pathogenic] and living R cells [nonpathogenic] killed mouse, concluding role of DNA in heredity; [4] Avery Experiments [1944] where fractionation shows only DNA is S-strain [rest R-strain], isolation of DNA as material for chromosomes; [5] Hershey-Chase Experiment [1952] where bacteriophages are labelled as phosphorous-labelled DNA and sulfur-labelled protein capsule, DNA produces radioactive host cells, while proteins result in radioactive phage ghosts confirm function of DNA as genetic material; [6] [1953] James Watson and Francis Crick introduced an elegant double-helical model DNA.

the Meselson-Stahl experiment compared the density of DNA following two replications, thus discarding the conservative and dispersive model and proving the semi-conservative model.

DNA replication: helicase binds at origin of replication, unwinds and separates parental DNA double helix; topoisomerase breaks, swivels, and rejoins parental DNA ahead of replication fork to relieve strain cause by unwinding. single-stranded binding proteins prevent single-stranded DNA from renaturing [re-annealing]; **RNA primase** synthesizes short RNA primer; DNA polymerase **III** selects free deoxyribonucleotides complementary to template strand, forms phosphodiester bonds between nucleotides from the 3' end of RNA primer, forming an Okazaki fragment; after reaching the next primer, DNA polymerase III detaches from the template strand; as replication bubble enlarges, more Okazaki fragments are synthesized; primer is hydrolysed by DNA polymerase **I** [exonuclease activity], which fills in gaps with complementary DNA bases; DNA ligase joins sugar-phosphate backbones of discontinuously synthesized Okazaki fragments to form a continuous strand.

telomerase catalyzes the lengthening of telomeres in eukaryotic germ cells, thus restoring their original length and compensating for the shortening that occurs during DNA replication; inactive in most somatic cells.
proof-reading of DNA: **DNA polymerase III** checks for incorrect incorporation of nucleotides at 3' end; exonuclease removes mis-paired base; continuation of DNA replication.

DNA *repair*: nuclease enzyme cuts the damaged DNA strand at two points, and the damaged section is removed by **DNA helicase**; repair synthesis by a **DNA polymerase III** fills in the missing nucleotides, using the undamaged strand as template; **DNA ligase** seals the free end of the new DNA to the old DNA, making the strand complete.

gene expression

the **genetic code** is a triplet code, almost universal, degenerate [wobble base phenomenon], non-overlapping, and punctuated; **activation of amino acid** occurs as amino acid and ATP enter the active site of aminoacyl-tRNA synthetase, which catalyses the joining of AMP to the amino acid with the release and breakdown of pyrophosphate; AMP is displaced by tRNA, creating aminoacyl tRNA [base pairing], which is then released.

large subunit: P site [**peptidyl-tRNA binding site**] holds tRNA carrying the growing polypeptide chain, while A site [**aminoacyl-tRNA binding site**] holds tRNA carrying the next amino acid to be added to the chain, and discharged tRNAs leave the ribosome from the E site [**exit site**]; the ribosome holds the tRNA and mRNA in close proximity and positions the new amino acid so that it can be added to the carboxyl end of the growing polypeptide, then catalyses the formation of the peptide bond; as the polypeptide becomes longer, it passes through an exit tunnel in the ribosome's large subunit, and is released from the tunnel when the polypeptide is complete.

codon recognition requires hydrolysis of one molecule of GTP, which increases the accuracy and efficiency of this step; one more GTP is hydrolysed to provide energy for the translocation step.

translation: a small ribosomal subunit binds to a molecule of mRNA; initiator tRNA [UAC] base pairs with the start codon; the arrival of a large ribosomal subunit completes the **initiation complex**; the next tRNA arrives at the A-site, and **peptidyl transferase** [enzymatic portion] catalyses formation of a peptide bond between the amino group of the new amino acid in the A site and the carboxyl end of the growing polypeptide in the P site; the ribosome translocate the tRNA in the A site to the P site, and the empty tRNA in the P site is moved to E site and released; mRNA moves along with the tRNAs, bringing the next codon to be translated into the A site.

termination: when a ribosome reaches a stop codon on mRNA, the A site of the ribosome accepts a "release factor," a protein shaped like a tRNA, instead of an aminoacyl tRNA; the release factor promotes hydrolysis of the bond between the tRNA in the P site and the last amino acid of the polypeptide, thus freeing the polypeptide from the ribosome; the two ribosomal subunits and the other components of the assembly dissociate with the hydrolysis of two GTP molecules.

signal mechanism for targeting proteins to ER: polypeptide synthesis begins on a free ribosome in the cytosol; **signal-recognition particle** [SRP] binds to the **signal peptide**, halting synthesis momentarily; SRP binds to a receptor protein in ER membrane [part of a protein complex that forms a pore]; SRP leaves, and polypeptide synthesis resumes, with simultaneous translocation across the membrane; signal peptide is cleaved by enzyme in the **receptor protein complex**; completed polypeptide leaves the ribosome and folds into final conformation.

regulation of gene expression

prokaryotic cell: the **σ subunit** of prokaryotic RNA polymerase recognizes consensus sequences found in the promoter region upstream of the transcription start site; the σ subunit dissociates from the polymerase after initiation of transcription, allowing RNA polymerase to synthesizing mRNA in the 5′ to 3′ direction; **ρ-dependent termination** occurs when polymerase encounters a list of G nucleotides on the DNA template and stalls, resulting in interactions with the protein and release of mRNA from the transcription bubble; **ρ-independent termination** happens when a stable hairpin loop formed through the complementary base pairing of C, G nucleotides that causes the polymerase to stall as it begins to transcribe a region of A − T nucleotides; the weak interaction of the complementary U − A region of the mRNA transcript with the template DNA coupled with the stalled polymerase induces enough instability for the core enzyme to break away and release the mRNA.

eukaryotic cell: several transcription factors, one recognizing the **eukaryotic promoter sequence** [TATA box; coding strand], bind to the DNA; additional **transcription factors** bind to the DNA with **RNA polymerase II**, forming the **transcription initiation complex**; RNA polymerase II unwinds the DNA double helix, and initiates RNA synthesis at the start point on the template strand [25]; the RNA polymerase moves along the DNA template strand, joining complementary RNA nucleotides to the 3′ end of the growing RNA transcript [RNA − DNA hybrid helix]; following transcription, RNA peels away from template strand, which reforms a double helix with coding strand; ***termination***: RNA polymerase transcribes the **polyadenylation signal sequence** that specify the polyadenylation signal [AAUAAA] in the pre−mRNA, which is immediately bound by certain proteins in the nucleus which cut the RNA transcript free from the polymerase, thus releasing the pre−mRNA [10 − 35].

unification of transcription, translation, and mRNA degradation is possible in prokaryotes as these processes occur in the same direction and there is no membranous compartmentalization in the prokaryotic cell; for eukaryotes, transcription can be selective, and RNA undergoes post-translational modification.

RNA *processing*: [in nucleus] **methylation of guanosine** [5′ cap] protects 5′ end, aids in attachment to ribosomes; **length of adenine** [poly-A tail] added to the 3′ end regulate half-life and preserve/protect integrity of mRNA [from degradation by hydrolytic enzymes], both facilitate/promote export of mature mRNA to cytoplasm; **RNA splicing** where introns are removed and exons joined together forms a continuous coding sequence. [removal of introns carried out by the spliceosome complex [of snRNP [small nuclear RNA [snRNA] and proteins] and other proteins], which binds to nucleotide sequences along an intron, which is then released [and rapidly degraded], and the spliceosome joins together the two exons that flanked the intron].

post-translational modification is the **folding by chaperone proteins** [creating right environment for protein folding] and **chemical modifications**; hydrolysis, acetylation, phosphorylation, and glycosylation activate/inhibit proteins; protein sorting, where free ribosomes in cytosol produce proteins for use inside cell, membrane bound proteins synthesise proteins in lumen of rER for use outside of cell.

viruses

gram-positive bacteria: thick peptidoglycan [modified protein-carbohydrate cell wall] does not allow complex [crystal violet, iodine in gram stain] to pass through, not removed by alcohol rinse, masks red safranin dye.
gram-negative bacteria [cyanobacteria]: thin peptidoglycan between plasma, lipopolysaccharide outer membrane allow crystal violet-iodine complex to pass through, removed by alcohol rinse, reveal red dye.

binary fission: chromosome replication begins at origin; one copy of origin moves rapidly toward other end of cell; plasma membrane grows inward, and new cell wall is deposited; two daughter cells result.

phage* T4 *[lambda phage]: complex capsid [capsomere] of icosahedral head and tail apparatus.
[endocytosis] Phage T4 tail fibers bind to specific proteins on E. coli cell that act as receptors; sheath of tail contracts, injecting double-stranded phage DNA into cell and leaving ghost particle outside, cell's DNA is hydrolysed; phage DNA directs production of phage proteins and copies of phage genome by host and viral enzymes, using components within cell; three separate sets of proteins self-assemble to form heads, tails, and tail fibers, phage genome is packaged inside capsid as head forms; phage directs production of enzyme that damages bacterial cell wall, allowing fluids to enter, cell swells and bursts, releasing phage particles.
Lambda Phage: phage attaches to host cell and injects [double-stranded] DNA; phage DNA circularizes; in **lytic cycle**, new phage DNA and proteins are synthesized and assembled into virions, cell lyses, releasing phage virions; in **lysogenic cycle**, phage DNA integrates within the bacterial chromosome by recombination, becoming a prophage; lysogenic bacterium reproduces normally; the prophage may excise from the bacterial chromosome occasionally by another recombinant event, initiating a lytic cycle.

influenza [enveloped RNA virus]: [binding] hemagglutinin [H1], [release] neuraminidase [N1];
[fusion] **glycoproteins** [hemagglutinin] on viral envelope bind to **sialic acid receptor** molecules on host cell, promoting viral entry into cell; capsid and viral genome [8 single-stranded RNA] enter cell; viral genome functions as a template for synthesis of complementary RNA strands by viral enzyme [RNA dependent RNA polymerase]; new copies of viral genome RNA made using complementary RNA strands as templates; capsid assembles around each viral genome molecule; complementary RNA strands also function as mRNA which is translated into both capsid proteins [in cytosol] and glycoproteins for the viral envelope [ER].

HIV [retrovirus]: gp41 transmembrane, gp120 docking glycoprotein for attachment, entry into host cell;
2 single-stranded RNA enveloped in nucleocapsid [reverse transcriptase and integrase] and p17 matrix protein [protease [cuts viral polypeptide to correct length], peptides, host proteins]; lipid envelope, MHC proteins.
fusion of HIV to the host cell surface; HIV RNA, reverse transcriptase, integrase, and other viral proteins enter the host cell; viral DNA is formed by reverse transcription; viral DNA is transported across the nucleus and into host DNA; new viral RNA is used as genome RNA and to make viral proteins; new viral RNA and proteins move to the cell surface, and a new immature HIV forms; the virus matures by protease releasing individual HIV proteins.

antigenic drift – new strain, point mutations [type A [animals] and B [humans]] [no proof-reading];
antigenic shift – new subtype [type A [inter-species]]; gene assortment; *radical* changes in principle antigen.

DNA tools and biotechnology

dideoxyribonucleotide* [ddNTP] *chain termination sequencing: terminate DNA strand elongation [lacks $-OH$ group for phosphodiester bond]; ddNTP radioactively or fluorescently labelled; resulting DNA fragments are heat denatured, separated by size [charge] via ***gel electrophoresis*** [agarose gel under electric field].
next-generation sequencing: genomic DNA fragmented; each fragment isolated with 1 bead in aqueous solution; fragment duplicated via PCR; 5′ ends of each strand specifically attached to the bead; placed into well with a single type of dNTP; complementary binding [3′ end] release PPi, which causes flash of light to be recorded; dNTP washed off, different type is added; pattern of flashes reveals sequence of original fragment in each well.

DNA cloning: preparing well-defined segments of DNA; loop of bacterial plasmid [as vector], fragment of foreign DNA [PCR] cut at recognition site by ***restriction endonucleases***; ***DNA ligase*** stabilizes attachment; plasmid is introduced into bacterium [transformation], via electroporation or heat shock $+ CaCl_2$; *antibiotic resistance screen method* filter bacteria with recombinant DNA [produce product, form clone library for research].
polymerase chain reaction: [denaturation] DNA strands separated via heating; [annealing] single strands cooled; primers form HB at end of target sequence [heat-stable Taq, Pfu polymerase]; 2 molecule form [end of 3 cycles].

in-situ hybridization: nucleic acid probe [labelled] pair with complementary mRNA [which cells express gene].
reverse-transcriptase polymerase chain reaction: reverse transcriptase form DNA strand with mRNA as template [$poly - dT$ as DNA primer], DNA polymerase synthesize complementary strand; cDNA formed carries complete coding sequence of gene without introns [possible for *gene expression* in bacteria; PCR amplification; gel electrophoresis [bands for samples from mRNA from gene of interest], quantitative $RT - PCR$ [fluorescent dye]].
DNA ***microarray assays***: single-stranded DNA fragments genes fixed on DNA chip, binds to cDNA [labelled];
RNA-***sequencing***: cDNA mapped onto genome sequence, frequency indicate gene expressed, level of expression.

in-vitro mutagenesis: specific mutations introduced into cloned gene, mutated gene is returned to cell, disables normal cellular copies of same gene; phenotype of mutant cell reveal function of normal protein [introduced mutations alter, destroy function of gene product]; $CRISPR - Cas9$ ***system***: $Cas9 -$ guide RNA complex enter nucleus, complementary sequence of guide RNA binds to part of target gene; active site on Cas9 cut both DNA strands; target gene can be *disabled* [no template provided, repair enzymes delete/insert random nucleotides] to study its function, or if target gene has a mutation can be *repaired* using normal gene as template;
genome-wide association studies: genetic markers [varying DNA sequences [basis for alleles]]; single-nucleotide polymorphism common to all affected to individuals [may not contribute directly; non-coding linked gene].

cloning of plant: mature cells “dedifferentiate”, give rise to all specialised cell types [totipotent];
cloning of animal: nuclear transplantation [somatic cell nuclear transfer] of nucleus of differentiated cell to enucleated egg; nucleus does not retain full genetic capability [stem cell: pluripotent [induced pluripotent cell]].

evolution and modification of genome

chromosomal mutations: *polyploidy* [extra chromosome sets]; *aneuploidy* [extra or missing chromosome; trisomy, monosomy]; *deletion* [missing part of chromosome]; *duplication* [extra part]; *translocation* [exchange of materials between two non-homologs]; *inversion* [segment of chromosome reversed].
point mutations [gene mutations]: *substitution* [silent, nonsense, missense], *insertion* and *deletion* [frameshift].
spontaneous mutation occur during DNA replication, recombination, repair; *induced mutations* are deliberately caused for scientific reasons; *mutagens*, mostly carcinogenic are physical/chemical agents that cause mutations.

genetic recombination; **transformation** after successful integration by nonreciprocal recombination following *uptake of* DNA *fragments*, or after *uptake of plasmid*;
transduction [viral transmission]; phage infects donor bacterial cell; phage DNA and proteins are made, bacterial DNA is broken down; pieces of bacterial DNA are packaged in phage capsid; donor cell lyses, releasing phage particles containing bacterial DNA; phage infects recipient cell; recombinant cell with different genotype form.
conjugation [cell-to-cell transfer via pilus, rolling circle mechanism]; DNA is nicked, 3′ end is elongated using 'unnicked' DNA as leading strand, 5′ end is displaced; displaced DNA is a lagging strand and made double-stranded via series of Okazaki fragments; replication of both 'unnicked' and displaced DNA completes; displaced DNA circulates; 2 F^+ cells are formed.

transposition ['jumping genes']; transposable elements change position in genome.
regulatory gene codes for protein that regulates **operon**; **control region** consists of promoter [initiates transcription of a particular gene] and operator [binding site]; **structural genes** codes for enzyme.
trp **[repression] operon**: presence of tryptophan activates repressor; operon off [anabolic].
[aporepressor is enabled by corepressor to join the operator gene]
lac **[induction] operon**: presence of allolactose inactivates repressor; operon on; β −galactosidase break lactose to glucose and galactose, lactose to allolactose in liver; permease transport lactose; transacetylase [catabolic].
[repressor is prevented by the inducer from joining operator gene]
positive control of *lac* operon by Catabolite Activator Protein; in the presence of cAMP [low glucose], CAP binds to the promoter and increases RNA polymerase activity.
chromosome: **euchromatin** [less compact, enzymatic activity, transcription active], **heterochromatin**.
non-coding DNA – introns, centromeres [kinetochore], telomeres [linear ends], promoters [binding site for RNA polymerase], enhancers [positive regulation], silences [negative regulation].

gene regulation; **chromatin level**: histone modification [acetylation of histone tails promotes loose chromatin structure that permits transcription], DNA methylation [prevents transcription];
transcription level: activator proteins bind to distal control elements grouped as an enhancer in the DNA, which has three binding sites, each called a distal control element, DNA bending protein brings bound activator closer to the promoter, activators bind to certain mediator proteins and general transcription factors, helping them form an active transcription initiation complex on the promoter;
post-transcriptional level: RNA processing [alternative splicing], RNA interference [cleavage by DICER into single-stranded miRNA [microRNA pathway] and double-stranded siRNA [RNAi pathway]; miRNA −protein complex block transcription for imperfect complements, mRNA is degraded in perfect complement; siRNA trigger formation of RNA – *Induced Silencing Complex* [RISC], helicase in complex unwind siRNA to passenger strand [degraded] and guide strand ssRNA, which degrade mRNA with perfect complement];
translational level: RNA decay [de-capping, binding of destabilizing RBP, de-adenylati mRNA on, degradation by exonuclease], initiation of transcription [operon model];
post-translational level: amino acid modification, cleavage, addition of polypeptide, addition of complex molecules, addition of chemical groups [hydroxylation, phosphorylation, acetylation, methylation].

vascular plant structure, growth, resource acquisition and transport

root anchors *vascular plant* in soil, absorb minerals and water, store carbohydrates [or other reserves]; ***primary root*** [originate in seed embryo] develop into ***taproot***, branch into ***lateral roots*** [taproot system], or die off, roots emerge from stem [adventitious [grows in unusual location]; fibrous root system]; root system form ***mycorrhizal association*** [symbiotic interaction; soil fungi]; ***stem*** elongate, orient shoot to maximize photosynthesis by leaves, elevate reproductive structure, facilitate dispersal of pollen, fruit; alternating system of ***nodes*** [leaves attached], and ***internode*** [stem segment between node]; ***apical bud*** at tip of shoot, ***axillary bud*** at axil [form lateral branch, thorn, flower]; modified stem [rhizome, stolon, tuber]; photosynthetic organ, exchange gas with atmosphere, dissipate heat, defence from herbivore, pathogen; ***petiole*** joins flattened blade to stem at node [monocots: lack petiole, base of leaf form sheath that envelop stem]; monocot: parallel major vein of equal diameter, run length of blade, eudicot: branched network of veins arising from major vein [midrib] that runs down center of blade.
dermal tissue: [non-woody plant] *epidermis* [guard cell, trichome], *cuticle* reduce water loss; [woody] *periderm*; ***vascular tissue*** [*stele*]: central vascular cylinder [root], vascular bundle; ***ground tissue***: *pith* [internal], *cortex*.

parenchyma: thin, flexible primary wall, lack secondary wall, large central vacuole [root: amyloplast [colorless plastid] store starch]; ***collenchyma*** [grouped in strands] support young parts of shoot [flexible support without restraining growth], elongated cell with thicker primary walls; ***sclerenchyma***: supporting element, secondary cell wall [produced after cell elongation *ceased*, dead at functional maturity], ***sclereid*** [thick, lignified secondary wall impart hardness to nutshells, seed coats], ***fibers*** [in strands, long, slender, tapered]; ***xylem*** [after protoplasm of ***tracheid*** or ***vessel element*** [wider, end walls have ***perforation plates***, enable water to flow freely] disintegrate, thickened walls form water conduit, interrupted by pits [thinner regions where only primary walls are present], allow water to migrate laterally between neighboring cells; phloem [sieve tube: sieve-tube element, sieve plates [pores facilitate flow of fluid] tube; companion cell [connected to sieve-tube element by ***plasmodesmata***].

indeterminate growth: ***apical meristem*** [undifferentiated tissue] [primary growth]; ***lateral meristem***: ***vascular cambium*** add vascular tissue [secondary xylem [wood], phloem]; ***cork cambium*** replace epidermis with thicker, tougher periderm; primary growth: dormant apical bud [shoot tip] enclosed by scales [protect apical meristem]; [in spring] bud sheds scales, begin new spurt of primary growth, producing series of nodes and internodes; in each growth segment, nodes marked by scars left when leaves fell; axillary bud, branch formed by axillary bud [above leaf scar]; bud scars from whorl of scales that enclosed apical bud; [***roots***] primary meristem: ***protoderm***: epidermis [single layer of cuticle-free cells, root hairs]; ***ground meristem*** [mature ground tissue; parenchyma in cortex; endodermis [innermost layer] as selective barrier, regulates passage of substance from soil to vascular cylinder; ***procambium*** [vascular cylinder, solid core of xylem, phloem tissues surrounded by pericycle]; ***leaves***: vein enclosed by ***bundle sheath***; sclerenchyma fibre; [palisade, spongy] mesophyll [photosynthetic parenchyma].

structure: [secondary xylem] heartwood [inactive], sapwood [conduct water; growth ring, vascular ray]; vascular cambium; [bark] secondary phloem, layers of periderm.

phyllotaxy [arrangement of leaves on stem]: [1 leaf per node] alternate, spiral; [2] opposite; [multiple] whorled; self-pruning of leaves that photosynthesize less than respired; ***apoplast*** [continuum of cell wall, extracellular space], ***symplast*** [cytosol connected by plasmodesmata], transmembrane [repeated crossing of cell membrane across cells] route; cotransport [sucrose, NO_3^-] using concentration gradient of H^+; water potential as sum of solute potential, pressure potential [$\Psi = \Psi_S + \Psi_P$] [water under positive Ψ_P [osmotic uptake]; turgor pressure].

transpirational pull: in transpiration, water vapour diffuse from moist air spaces of leaf to drier surrounding air via stomata; vapour lost replaced by evaporation from water film that coats mesophyll cells, causing air-water interface to retreat farther into cell wall; curvature increases rate of transpiration, surface tension, which pulls water from surrounding cells and air spaces; water pulled from xylem to replace water loss.
pressure flow hypothesis: loading of sugar reduces water potential inside sieve tube elements, water is taken up via osmosis; positive pressure force sap to flow along the tube, pressure relieved by unloading of sugar at sink.

guard cell turgid [transport of K^+ [light]; depletion of CO_2; abscisic acid [water deficiency] close stomata], radial orientation of cellulose microfibril cause cell to increase more in length than width; 2 guard cells tightly joined at tips, bow outward when turgid, cause stomatal pore to open; plants adapted to arid environment [***xerophytes***]: thick cuticle, multi-layered epidermis, stomata recessed in cavities [crypts], where trichome break flow of air.

weathering of rock; mechanical fracture [water freezing in crevices], chemical breakdown by weak acids in soil; accelerated when organisms [roots] penetrate the rock; mineral particles released by weathering mix with living organism, humus [remains of dead organism, other organic matter], form ***topsoil*** [A horizon]; *loam* [most fertile] composed of sand, silt, clay [equal amounts], [small slit, clay] provide ample surface area for adhesion, retention of minerals, water [molecules attracted to negatively charged surface of particles], large spaces [sandy soil] enable efficient diffusion of oxygen to roots; balance between aeration, drainage, and water storage capacity. [−] soil do not bind plant nutrients $NO_3^-, H_2PO_4^-, SO_4^{2-}$, easily lost by leaching, percolation of water through soil; K^+, Ca^{2+}, Mg^{2+} absorbed from soil solution via cation exchange [$CO_2 + H_2O \rightarrow HCO^- + H^+$, displace ions; depend on number of adhesion site, pH]; phytoremediation [pollutants], no-till agriculture, contour tillage [erosion].

essential element [determined via hydroponic culture]: [***macronutrients***] ***carbon***, ***oxygen***, ***hydrogen***, ***nitrogen*** [*proteins*, *nucleic acids*, *chlorophyll*] [*chlorosis at tips of older leaves*; *heavily cultivated soils*, low in organic material], ***phosphorus*** [*nucleic acids*, *phospholipids*, ATP] [healthy appearance but very *slow development*, thin stems, *purpling of veins*, poor flowering and fruiting; *acidic, wet, or cold soils*], ***sulfur*** [*proteins*] [general *chlorosis in young leaves*; *sandy or very wet soils*], ***potassium*** [*cofactor*; *water balance*; operation of *stomata*] [*mottling* of older leaf, drying of leaf edges, weak stems, poorly developed roots; *acidic or sandy soils*], ***calcium*** [component of *middle lamella*, *cell wall*; maintain *membrane function*; *signal transduction*] [crinkling of young leaf, death of terminal buds; *acidic or sandy soils*], ***magnesium*** [chlorophyll; cofactor] [*chlorosis between veins*, found in older leaves; *acidic or sandy soils*]; [***micronutrients [cofactors]***] ***chlorine***, ***iron***, ***manganese***, ***boron***, ***zinc***, ***copper***, ***nickel***, ***molybdenum***, ***sodium*** [C_4, CAM pathways; needed for the regeneration of *phosphoenolpyruvate* [CO_2 acceptor]].

roots emit chemical signals, attract *Rhizobium* bacteria; bacteria stimulate root hairs to elongate, form infection thread by invagination of plasma membrane; infection thread [containing bacteria] penetrates root cortex; cells of cortex, pericycle divide, vesicles containing bacteria bud into cortical cells from branching infection thread; bacteria within vesicles develop into nitrogen-fixing bacteroid, dividing cells of cortex, pericycle fuse to form the nodule, which develops vascular tissue that supplies nutrients to the nodule and carries nitrogenous compound into the vascular cylinder for distribution throughout the plant; layer of lignin-rich sclerenchyma cells reduce absorption of oxygen, maintain anaerobic environment needed for nitrogen fixation.

etiolation [morphological adaptation of growing in darkness]; reception of light by phytochrome [pigment], activation increase cytosolic Ca^{2+} levels, conformational change activates *guanylyl cyclase*, which produce 2nd messenger cyclic GMP; ***hormones***: ***auxin*** [IAA] [*shoot apical meristem*, *young leaves* as primary site of synthesis; developing seed and fruit contain high level of auxin; stimulates *stem elongation* [low concentration], promote *formation of lateral, adventitious root*, regulate *development of fruit*, enhance *apical dominance*, function in ***phototropism***, ***gravitropism*** [***thigmomorphogenesis*** [mechanical stimuli]], promote *vascular differentiation*, *retard leaf abscission*]; ***cytokinin*** [*root*, transport to other organs; *regulate cell division* in shoot and roots *modify apical dominance*, promote *lateral bud growth*; promote *movement of nutrient into sink tissues*; stimulate *seed germination*; *delay leaf senescence*]; ***gibberellins*** [GA] [meristem of *apical bud/root*, *young leaf*, *developing seed*; stimulate *stem elongation*, *pollen development*, *pollen tube growth*, *fruit growth*, and *seed development and germination*; regulate *sex determination*, transition from *juvenile to adult phases*]; ***abscisic acid*** [ABA] [*all cells*; *inhibits growth*, promotes *stomatal closure* during drought stress, *seed dormancy* [inhibit early germination], promote *leaf senescence*, *desiccation tolerance*]; ***ethylene*** [promote *ripening of fruit*, *leaf abscission*, triple response in seedlings [*inhibition of stem elongation*, promote *lateral expansion*, *horizontal growth*], enhance *senescence* rate, promote *root, root hair formation*; promotes *flowering in pineapple family*]; ***brassinosteroid*** [promote *cell expansion, division in shoot*, *root growth* [**low** concentration], *inhibit root growth* [**high** conc.], promote *xylem differentiation*, *inhibit phloem differentiation*; promote *seed germination* and *pollen tube elongation*]; ***jasmonate*** [derived from linolenic acid; *fruit ripen*, *floral development*, *pollen production*, *tendril coil*, *root growth*, *seed germination*, *nectar secretion*, or in *response to herbivory and pathogen invasion*]; ***strigolactone*** [carotenoid-derived hormone produced in root; response to low phosphate condition, high auxin flow from shoot] [promote *seed germination*, control of *apical dominance*, *attract of mycorrhizal fungi* to root];

hypersensitive response [local cell, tissue death] in response to secreted effectors that bypass **PAMP** – ***triggered immunity*** [pathogen-associated molecular patterns] [prevent systemic spread]; ***methylsalicylic acid*** [produced around infection site], carried by phloem throughout plant, converted to ***salicylic acid*** which activates signal transduction pathway, induces systemic-acquired resistance.

angiosperm reproduction and biotechnology

flower [sporophytic structure; determinate shoot]: ***carpel***, ***stamen*** [sporophyll: modified leaf for reproduction], ***petal***, ***sepal*** [sterile modified leaf] attached to ***receptacle***; carpel [*megasporophyll*; *stigma*, *style*, *ovary* [ovules become seeds if fertilized]; *unfused* carpel [simple pistil], *fused* carpel [multiple, lobed stigma, compound pistil]].

[in]complete flowers [sterile, unisexual]; exist singly or inflorescences; abiotic pollination by wind [production of copious pollen, floral structure create eddy current], pollination by bees [delicate fragrance; UV markings], moth and butterfly [sweet fragrance, white [nocturnal]], bat [light coloured, aromatic], fly [red, fleshy, carrion smell].

alternation of generation: 1 cell in ***megasporangium*** [inside ***ovule***, covered by 2 ***integument*** [sporophytic tissue, develop into seed coat], except at micropyle [gap]] enlarges, undergo meiosis, producing 4 haploid megaspores [3 degenerate]; nucleus of surviving megaspore divides by mitosis thrice without cytokinesis, multinucleate mass then divided by membrane to form embryo sac [female ***gametophyte***]: [8 nuclei contained within 7 cells] [near micropyle] 2 cell [synergids] flank the egg, attract and guide pollen tube to embryo sac; 3 antipodal cell at opposite end of unknown function; 2 polar nuclei share cytoplasm of large central cell of the embryo sac.
anther develops 4 ***microsporangia*** [pollen sac] containing diploid ***microsporocytes*** [microspore mother cells], undergoes meiosis, form 4 haploid microspore; each undergoes mitosis to produce haploid male ***gametophyte*** consisting of ***generative cell*** and ***tube cell*** [with spore wall [of material produced by microspore and anther] constitute ***pollen grain***]; during maturation, generative cell passes into tube cell.

microsporangium breaks open, releases pollen that is transferred to a receptive surface of a stigma, absorbs water and germinates by producing a ***pollen tube*** [long cellular protuberance] that elongates through the style; nucleus of generative cell divides by mitosis, produces two sperm which remain inside tube cell; tube nucleus leads two sperm as tip of pollen tube grows toward micropyle in response to chemical attractant produced by synergids; arrival of pollen tube initiates death of one synergids, providing passage into embryo sac; tube nucleus and 2 sperms discharged from pollen tube in the vicinity of the female gametophyte.

1 sperm fertilizes the egg, forming zygote; the other sperm combine with 2 polar nuclei, forming triploid nucleus that develops to endosperm [food-storing tissue of seed] [double-fertilization: union of 2 sperm with different nuclei of female gametophyte, ensures that endosperm develops only in ovules where egg has been fertilized]; tube nucleus, other synergid, and antipodal cells degenerate.

each ovule develops into a seed, ovary develop into fruit; sporophyte embryo develops from zygote, swelling cotyledons [seed leaves] may replace endosperm; seed germinates, embryo develops into new sporophyte; germination initiated by inhibition; straightening of hook of hypocotyl pulls cotyledon from soil, or shoot grows straight up through tube of coleoptile; simple fruit from single carpel [or fused carpels] of one flower; aggregate fruit from many separate carpels of flower; multiple fruit from carpels of many flowers that form inflorescence; accessory fruit largely from tissues other than ovary [instance, receptacle]; dispersal by water, wind, animal.

triploid nucleus divides, forming multinucleate ***endosperm*** [milky consistency]; becomes multicellular when cytokinesis partitions cytoplasm by forming membranes between the nuclei; cells produce cell walls, endosperm becomes solid; in few eudicot seeds, food reserves of endosperm are completely exported to cotyledons before development completes; mature seed lacks endosperm; [embryo development] 1st mitotic division of zygote is asymmetrical, splits fertilized egg into basal and terminal cell; basal cell divide, producing suspensor [thread of cells] that anchors embryo to the parent plant [helps in transferring nutrients from plant or endosperm], push embryo deeper into the nutritive and protective tissues as it elongates; terminal cell divides several times and forms spherical proembryo, cotyledons form as bumps on proembryo; embryo elongates, with embryonic shoot apex between cotyledon, embryonic root apex at opposite end; seed dehydrates, enters dormancy.

[eudicot] embryonic axis [plumule [epicotyl [1st pair of miniature leaves], shoot apical meristem], hypocotyl, embryonic root [radicle]] attached to 2 thick, fleshy cotyledons; [monocot] scutellum [specialized cotyledon] pressed against the endosperm [absorbs nutrients, transfer to rest of embryo during germination]; enclosed within coleoptile [covers young shoot], coleorhiza [covers young root] [both aid in soil penetration after germination]; pericarp fuses with seed coat; inner, outer layers of pericarp.

basic principles of animal form and function

epithelial tissue [cover outside of body, line organs, cavities within body; function as barrier against mechanical injury, pathogens, and fluid loss; form active interfaces with environment [detect sensory stimuli]: ***stratified squamous epithelium*** [surfaces subject to abrasion; outer skin, linings of mouth, anus, vagina] new cells from division near basal surface push outwards, replacing cell sloughed off near apical surface; ***pseudostratified columnar epithelium*** [mucous membrane, lines portions of respiratory tract] single layer of cells varying in height, position of their nuclei, beating cilia sweep film of mucus along the surface; ***simple squamous epithelium*** [thin and leaky, lines blood vessels, air sacs of lungs] single layer of plate-like cells allow exchange of material by diffusion; ***simple columnar epithelium*** [lines intestines] large, brick-shaped cells covered with villi, microvilli to increase surface area for secreting digestive juices, absorbing nutrients; ***cuboidal epithelium*** [epithelium of kidney tubules, glands such as thyroid, salivary glands] dice-shaped cells specialized for secretion.

connective tissue [sparse population of cells scattered through extracellular matrix [web of fibers embedded in liquid, jellylike, or solid foundation containing numerous cells [fibroblasts: secrete fibre proteins; macrophages [phagocytosis]: engulf foreign particles, cell debris]]; *collagenous fibre* provide strength, flexibility; *reticular fibre* join connective tissue to adjacent tissues, *elastic fibre*]: ***loose connective tissue*** [loose weave of all 3 fibre] in skin bind epithelia to underlying tissue, hold organ in place; ***fibrous connective tissue*** [dense with collagenous fibre] tendon: attach muscles to bone, ligament: connect bone at joint; ***bone*** [concentric layers of mineralized matrix, deposited around central canal [blood vessel, nerve]] osteoblasts [bone-forming cell] deposit matrix of collagen where Ca, Mg, phosphate ion combine into osteons [repeating unit]; ***adipose tissue*** [specialized loose connective tissue, store fat in adipose cell [contain fat droplet: swell [fat stored] shrink [fat used as fuel]] pad, insulate body, store fuel as fat; ***cartilage*** collagenous fibre within chondroitin sulfate [rubbery protein-carbohydrate complex], both secreted by chondrocytes; ***blood*** plasma [matrix] containing erythrocytes [RBC], leukocytes [WBC], platelet.

muscle tissue: ***skeletal [striated] muscle*** for voluntary motion; ***smooth muscle*** [spindle-shaped cell found in walls of digestive tract, urinary bladder, arteries, other internal organs] for involuntary body activities [churning of stomach, constriction of arteries]; ***cardiac muscle*** [form contractile wall of heart] branched fibre interconnected via intercalated disks, relay signals between cells, help synchronize heart contraction.

nervous tissue [receipt, processing, transmission of information]: ***neurons***, ***glia***.

homeostasis [maintain relatively stable internal environment for independence from environmental variations; ***thermoregulation***: controlling *heat gain* and *heat loss* mechanisms; ***principles of homeostasis***: stimulus [change from normal conditions [set point]]; ***thermoreceptors*** detect stimulus, send signals to ***hypothalamus***; control center compares with setpoint, decide on appropriate response, sends signals to the effectors; corrective mechanism by effectors produce response to bring opposite effect to changes detected to restore system to its original state; negative feedback sent to 'inform' receptor that condition has been restored to original state.

hair erector muscles relax, hair lie flat, air circulate over skin, remove heat; reflex contraction of ***skeletal muscles*** generate heat [increase metabolism]; ***skin arteriole*** vasodilate, ***shunt vessel*** vasoconstrict, divert blood to capillaries, increase heat loss via conduction, convection, radiation at skin surface [minimized by countercurrent exchange]; physiological mechanism [expelled air from lungs, evaporative heat loss]; behavioral mechanism.

skin consists of ***epidermis*** [cornified, granular, malpighian layer] [sweat pore, hair follicle], ***dermis*** [sweat gland, blood capillaries, sebaceous gland, hair erector muscle, pain receptor], ***subcutaneous layer*** [thermoreceptor, hair papilla, skin arteriole].

animal nutrition

nutritional need of diet: ***chemical energy*** for cellular respiration, energy storage; ***raw material*** for biosynthesis of macromolecule; ***essential nutrient*** [no enzyme for synthesis; intake in prefabricated form]: ***amino acid*** [leucine, isoleucine, lysine, methionine, phenyl-alanine, threonine, tryptophan, valine [infant: ninth, histidine], 'complete' in animal products [in proper proportions], "incomplete" in plants]; ***fatty acids*** [animals lack enzyme for double-bonds, obtained from plants; linoleic acid to γ – linoleic acid [phospholipid, prostaglandins [cell-signaling]]].

vitamin: A [***retinol***] [*green, orange vegetable, fruit, dairy product*; component of visual pigment, maintenance of epithelial tissue; *blindness, skin disorder, impaired immunity*]; **D** [*dairy, egg yolk*; absorption, use of Ca, P; *rickets [bone deformities; children], bone softening [adult]*; E [***tocopherol***] [*vegetable oil, nut, seed*; antioxidant, prevent damage to cell membrane; NS *degeneration*; K [***phylloquinone***] [*tea, green vegetable, made by colon bacteria*; blood clotting]; B_1 [***thiamine***] [*pork, legume, peanut, whole grain*; coenzyme [remove CO_2 from organic compound]; *beriberi [poor coordination, reduced heart function]*]; B_2 [***riboflavin***] [*dairy, meat, enriched grain, vegetable*; component of coenzyme FAD, FMN; *skin lesion*]; B_3 [***niacin***] [*nuts, meats, grains*; component of coenzyme NAD^+, $NADP^+$; *skin, gastrointestinal lesion, delusion, confusion*]; B_5 [***pantothenic acid***] [*meat, dairy, grain, fruits, vegetables*; component of coenzyme A; *fatigue, numbness of hands and feet*]; B_6 [***pyridoxine***] [*meat, vegetable, whole grain*; coenzyme [amino acid metabolism]; *irritability, convulsion, anemia*]; B_7 [***biotin***] [*legume, vegetable, meat*; coenzyme [synthesis of fat, glycogen, amino acid]; *scaly skin inflammation, neuromuscular disorders*]; B_9 [***folic acid***] [*green vegetables, oranges, nuts, legumes, whole grains*; coenzyme [nucleic acid, amino acid metabolism]; *anemia, birth defects*]; B_{12} [***cobalamin***] [*meats, eggs, dairy products*; production of nucleic acids, RBC; *anemia, numbness, loss of balance*]; C [***ascorbic acid***] [*citrus fruit, broccoli, tomato*; collagen synthesis, antioxidant; *scurvy, delayed wound healing*].

mineral: Ca [*dairy product, dark green vegetable, legume*; bone and tooth formation, blood clotting, nerve and muscle function; *impaired growth, loss of bone mass*]; P [*dairy product, meat, grain*; bone, tooth formation, acid -base balance, nucleotide synthesis; *weakness, loss of mineral from bone,* Ca *loss*]; S [protein; form amino acid; *impaired growth, fatigue, swelling*]; K [*meat, dairy, fruit, vegetable, grain;* acid-base and water balance, nerve function; *muscle cramp, reduced appetite*]; Mg [*whole grain, leafy vegetable*; cofactor, ATP bioenergetic; NS *disturbance*]; Fe [*meat, egg, legume, whole grain, leafy vegetable*; component of e^- carrier and haemoglobin, cofactor; *iron-deficiency anaemia, weakness, impaired immunity*]; F [*water, tea, seafood*; maintenance of tooth structure]; I [*seafood, iodized salt*; component of thyroid hormones; goitre], Co, Cu, Mn, Mo, Se, Zn in trace.

filter feeding: strain food particles from surrounding medium [baleen [comb-like plates] in humpback whale]; ***substrate feeding***: live in or on food source; ***fluid feeders***: suck nutrient-rich fluid from living host; ***bulk feeding***. ***hydra***: digestion begins in gastrovascular cavity, digestive enzymes released from gland cell, break down food into small particles, engulfed and digested in vacuoles [intracellular digestion]; ***earthworm*** [muscular pharynx suck food through mouth, pass through esophagus, stored and moistened in crop; mechanical digestion occurs in muscular gizzard, which pulverizes food with bits of sand and gravel; further digestion and absorption occur in intestine]; ***grasshopper*** [food is moistened, stored in crop [foregut], most digestion occurs in midgut, *gastric cecae* [pouch] extend from the beginning of midgut and function in digestion and absorption]; ***bird*** [crop store food; stomach, gizzard for mechanical digestion; chemical digestion, absorption of nutrients occur in intestine].

mouth [*salivary amylase* break down *starch, glycogen to maltose, disaccharides*, chewing creates bolus which is swallowed]; ***pharynx*** [epiglottis move down, glottis move up [close], oesophageal sphincter relax]; ***oesophagus*** [peristalsis]; enter ***stomach*** via ***cardiac sphincter*** [stretch wall, release hormone *gastrin*], gastric gland [gastric pit] contain chief [pepsinogen], parietal [HCl], mucous cell [H. pylori cause ulcer] [HCl: *pepsinogen* to *pepsin*, activate more pepsinogen; *protein to small polypeptide*]; chyme enter ***small intestine*** via ***pyloric sphincter*** [*pancreatic amylase* [polysaccharide to disaccharide], *disaccharidase* [to monosaccharide]; *pancreatic trypsin*, *chymotrypsin* [cleave bond near certain amino acid; small polypeptide to smaller polypeptide], *pancreatic carboxypeptidase* [to small peptide, amino acid], *carboxy-peptidase, dipeptidase, aminopeptidase* [to amino acids]; *pancreatic nuclease* [DNA, RNA to nucleotides], *nucleotidase* [to nucleosides], *nucleosidase*, *phosphates* [nitrogenous base, sugar, phosphates]; pancreatic lipase [triglycerides [in droplets coated with *bile salts* [break up fat droplets]] to glycerol, fatty acids, monoglycerides]] [secretin stimulate alkaline secretion [bicarbonates] from pancreas [cholecystokinin stimulate pancreatic enzyme], absorption occurs in jejunum, ileum: amino acid, glucose to bloodstream, fatty acids, monosaccharides to lymph [monoglycerides, fatty acids re-formed into triglyceride in epithelial cells, incorporated to chylomicrons [water-soluble by phospholipid, protein on surface], leave epithelial cells by exocytosis, enter lacteals, carried away by lymph]]; colon leads to rectum and anus, appendix extension of cecum [symbiotic bacteria]; dentition [incisor, canine, premolar, molar] depends on diet.

neurogenic heart: initiated by AP; ganglion [cluster of neurons] present on wall of the heart.
myogenic heart: sinoatrial [SA] node; autorhythmic cells located in wall of right atrium, near superior vena cava.

heart walls; *endocardium* [3 layers, lines inside of heart chamber, forms surface of valves]; *myocardium*; *epicardium* [innermost layer of pericardium, attached to muscles of wall of heart].
atrioventricular valves; *tricuspid*, *mitral* [bicuspid]; semilunar [3 half-moon shaped flaps]; *aortic*, *pulmonary*.
intercalated discs; *desmosome*, *gap junctions* [connexin; direct transmission of AP].
sinoatrial [SA] node produces electrical impulses which spread rapidly through walls of the atria, causing both atria to contract in unison. During atrial contraction, impulses originating at SA node reach other autorhythmic cells located in the wall between left and right atria, which form a relay point, the **atrioventricular [AV] node**. Impulses are delayed [$0.1s$] to allow atria to empty completely before ventricles contract, before spreading to heart apex and throughout the ventricular walls by **bundle branches** and **Purkinje fibers**.
His bundle branches into the left and the right bundle branches, which run along the interventricular septum. The **left bundle** branch further divides into the left anterior and the **left posterior fascicles**. These bundles and fascicles give rise to thin filaments known as *Purkinje fibers*.

autorhythmic cells: ***P4*** HCN channel open [cell is hyperpolarized], K^+ close, slow Na^+ open, slow depolarization [pacemaker potential]; ***P0*** Ca^{2+} open, rapid depolarization [AP]; ***P3*** Ca^{2+}, Na^+ close, K^+ open, rapid polarization.
contractile cells: ***P4*** resting potential; ***P0*** fast Na^+, slow Ca^{2+} open; ***P1*** Na^+ close, voltage-gated K^+ channel open – early repolarization; ***P2*** plateau, influx of K^+ counter-balanced by Ca^{2+} – cardiac muscles start to contract [refractory period]; ***P3*** Ca^{2+} induced Ca^{2+} release from SR – contraction period [longer refractory period].

long refractory period; prevent summation of stimulus [prevent tetanus], ensure all blood is pumped out.
[heart attack; ventricular fibrillation – random, uncoordinated excitation and contraction of cardiac muscles.]

electrocardiogram; atrial depolarisation initiated by SA node causes P wave; impulse is delayed at AV node after atrial depolarisation is complete; ventricular depolarization at apex cause QRS complex, atrial repolarization; ventricular depolarisation complete; ventricular repolarization begins at apex causing T wave; VR complete.
atrial systole [depolarisation]; mitral valve close; ventricular isovolumetric contraction; aortic valve open; rapid ventricular ejection; slow ventricular ejection; aortic valve close; ventricular isovolumetric relaxation; mitral valve opens; ventricular filling; diastasis [before atrial systole].

pressure volume loop; end of ventricular filling [diastole], represents the end-diastolic pressure and volume [EDV] for the ventricle; ventricle begins to contract isovolumetrically, mitral valve closes and LVP increases, but the LV volume remains the same, therefore resulting in a vertical line; when LVP exceeds aortic diastolic pressure, the aortic valve opens and ejection begins; LV volume decreases as LVP increases to a peak value [peak systolic pressure] and then decreases as the ventricle begins to relax; as the aortic valve closes, ejection ceases and the ventricle relaxes isovolumetrically; LV volume is the end-systolic [residual] volume [ESV]; when LVP falls below left atrial pressure, the mitral valve opens and the ventricle begins to fill; the LVP continues to fall initially as the ventricle fills since the ventricle is still relaxing, however once the ventricle is fully relaxed, the LVP gradually increases as the LV volume increases; the width of loop represents the difference between EDV and ESV, which is the **stroke volume [SV]**; **cardiac output** is stoke volume times heart rate.

increased contractility – increase SV, ejection fraction, decreased ESV;
increased preload [initial stretching], increased SV; ***increased afterload***, increased ESV, decreased SV.
wall stress is ventricular pressure times ventricular radius over two times wall thickness.
blood pressure; maximum pressure exerted on arteries when blood is pumped in during ventricular systole [high and pulsatile]; minimum pressure exerted on arteries when blood is draining off to rest of vessel during ventricular diastole [low and non-pulsatile].

Renin-Angiotensin-Aldosterone System [RAAS] involves the juxtaglomerular apparatus [JGA] [around afferent arteriole] which supplies blood to the glomerulus; when blood pressure or volume drops in the afferent arteriole, JGA releases the enzyme renin, which initiates a sequence of steps that cleave a plasma protein angiotensinogen [liver], yielding a peptide angiotensin II [angiotensin converting enzyme, from surface of pulmonary and renal endothelium], which as a hormone, triggers vasoconstriction, increasing blood pressure and decreasing blood flow to capillaries; angiotensin II also stimulates the adrenal glands to release a hormone called aldosterone, which causes the nephrons' distal tubules and collecting duct to reabsorb more Na^+ and water, increasing blood volume and pressure; increase sympathetic activity; stimulate adrenal gland cortex to secrete aldosterone, which; promote tubular Na^+ and Cl^- reabsorption and K^+ excretion, H_2O retention.

the immune system

innate immunity [recognition of traits shared by broad ranges of pathogens, using small set of receptors; rapid response]: ***barrier defenses*** [skin, mucous membranes, secretions]; ***internal defenses*** [phagocytic cells, natural killer cells, antimicrobial proteins, inflammatory response]; ***adaptive immunity*** [vertebrates; recognition of traits specific to particular pathogens, using a vast array of receptors; slower response]: ***humoral response*** [antibodies defend against infection in body fluids]; ***cell-mediated response*** [cytotoxic cell defend against infections in cells].

insects: exoskeleton [polysaccharide chitin] as physical barrier against infection; ***chitin*** lines intestine, blocks infection by pathogen ingested with food [***lysozyme*** break down bacterial cell wall]; ***[phagocytosis]*** pseudopodia of ***hemocyte*** [immune cell] surround pathogens, engulfed by endocytosis, vacuole forms, enclosing pathogens, vacuoles and lysosome fuse, toxic compounds and lysosomal enzymes destroy pathogens, debris released by exocytosis; other hemocyte release ***antimicrobial peptides***, which circulate throughout body of insect, inactivate or kill pathogen by disrupting their plasma membrane; specificity by transmembrane receptor **Toll**; ***[antiviral defense]*** host enzyme **Dicer − 2** recognize double-stranded RNA structure, cuts viral RNA into 21 nucleotides long fragments, protein complex containing host enzyme **Argo** bind to RNA fragment, displacing one of two strands, Argo complex uses bound single-stranded fragment as a guide, matching it to the complementary sequence in a viral mRNA, which is cut, inactivating and blocking synthesis of viral proteins.
mammals: [phagocytic cells] ***neutrophils*** [attracted by signals from infected tissue] and ***macrophages*** rely on **Toll** − ***like receptor***; ***dendritic cells*** [skin; contact with environment] stimulate adaptive immunity against pathogens [migrate to lymph nodes after interacting with pathogens]; ***eosinophils*** [tissues underlying epithelium] defend against multicellular invaders [discharge destructive enzyme]; ***[lymphatic system]*** interstitial fluid bathing tissues [along with WBC] continually enters lymphatic vessels, within lymph nodes, pathogens and foreign particles in circulating lymph encounter, activate macrophages and other cell that carry out defensive action, lymphatic vessels return lymph to blood via two large ducts that drain into veins near shoulders; virus-infected body cells secrete ***interferon*** [protein] that induce nearby uninfected cells to produce substances that *inhibit viral replication*, WBC secrete different type of interferon that *activate macrophages*; ***infection-fighting complement system*** [~30 proteins in plasma] circulate in inactive state, activated by substances on surface of pathogens, result in cascade of biochemical reactions that can lead to lysis of invading cells; ***[inflammatory response]***: signaling molecules released upon infection activate macrophages, discharged cytokines recruit neutrophils to site of infection, mast cells [immune cell in connective tissue] release histamine at site of damage, trigger nearby blood vessels to dilate and become more permeable, activated complement proteins promote further release of histamine, attracting more phagocytic cells to carry out additional phagocytosis, while enhanced blood flow helps deliver antimicrobial peptides, resulting in accumulation of pus [fluid rich in WBC, dead pathogens, and debris from damaged tissue]; overwhelming *systemic* inflammatory response lead to septic shock [high fever, low blood pressure, poor blood flow through capillaries].

adaptive response rely on lymphocytes [originate from stem cells; T cells migrate from bone marrow to thymus [organ in thoracic cavity]; B cell remain, mature in bone marrow; natural killer cells [innate immunity] remain in blood]; recognition occurs when T, B cell bind to *one* epitope on antigen [bacterial, viral protein; elicit response] via ***antigen receptor***; **[B cell]** Y-shaped protein [4 polypeptides; 2 identical heavy, light chain] linked by disulfide bridge; *constant region* [amino acid sequence vary little for different cell; *variable region*: specific binding site] of heavy chain contain transmembrane region, anchors receptor in plasma membrane; activation [binding] lead to formation of cell that secrete soluble form of receptor [antibody; immunoglobulin]; **[T cell]** α, β chain linked by disulfide bridge; recognize antigen fragment bound to major histocompatibility complex MHC of host cell.

receptor diversity [*recombinase* joins random V, J gene segment [*variable region*]], ***self-tolerance*** arise as cell mature [tested for self-reactivity; render nonfunctional; apoptosis [programmed cell death]]; ***proliferation of cell*** [clonal selection; activated cell undergoes multiple cell divisions, forming [short-lived] *effector cells*, [long-lived] *memory cell*], formation of ***immunological memory*** [prior exposure to antigen alters speed, strength, duration of immune response] occur after mature lymphocyte encounters, binds to specific antigen; ***humoral immune response*** occur in blood and lymph [antibody neutralize or eliminate toxins and pathogens in body fluids]; ***cell-mediated immune response*** [specialized T cells destroy infected host cells]; binding of helper T cells promotes secretion of cytokines by antigen-secreting cell, cell proliferation produces clone that secrete other cytokines, activate plasma [B] cells [secrete antibodies; neutralization, opsonization [recognition], activation of complement system and pore formation [foreign cell lyse]] and cytotoxic T cells [perforin form pores in cell membrane, granzymes degrade proteins [enter via endocytosis]].

osmoregulation and excretion

formation of urine [ultrafiltration]; efferent arteriole has narrower lumen than afferent arteriole, high resistance to blood flow out of the glomerulus leads to build-up of blood, high blood pressure, resulting in faster ultrafiltration [hydrostatic pressure]; filtered out solvent goes on to PCT as glomerulus filtrate; not filtered solute [too large to pass through the pores of the glomerulus filtration barrier]: renal artery, afferent arteriole, peritubular capillaries [Vasa Recta in medulla], efferent arteriole; 3 filtration barriers: **glomerulus endometrium** stop RBCs, WBCs, platelets; **basement membrane** stop plasma proteins; **epithelium of Bowman's Capsule** contains podocytes, which creates gaps [filtration slits] to speed up the movement of glomerulus filtrate.

selective reabsorption at tubular region of nephron; at proximal convoluted tubule, all amino acids and glucose are reabsorbed most water [65%] and mineral salts are reabsorbed; at descending limb of loop of Henle; water is reabsorbed to interstitial fluid of medulla [only contains aquaporin: only permeable to water]; at ascending limb diffusion occurs at thin region, at thick region [equilibrium is reached at boundary] active transport of salts out [thicker to accommodate more layers of cells for more mitochondria to produce more ATP]; at distal convoluted tubule some water and mineral salts are reabsorbed; at collecting duct some water and mineral salts are reabsorbed, and some urea diffuses out via diffusion purely by concentration gradient to maintain hyperosmotic nature of the medulla [regulation by anti-diuretic hormone depending on need or condition of body; remaining fluid passes out collecting duct into renal pelvis to form urine.

dehydration *increases the blood osmolarity*; change from the usual setpoint detected by *osmoreceptors at hypothalamus*, signals to *pituitary gland to increase secretion of ADH*; ADH is released from the pituitary and travels in the blood to the kidneys and *bind to receptors* located on cells lining CD of nephron, activates vesicles containing aquaporins; aquaporins inserted into plasma membrane of CD and DCT *increases water permeability*, *increase in water reabsorption* into the blood reduces the water loss in urine and increase urea/salts in urine.

urine produced by each **kidney** exists through **ureter**, both drain into **urinary bladder** [common distensible sac]; during urination, urine is expelled from balder through **urethra**, which carries urine to near the vagina in females, through the penis in males; **sphincter muscles** near junction of urethra and balder regulate urination.

each kidney is enclosed by a layer of fatty tissue [adipose capsule] and a tough fibrous capsule; adipose tissue act as insulating layer, reduce heat loss, mean of energy storage, fibrous capsule provide mechanical protection and support for kidneys; renal hilum [concave depression on kidney surface] ureter and renal vessels connect; urine collected in renal pelvis [extension of ureter]; renal pyramid contain **cortical** [short distance into medulla] and **juxtamedullary nephrons** [extend deep into medulla, essential for production of hyperosmotic urine].

haemodialysis and peritoneal dialysis: weeks or month before haemodialysis, a vascular access is created to strengthen the vessel [delay collapse], and for easier identification of vessels for injection; **arteriovenous graft**: small plastic tube [graft] used to connect an artery to a vein; **arteriovenous fistula**: connect artery and vein to form larger vessel [fistula]; dialysate flows in the opposite direction; counter-current maintains a constant concentration gradient for continuous removal of wastes, excess water and salts.

components of the haemodialyser: roller blood pump ensure continuous flow of blood; anti-coagulant [heparin] prevent blood from clotting; temperature regulator [37°C] for thermoregulation and prevent plasma proteins denaturing; bubble trap prevent bubbles from entering bloodstream, block vessels, damage tissues; cellophane tubings mimic capillaries [numerous long & thin tubes for greater surface area to volume ratio; partially permeable membrane [by size] allow exchange of small molecules].

central diabetes insipidus: osmoreceptors at hypothalamus unable to detect change in blood osmolarity; pituitary gland does not increase/decrease secretion of ADH, circulating anti-bodies to ADH-secreting cells; ***nephrogenic diabetes insipidus***: ADH receptors does not respond to ADH; no increase/decrease of aquaporins; ***diabetes mellitus***: unable to produce adequate insulin [T1] or unable to respond to insulin [T2], high blood glucose level, large amount of glucose enters the filtrate during ultrafiltration, reabsorption cannot happen fast enough at the PCT, water potential of filtrate lower than normal, less steep water gradient between filtrate and interstitial fluid, less water reabsorption at collecting duct, larger volume of ***urine*** produced;
high levels of blood glucose damage the kidney nephrons [PCT], increase filtration workload, increase pressure on kidneys, kidneys lose their vital filtering ability, damage to plasma membrane of ***kidneys***.

hormones and endocrine system

endocrine gland is a ductless gland that releases its secretions directly into the blood for distribution around the body to the target organs or cells [travels in bloodstream]; **exocrine gland** has a duct or tube that carries its secretions out of the body such as onto the body surfaces or into body cavities; **hormone** is a chemical signal molecule [protein or steroid] produced in minute quantities by an endocrine gland, after exerting effects, it is destroyed by the liver and excreted by the kidneys.

significance of hormones: hormones influence growth, development, activity of organism, chemical messengers that help to control and co-ordinate body activities [maintain homeostasis, mediate responses to environmental stimuli; regulate growth, development and reproduction]; production and secretion must be carefully regulated to maintain normal functioning [inadequate or excess production: adverse effects of functioning of the body.

pancreatic islet cells secrete insulin [β – cell] and glucagon [α – cell] into the blood [exocrine: acinar cells secrete pancreatic enzymes into pancreatic duct]; hypothalamus regulates secretion of some pituitary hormones via feedback loop [positive + negative], receives ***AP***, send signals to stimulate pituitary gland to secrete hormones.

blood *glucose level rise* above normal setpoint [$0.9\mathrm{g/L}$] [negative feedback], [***insulin***] stimulate body cells to *increase uptake of glucose* from bloodstream, *increases permeability of cell membranes* to glucose; *increase glucose metabolism*; increase glucose storage, stimulates liver, muscle cells to convert *glucose into glycogen* for storage; [***glucagon***] stimulates liver to convert *glycogen into glucose* [glycogenolysis]; conversion of *fatty acids and amino acids into glucose* at the liver [gluconeogenesis]; release of glucose into the bloodstream.

in a ***diabetic person***, insulin levels remain relatively constant due to their inability to increase insulin secretion in response to the rise in blood glucose level; the blood glucose concentrations are much higher, due to the insufficient levels of insulin to trigger an increase uptake of blood glucose by body cells; ***during exercise***, body metabolism increases, increasing the demand for glucose, the low glycogen stores in muscles are depleted quickly, muscle increase glucose uptake directly from blood, resulting in a drop in blood glucose concentration, the glycogen stores in the liver to be converted into glucose is too little to compensate for the drop in blood glucose level, resulting in a larger/further drop in blood glucose concentration; in a ***healthy person***, high glycogen storage in muscle cells reduce the need to uptake glucose directly from the bloodstream, resulting in an initial slight drop in blood glucose level, this stimulates the conversion of high glycogen stores in the liver to glucose which is then released into the blood in order to return the blood glucose level back towards normal and to maintain it at a relatively constant level.

adrenaline secreted by medulla of adrenal gland; hypothalamus to signal the adrenal medulla [which mediates ***short-term-stress-response***] via nerve impulses, the stress response is triggered through the stimulation of the adrenal medulla, this stimulation causes the release of adrenaline [epinephrine] which helps the body to cope with short-term stressful situations; effects of epinephrine: contracts hair erector muscles, dilation of pupils, increase rate of blood coagulation, changes in blood flow pattern, increase blood pressure, rate of heartbeat, increase rate and depth of ventilation, increase metabolic rate, increase blood glucose level; ***long-term-stress-response***: release of glucocorticoids and mineralocorticoids from adrenal cortex.

diabetes mellitus [body unable to control blood glucose concentration within range]; type 1 [insulin dependent] diabetes is autoimmune disorder in which the immune system destroys the beta cells of the pancreas; type 2 [insulin-independent] where target cells [muscle cells] do not respond well to insulin, due to excess body weight and lack of exercise or heredity; symptoms: persistently high blood glucose concentration [hyperglycaemia], presence of glucose in the urine after a meal ['honey urine'], production of copious amount of urine, excessive thirst and hunger, muscle weakness and fatigue, weight loss, slow healing of wounds; treatments: measure blood glucose concentrations and test their urine regularly, watch their diet, not take in excess carbohydrates; ***type 1***: inject Insulin several times a day, ensure that they have a supply of sugary food such as glucose sweets [ensure that blood glucose level does not drop too low, when they use too much insulin, exercise too much, or eat too little], in severe cases, low blood glucose can cause them to go into coma; ***type 2***: regulate carbohydrate content and type in their diet, exercise regularly, if lifestyle changes fall, they may have to take medication.

animal reproduction

structure	function
testes	production of sperm and testosterone [+ other androgen/steroid hormones]
penis*	deposits sperm in vagina of female reproductive tract
erectile tissues of penis*	fills with blood to cause erection during sexual arousal
scrotum*	consists of loose skin and supports the testes
prostate gland*	secrets a fluid into urethra, which further nourishes the sperms.
vas deferens	conducts sperms from testes to penis [sperm duct]
urethra	conducts semen from vas deferens or urine from urinary bladder to tip
seminal vesicle	ejaculatory duct opens into the seminal vesicle. secrets an alkaline fluid that contains mucus into the urethra. fructose is found in the mucus.
bulbourethral gland	secrets clear, alkaline fluid to neutralize any acidic urine remaining in the urethra
epididymis	coiled duct; stores sperms temporarily

structure	function
ovaries	produces egg and female sex hormones such as oestrogen and progesterone
oviducts	conducts egg to uterus with its cilia muscles. site of fertilization
uterus	muscular chamber where foetus develops
cervix	closes off lower end of uterus
vagina	receptacle for semen; birth canal; route for menstrual blood
fimbria [opening]	has cilia that sweep egg into the oviduct
clitoris	engorges with blood and becomes enlarged during sexual intercourse
labia	folds of skin that protect the female genital region
endometrium	lining of uterus. made up of blood vessels and nutrient producing glands

oogenesis: hypothalamus secrete GnRH; pituitary gland secretes FSH to ovary; FSH stimulates development of primary follicle in ovaries; primary follicle secretes oestrogen to uterus for repair and growth of endometrium on the uterus; high levels of oestrogen cause pituitary gland to secrete LH; LH stimulates primary follicle to develop into Graafian follicle; high levels of oestrogen cause positive feedback to secret more FSH and LH; pituitary gland secrets LH to ovary; LH causes ovulation, cause ruptured Graafian follicle to form corpus luteum; corpus luteum secretes progesterone, oestrogen to uterus to grow endometrium, and maintain thickness for implantation; high concentration of oestrogen and progesterone sends negative feedback to hypothalamus, oestrogen inhibit FSH production, prevent maturation and development of more follicles, progesterone inhibit LH and ovulation. [menstrual phrase [0 – 5], proliferate phrase [5 – 14], secretory phrase [14 – 28]].

development of zygote: ***fertilization***: sperms swim towards the egg [vagina, cervix, uterus, oviduct], follicle cells are scattered by enzymes sperms; hydrolytic enzyme released from acrosome digests *zona pellucida*, acrosomal process protrudes from sperm head, penetrates jelly coat, and binds to receptors on plasma membrane; fusion trigger depolarization [Ca^{2+}] of membrane [fast block], cortical granule fuse with membrane, secreted contents clip off sperm-binding receptors, fertilization envelope form [slow block to polyspermy; ***development of embryo***: implanted embryo develop into foetus, developing placenta secretes Human Chorionic Gonadotropin, which supports corpus luteum [secretes OP], levels of hCG in the maternal blood rises [till some is excreted in the urine], when developing placenta has matured, it can produce OP, hence hCG decreases and corpus luteum degenerates; ***placentation***: formation of a placenta, a temporary organ that originates from both maternal and embryonic tissues, placenta will be shed off after birth of baby and cutting of umbilical cord; ***functions of placenta***: secrete hormone OP, site of exchange of materials between the mother and foetus, allow antibodies to diffuse from the mother's blood into the foetus's blood to protect the foetus against diseases;

adaptations of placenta: maternal blood directly bathes the whole surface of chorionic villi [ensures constant diffusion of materials by having a high concentration of oxygen and nutrients], continuous flow of foetal blood in foetal capillaries and maternal blood in maternal blood spaces to maintain a constant diffusion gradient, chorionic villi have highly folded structure to increase surface area to volume ratio for exchange of materials by diffusion, maternal blood not confined in blood vessels, but is found in the maternal blood spaces [facilitates diffusion of materials efficiently]; ***functions of amniotic fluid***: protective buffer for the embryo and foetus, provides room for foetal movements to occur, assists in regulating foetal temperature.

initial development carried out by mRNA and proteins deposited in egg during oogenesis; ***cleavage*** to restore balance between cell's size and DNA content; [gap phases skipped, little protein synthesis occur, no increase in mass] cleavage partition cytoplasm, form blastula [single layer of blastomeres surrounding blastocoel [cavity]]; ***[frog]*** yolk [stored nutrients] concentrated toward vegetal pole [away from animal pole]; first 2 cleavage furrows parallel to meridian [line] connecting 2 poles [divides grey crescent]; 3rd division is equatorial produces 8 cell embryo; yolk near vegetal pole displaces mitotic apparatus, cleavage furrow from equator toward animal pole; blastocoel form entirely in animal hemisphere; holoblastic [cleavage furrow pass entirely through egg]; ***[human]*** egg contain little yolk, blastocoel form centrally; **[avian]** meroblastic [incomplete cleavage due to yolk]; cell division limited to whitish area at animal pole; cap of cells sorted into epiblast [upper], hypoblast [lower] layers; blastocoel [cavity between layers]; ***[insect]*** yolk found throughout egg; multiple rounds of mitosis occur without cytokinesis, before plasma membrane form around each nucleus; blastomeres surrounding mass of yolk.

morphogenesis: [***gastrulation***: reorganization of blastula into gastrula [embryo of 2,3 embryonic germ layers]; [radially symmetrical: ***diploblast***] *ectoderm* form epidermis of skin, nervous and sensory systems, pituitary gland, adrenal medulla, jaws, teeth; *endoderm* form epithelial lining of digestive, respiratory, excretory, reproductive tracts and ducts, thymus, thyroid, parathyroid gland; [bilaterally symmetric: ***triploblast***] *mesoderm* form skeletal, muscular, circulatory, lymphatic, excretory, reproductive system [except germ cell], skin dermis, adrenal cortex.

[***frog***] cells on dorsal side invaginate, form *blastopore* [crease; above: dorsal lip [positional information; equivalent of apical ectodermal ridge, zone of polarizing activity of vertebrate limb bud] [derived from grey crescent]]; sheet of cells [*ectoderm*] spread out of animal hemisphere, rolls inward over dorsal lip [involution] [*mesoderm*], and moves into interior [form endoderm, mesoderm]; cells at animal pole change shape, spread over outer surface; *blastopore* form circle around embryo as more cells invaginate, shrinks as ectoderm spreads downward over the surface; [internally] continued involution expands *endoderm* and *mesoderm*, *archenteron* forms and grows [*blastocoel* shrinks]; circular *blastopore* surrounds plug of yolk-filled cells.
[***chick***] epiblast [form embryo], *hypoblast* lie atop yolk mass; epiblast cells move toward midline, detach, move inward toward yolk [create *primitive streak*]; move downward, form *endoderm* [push aside *hypoblast* cell]; move laterally, form *mesoderm*; non-migrating cells form *ectoderm*; *hypoblast* cells segregate from *endoderm*, form part of sac that surrounds yolk, stalk that connects yolk mass to embryo.
[***human***] *blastocyst* [*trophoblast* around central cavity; *inner cell mass* [source of embryonic stem cell lines]] reaches *endometrial epithelium* [uterine lining]; enzyme secreted by trophoblast break down lining, allow invasion by blastocyst [implantation]; trophoblast extend projections, cause capillaries to spill blood captured by trophoblast tissues; inner cell mass forms *epiblast* [inner], *hypoblast* [outer flat disc]; trophoblast continues to expand into endometrium, *amniotic cavity* form within *epiblast*, *yolk sac* form from *hypoblast*, *extraembryonic mesoderm cell* form from *epiblast*, *chorion* form from *trophoblast*; gastrulation: epiblast remain as ectoderm on the surface, or move inward through primitive streak, form mesoderm and endoderm; embryonic germ layers formed; extraembryonic mesoderm and 4 extraembryonic membranes [*amnion*, *chorion*, *yolk sac*, *allantois*] surround embryo; trophoblast, epiblast, and adjacent endometrial tissue contribute to formation of placenta.

generation of *wedge-shaped cell* [apical contraction of actin filaments], elongation by microtubules; convergent extension [cell elongate, crawl past, cell sheet become longer, narrower]; cell migration via *cytoskeletal fibers* [extend, retract cellular protrusions; akin to amoeboid movement], cell adhesion molecules [transmembrane glycoprotein; promote interaction between cell pairs]; extracellular matrix [meshwork of secreted glycoprotein, other macromolecule outside of plasma membranes] guide cells [migration, shape changes of cell sheets].

organogenesis: [***frog***] [***neurulation***] cells from *dorsal* mesoderm form *notochord* [rod that extends along dorsal side of chordate embryo; disappear before birth; parts persist as inner portions of disks in spine [disks that can herniate, rupture]], signalling molecules secreted cause *ectoderm* above *notochord* to become the *neural plate* [induction: cells, tissue influences development of another group through close-range interactions]; cells change shape, curving the structure inward; neural plate rolls itself into the *neural tube* [brain, spinal cord], which runs along the *anterior-posterior axis* of embryo [spina bifida: portion of neural tube fail to develop, close properly]; [***cell migration***] *neural crest* [cells that develops along borders where neural tube pinches off from ectoderm] migrate to parts of embryo, forming tissues including peripheral nerves, parts of teeth, skull bones; groups of *mesodermal cells* lateral to notochord separate into *somites* [blocks] [role in organising segmented structure of vertebrate body; form vertebrae, muscles associated with vertebral column, and ribs]; [***chick***] borders of chick blastoderm fold downward and come together, pinching embryo into 3-layered tube joined under the middle of body to yolk; [***insect***], tissues of nervous system form on *ventral* side of embryo.

organisation of the nervous system	
central nervous system [CNS]	***peripheral nervous system [PNS]***
consists of brain and spinal cord, main control center	nerves that branch from the CNS [cranial nerves and spinal nerves], allows CNS to communicate with body
sensory division [afferent division]	***motor division [efferent division]***
picks up sensory stimuli, sends information to brain	carry signal to skeletal muscle, both voluntary and involuntary [pain withdrawal]
somatic nervous system [voluntary]	***automatic nervous system [involuntary]***
controls skeletal muscles movement	carries out basic body processes *[regulates smooth and cardiac muscles, generally involuntary]*
sympathetic division	***parasympathetic division***
gets body into action for fight-or-flight situations *[exit CNS midway along spinal cord, form synapses in ganglia just outside of spinal cord; norepinephrine]*	relaxes body, calms it for rest-and-digest situations *[nerves exit CNS at base of brain or spinal cord, form synapse in ganglia near or within internal organ; ACh]*
regulate the organs of the digestive, cardiovascular, excretory, and endocrine systems; **enteric NS** [auto. NS] exerts direct, partially independent control over digestive tract, pancreas, gallbladder.	

myelin sheath: layer of fatty substance [lipid] that wraps around/encloses the axon, formed by Schwann cells; plasma membrane surrounding myelin sheath: neurilemma; protect myelin sheath, layer of nutrition [helps axon regeneration], 2 layers of phospholipid that prevents water from passing through.
axon terminal: forms a synapse with neuron's target cell, thus allow signal to be transmitted from neuron to target cell; contains large number of synaptic vesicles which store neurotransmitters; arrival of AP at the axon terminal stimulates the release of neurotransmitters via exocytosis which will be received by the target cell.

signal integration: message depends on frequency of AP and where it is transmitted from; weak impulses collected at cell body, integrated into one single AP by the axon hillock.
signal transmission: AP from the axon reaches end of axon terminal; triggers the synaptic vesicle to carry out exocytosis [fusion of synaptic vesicles with plasma membrane, release of neurotransmitters into synaptic cleft]; neurotransmitters binds to specific receptors, causes activation of receptors [Ligand Gated Ion Channels]; Na^+ influx, generation of weak electrical impulses; to remove neurotransmitters: degrade [neurotransmitters detach from receptors, degraded by enzymes], reuse [degraded NT enter pre-synaptic neuron via neurotransmitter channels], recycle [degraded NT reform in synaptic vesicles].
signal conduction: myelin sheath and nodes of Ranvier allow electrical impulses to 'jump' from one node to the next in the process called saltatory conduction; myelin sheath that wraps around the axon at regular intervals provides electrical insulation to reduce the loss of electrical signals as electrical impulse is conducted along the axon as a strong, fast-flowing current; nodes of Ranvier ensures that the electrical impulse is only regenerated at the nodes, hence maintain strength of signal and ensuring fast conduction; when AP reaches Node of Ranvier, Voltage Gated Ion Channels are activated, allowing influx of positive charges.

reflex action: immediate [sensory information used to activate motor neurons without first travelling from the spinal cord to brain and back], stereotyped response to specific stimulus without conscious control, involuntary. importance of reflexes: maintain posture and balance, respond to changes in the external and internal environment to avoid danger, maintain optimal working conditions for cells [homeostasis].
reflex arc: shortest pathway along which nerve impulses travel from the receptor to the effector to carry out a reflex action; receptors, sensory neuron, CNS [spinal cord], motor neuron, effectors.

spinal reflex: stretch stimulus detected by stretch receptors [muscle spindle], reflex contract of extensor muscle, patellar tendon stretched, quadriceps contract, hamstring relax [interneuron in spinal cord receive signals from sensory neurons, inhibits motor neurons that lead to hamstring muscle, prevent contraction of hamstring, [which would resist the action of quadriceps]], leg extends.
pain-withdrawal reflex: pain stimulus detected by pain receptors, reflex contraction of flexor muscles, detection of pain by pain receptors, triceps relaxes, biceps contracts, forearm flexes [motor endplate].

nervous systems

specialised nervous systems originated from **prokaryotes** [following Cambrian explosion]; minimal cephalization of sessile, slow-moving species, and more sophisticated NS of active predators suggest correlation with lifestyle; simplest animals [hydras, jellies, other **cnidarians**] have interconnected neurons organized in diffuse nerve net; axons of multiple neurons are bundled together in more complex animals, forming nerves; radial symmetry of NS of a sea star [**echinoderm**] is less specialised than bilateral symmetry of more complex flatworms [**planarian**], which exhibit cephalization [clustering of sensory organs [sensory neurons and interneurons] at anterior [front] end of body; nerves extends out at posterior end]. leech [**annelids** and insects] have segmentally arranged clusters of neurons called ganglia, while the squid [**mollusc**] has a clearly defined brain; the spinal cord becomes apparent in animals such as the salamander [**vertebrate**]; both CNS and PNS display regional specialization.

glial cells: glial cells nourish, support, regulate NS; **radial glia** function in development of NS in embryos, form tracks along which newly formed neurons migrate from neural tube; **astrocytes** adjacent to brain capillaries facilitate information transfer, regulate extracellular ion concentration, promote blood flow to neuron, maintenance of blood-brain barrier [physiological mechanism that restricts entry of many substances from blood into CNS]; both radial glia and astrocytes can act as stem cells, which undergo unlimited cell divisions to self-renew and form more specialized cells [neurons are amitotic] [mature, migrate to particular locations, incorporate into circuitry]; **ependymal cells** line ventricle of brain, cilia promote circulation of cerebrospinal fluid that fills brain ventricles; **oligodendrocytes** myelinate axons in CNS, increase conduction speed of AP [**Schwann cells** myelinate axons in PNS]; **microglia** are immune cells in CNS, protect against pathogens.

organisation of vertebrate NS: CNS consists of brain, spinal cord [dorsal root, ventral root, lateral horn], PNS of cranial nerves, spinal nerves, ganglia; during embryonic development, CNS develops from hollow dorsal nervous cord [chordates]; cavity of nerve cord gives rise to **central canal** of spinal cord and **ventricles** of the brain, which fill with cerebrospinal fluid [supplies CNS with nutrients, hormones, carries away wastes]; **grey matter** consists of neuron cell bodies, dendrites, and unmyelinated axons, **white matter** of bundles of myelinated axons.

regional specialisation: ***forebrain*** [*olfactory bulb* and *cerebrum]* controls processing of olfactory input [smells], regulation of sleep, learning, and complex processing; ***midbrain*** coordinates *routing of sensory input*; ***hindbrain*** [part of which forms *cerebellum*] controls involuntary activities [blood circulation], coordinates motor activities. ***embryonic development***: neural tube forms three anterior bulges [forebrain, midbrain, and hindbrain]; midbrain, portions of hindbrain give rise to *brainstem* [stalk that joins with spinal cord at base of brain]; rest of hindbrain give rise to cerebellum [lies behind brainstem]; forebrain develops into *diencephalon* [including neuroendocrine tissues of brain], and *telencephalon* [becomes cerebrum]; rapid, expansive growth of telencephalon during second and third months causes cortex of cerebrum to extend over and around much of the rest of the brain.

cerebrum controls skeletal muscle contraction and is the centre for learning, emotion, memory, and perception; divided into *right and left cerebral hemispheres*; ***cerebral cortex*** [outer layer of cerebrum] receives input from sensory organs and somatosensory receptors, provide information about touch, pain, pressure, temperature, and proprioception [position of muscles and limbs], and is vital for perception, voluntary movement, learning [alternate sides of cerebral cortex receives information from, and controls the movement of, the other side of the body; most axons that carry instructions of large-scale body movements cross from one side of the CNS to the other in medulla]; ***corpus callosum*** [thick band of axons] enables right and left cerebral cortices to communicate; within the white matter, ***basal nuclei*** [clusters of neurons] serve as centres for planning and learning movement sequences; ***cerebellum*** coordinates movement and balance and helps in learning and remembering motor skills; ***sulci*** [groove] and ***gyri*** [ridge] increase neuron connections.

diencephalon: **thalamus** is formed by two masses, and incoming information from all the senses, as well as from the cerebral cortex, is sorted in the thalamus and sent to the appropriate cerebral centres for further processing [main input centre for sensory information going to the cerebrum]; **hypothalamus** manages thermoregulation, central biological clock, source of posterior pituitary hormones and released hormones that act on anterior pituitary; **epithalamus** includes pineal gland [source of melatonin]; ***brainstem***: **midbrain** receives and integrates several types of sensory information and sends it to specific regions of the forebrain; **pons** and **medulla** transfer information between PNS and midbrain, forebrain; medulla control several automatic, homeostatic functions [breathing, heart and blood vessel activity, swallowing, vomiting, and digestion]; pons also participates in some of these activities [regulates breathing centres in medulla].

arousal [state of awareness of external world] and ***sleep*** [external stimuli are received but not consciously perceived] are controlled partly by **reticular formation**, diffuse network formed primarily by neurons in midbrain and pons [transitions regulated by brainstem and cerebrum]; control timing of sleep periods characterized by rapid eye movements [REMs] and by vivid dreams [electroencephalogram [EEG]]; filter sensory input, blocking familiar, repetitive information that constantly enters nervous system before sending filtered input to cerebral cortex; also regulated by biological clock and regions of forebrain that regulate sleep intensity and duration; **circadian rhythm** [including cycles of sleep and wakefulness] rely on a ***biological clock***, a molecular mechanism that directs periodic gene expression and cellular activity, and is coordinated by clustered neurons in the hypothalamus that form the **suprachiasmatic nucleus** [SCN], which acts as a pacemaker in response to sensory information from eyes, synchronising biological clock in cells throughout body to natural cycles of day length.

generation, experience of ***emotions*** depend amygdala [clusters of neurons located near base of cerebrum], hippocampus, and parts of thalamus [border brainstem; limbic system]; store emotional experiences as memories that can be recalled by similar circumstances; laughing and crying involve limbic system interacting with sensory areas of forebrain; structures in the forebrain attach emotional "feelings" to survival-related functions controlled by the brainstem, including aggression, feeding, and sexuality.

functional imaging of brain [*cerebrum*] using functional magnetic resonance imaging [fMRI] [previously positron-emission tomography [PET]]; ***frontal lobe***: *prefrontal cortex* [decision making, planning], *Broca's area* [forming speech; *Wernicke's area* [posterior portion of left temporal lobe] in speech comprehension], *motor cortex*[*] [control of skeletal muscles]; ***parietal lobe***: *somatosensory cortex*[*] [sense of touch], *sensory association cortex* [integration of sensory information]; ***occipital lobe***: *visual association cortex* [combining images and object recognition], *visual cortex* [processing visual stimuli and pattern recognition]; ***temporal lobe***: *auditory cortex* [hearing]; [*]neurons are arranged according to part of the body that generates input or receives commands. ***lateralisation***: difference in function between the right [recognition of faces and patterns, spatial relations, and nonverbal thinking] and left [math and logical operations] hemispheres; ***cortex structure***: extensively convoluted cerebral cortex [primates, cetaceans [aquatic mammal]], six parallel layers of neurons arranged tangential to surface; clustered organization of neurons within pallium [outer layer of cerebrum] [birds].

formation of NS: regulated gene expression and signal transduction determine where neurons form in the developing embryo; neurons compete for growth-supporting factors, which are produced in limited quantities by tissues that direct neuron growth, in order to survive [net effect is the preferential survival of neurons that are in a proper location [neurons that do not reach the proper locations do not receive such factors and undergo programmed cell death]]; synapse elimination takes place, activity of neuron stabilizes some synapses, remove extra synapses not required for its proper function formed during development; phases establish the basic network of cells and connections within the nervous system required throughout life.

neural plasticity: capacity for the nervous system to be remodelled, especially in response to its own activity [although overall organization of CNS is established during embryonic development, connections between neurons can be modified; ***synaptic elimination*** [*synaptic pruning*] continues after birth and throughout childhood]; synapses belonging to circuits that link information in useful ways are maintained, whereas those that convey bits of information lacking any context may be lost; when activity of a synapse coincides with that of other synapses, changes may occur to reinforce synaptic connection [converse also true]; net effect to increase signalling between particular pairs of neurons, decrease signalling between other pairs; signalling at a synapse can also be strengthen/weakened; defect in neuronal plasticity may underlie autism [genetic disorder; impaired communication, social interaction, stereotyped and repetitive behaviours beginning in early childhood].

mechanisms of ***long-term memory*** are activated for knowledge that are to be retained [information held for a time in short-term memory, then released if it becomes irrelevant], memory is fetched from long-term memory and returned to ***short-term memory*** when recalled; both involve storage of information in cortex; short-term memory: information accessed via temporary links formed in **hippocampus** [essential for acquiring new long-term memories but not for maintaining them]; long-term memory: connections within **cerebral cortex** [reactivation of hippocampus for memory consolidation likely form basis for dreams]; delay in forming connections in cerebral cortex allows long-term memories to be integrated gradually into existing knowledge and experience, providing basis for more meaningful associations; **muscle memory** [learned by repetition] involve cellular mechanisms where neurons make new connections, while **memorisation** [rapid, require only one exposure to relevant item] rely mainly on changes in the strength of existing neuronal connections.

long-term potentiation: lasting increase in the strength of synaptic transmission [physiological basis of memory: via processes that can alter a synaptic connection, making the flow of communication more efficient or less]; LTP involves a presynaptic neuron that releases the excitatory neurotransmitter glutamate; LTP occurs with a high-frequency series of AP in the presynaptic neuron, which arrive at the synaptic terminal simultaneously as postsynaptic cell receives a depolarizing stimulus at another synapse; net effect to *strengthen a synapse whose activity coincides with that of another input*; ***NMDA*** and ***AMPA*** [glutamate receptors] can be used to artificially activate the particular receptor; set of receptors present on the postsynaptic membrane changes in response to active synapse and a depolarizing stimulus, resulting in a stable increase in size of postsynaptic potentials at the synapse [LTP]; LTP thought to represent one of the fundamental processes by which memories are stored and learning takes place [lasts in dissected tissue]; long-term depression: long-lasting decrease in synaptic strength.

schizophrenia [1%]: severe mental disturbance characterized by psychotic episodes, patients have distorted perception of reality, including hallucinations and delusions; fragmentation of integrated brain functions; not necessarily result in multiple personalities; neuronal pathways that use dopamine as NT are disrupted.
depression: depressed mood, abnormalities in sleep, appetite, and energy level; major depressive disorder [$1/_7$]: periods where once enjoyable activities provide no pleasure, provoke no interest; bipolar disorder [1%] [manic-depressive disorder]: extreme swings of mood; fluoxetine [Prozac] increases activity of biogenic amines in brain.
Alzheimer's disease [age-related]: progressive mental deterioration or dementia characterized by confusion and memory loss; brains of patients show amyloid plaques and neurofibrillary tangles, often massive shrinkage of brain tissue, reflecting death of neurons in many areas of the brain, including hippocampus and cerebral cortex; ***plaques*** are aggregates of β–amyloid [insoluble peptide cleaved from extracellular portion of membrane protein in neuron catalysed by secretase]; β–amyloid plaques accumulation outside trigger surrounding neuronal death. ***neurofibrillary tangles*** are tau protein, which normally helps assemble and maintain microtubules that transport nutrients along axons, but in Alzheimer's undergoes changes that cause self-binding [changes suggest onset].
Parkinson's disease: motor disorder, include muscle tremors, poor balance, a flexed posture, and shuffling gait, facial muscles become rigid, cognitive defects may develop; involves death of neurons in midbrain that normally release dopamine at synapse in basal nuclei, due to accumulation of protein aggregates; genetic basis suspected as cause for early-onset, mitochondrial defects for later-onset form; treated [not cured] via brain surgery, deep-brain stimulation, *l-dopa* [dopamine related drug], which unlike dopamine, crosses blood-brain barrier; within the brain, enzyme dopa decarboxylase converts the drug to dopamine, reducing severity of Parkinson's disease symptoms; potential cure for to implant dopamine-secreting neurons in midbrain or basal nuclei.

sensory pathway begins the detection of a stimulus [represent forms of energy] by sensory receptors [sensory cell [specialized neuron or non-neuronal cell that regulates a neuron], organ, or subcellular structures]; affect channels, change in the flow of ions across membrane alters membrane potential; conversion of stimulus to change in membrane potential [signal transduction; *graded* receptor potential]; neuronal sensory receptor generates AP that travel along an axon extending into CNS [larger receptor potential results in more frequent AP], non-neuronal sensory receptor conveys information to afferent neurons via chemical synapses [alters rate at which afferent neurons produce AP], alert NS to changes in stimulus intensity; receptor potentials produced by stimuli delivered to different parts of *sensory receptor cell*, post-synaptic potentials in *sensory neurons* that form synapses with multiple receptors, are integrated through summation, *sensory structures* provide integration, *brain* processes all incoming signals; circuits of neurons process input of AP, generate perception of stimulus; stimuli distinguished depending on path along which AP arrived; motor response may be generated. [**amplification**, **adaptation** may occur during transduction/in accessory structures; upon continued stimulation]

mechanoreceptors enables detection of touch, proprioception, pressure sensing and ***hearing*** [invertebrates use statocysts, with statoliths in chamber lined with ciliated cells to sense gravity and maintain ***equilibrium***; insects have hairs that vibrate in response to sound waves; detect sound with localised organs consisting of a tympanic membrane stretched over an internal air chamber]; sense physical deformation, consist of ion channels linked to structures that end outside cell [cilia, dendrites of sensory neurons]; **chemoreceptors** transmit information about total solute concentration of a solution or respond to specific molecules [permeability to ions change when stimulus molecule binds]; **electromagnetic receptors** detect electromagnetic energy [light, electricity], electric field generated by prey, migration using Earth's magnetic field for orientation; **thermoreceptors** detect heat and cold [response open calcium channels], infrared radiation emitted by warm prey [snakes], variety specific for a particular temperature range [mammal]; **pain receptors** [nociceptors]: sensory neurons [bare nerve endings] detect stimuli that reflect harmful conditions, respond to excess heat, pressure, or chemicals released from damaged or inflamed tissues [pain perceived when stimulus crosses threshold].

structure of the eye: ***eyelids*** protect exposed surface of eye from mechanical damage, prevent excessive light from entering the eye [damage of photoreceptors], blinking spreads tear over the exposed surface of eye to keep it moist and wipe away dust; ***eyelashes*** help shield eye from dust particles; ***tear gland*** keep exposed surface of eye lubricated during blinking [no lubrication: cannot blink], keep exposed surface of eye moist for atmospheric oxygen to dissolve and diffuse into cornea, tear wash away dust particles, tear ducts carry tear to tear sac, which empties into nasal cavity; ***conjunctiva*** [thin transparent membrane covering part of the sclera and fusing into the eyelid] secretes mucus to keep exposed surface of eye moist and lubricated; ***cornea*** [transparent to allow light to enter pupils, curved and dense to provide greatest amount of refraction for clear vision [rigid and cannot adjust, lens does the fine adjustments], continuous with the sclera] covers the pupil and prevent foreign substances from entering the eye; ***iris*** [muscular diaphragm] controls size of pupil; ***sclera*** [outermost layer, white and opaque to ensure light only enters through pupil, tough fibrous [collagen fibers] layer] protect and maintain shape of eyeball, provide firm attachment of external eye muscles [rectus muscle]; ***choroid*** [middle layer] pigmented black [high concentration of melanin] to absorb maximum light that enters retina [prevent internal reflection which distorts image], rich supply of blood vessels supplies oxygen and nutrients to cells of eye, continuous with ciliary body and iris; ***retina*** [innermost layer] is the light sensitive layer on which images are formed, contains photoreceptors, bipolar neurons, and ganglion cells.

cell body of ***photoreceptors*** [rods: larger outer segment, greater number of discs[folding of inner membrane], colour pigments, more sensitive] integrate weak impulses, synaptic terminals form synapses with ***bipolar cells*** [relay neurons]; ***blind spot*** [optic disc]: central artery and vein emerging from optic disc provides oxygen and nutrients to the retina, and carries away metabolic waste [long axon of ganglion cells exit retina and extends to brain: optic nerve], no photoreceptors are present, no phototransduction occur, no electrical signal of image on retina are generated and sent to the brain [visual context], hence no integration and processing of the image by the brain, no perception of mental image; ***fovea*** [yellow spot] is structurally adapted to give clearest vision: photoreceptors consist entirely of cones [no rods] to provide high resolution vision, small depression where *neurons are pushed aside* to allow more light to reach the cones for greater stimulation; maximum and direct detection of light for clearest image; image that does not form on fovea [peripheral vision] is blurred.

pupil reflex [cranial reflex]: low [high] levels of light reaches retina, thus stimulating pupil reflex; this brings about the contraction of radial [circular] muscles and relaxation of circular [radial] muscles, causing the pupil to dilate [constrict]; the ability of the iris to dilate and constrict allows more light to enter in dim light and less light in bright light, thus preventing overstimulation and damage of photoreceptors.

accommodation: ability to focus a clear image on retina, achieved by changing the thickness [curvature] of the [convex] lens [via antagonistic structures]: light rays from near [far] objects are diverging [converging] when they reach the eye; ciliary muscles contract [relax], and the suspensory ligaments loosen [tighten]; lens undergo elastic recoil [stretched] and becomes thicker [thinner], a greater [lesser] refraction for incoming diverging [converging] light rays allow light rays to converge on retina, instead of behind it, thus forming a clear image.

cataracts causes clouding of the lens, which obstructs passage of light through the lens, thus reducing amount of light falling on retina, hence light cannot be converged properly. The low stimulation of photoreceptor causes less information to be sent to brain, causing the brain to perceive and construct a blurred and dim image.
myopia is a refractive error, where the light rays converge before the retina, hence there is no single point of convergence on retina: lens is too round/thick, or steeper cornea: excessive refraction; elongated eyeball [normal cornea and lens]: genetics, or formed as a child; concave/diverging lenses, diverge light rays before entering eyes; LASIK [refractive surgery]: reshape cornea, correct curvature, refraction of light corrected.
hyperopia [presbyopia] is caused by the loss of elasticity of the lens, which reduces the ability of the lens to undergo elastic recoil, causing the maximum thickness of the lens to decrease. This reduce the ability of the lens to refract light and converge diverging rays from near objects.
glaucoma is caused by a buildup of pressure inside the eye, when the channel that allows the aqueous humour to flow out of the eye gets blocked. The increased pressure [intraocular pressure] can damage the optic nerve, affecting the transmission of images to the brain, thus leading to vision loss.

motor mechanisms

myofibrils [bundles of proteins] of **thick** [staggered array of *myosin* molecules anchored in middle of sarcomere; *M line*] and **thin** [two coiled strands of polymerized *actin* attached at *Z lines* at sarcomere ends] filaments are made up of **sarcomeres** [repeating sections], surrounded by **sarcoplasm** [cytoplasm of striated muscle cells], forms muscle fibers [myocytes]; muscle cells are attached by the **sarcolemma**, forming a **fascicle** connected by **endomysium** and wrapped around by **fascia** [connective tissue]; numerous fasciculi connected by **perimysium** and **blood vessels** form the **muscle belly**, which is covered by the **epimysium** [tendon continuation].

myofibrils are connected by the **triad**; **transverse tubule** [infolding of plasma membrane, located at junction of A, I band [M] or Z-disc [C], connected to extracellular fluid], and two **terminal cisterns** of **sarcoplasmic reticulum**; ***sliding-filament model***: hydrolysis of bound ATP converts myosin to a high-energy form that binds to actin, form cross-bridge between thick and thin filament; myosin head pulls thin filament toward center of sarcomere, returns to low-energy form; new ATP molecule binds to myosin head, *disrupting cross-bridge* and *releasing myosin head* from actin filament; cleaves newly bound ATP, binds again to actin; since thin filament moves toward center of sarcomere in each cycle, myosin head attaches to a binding site farther along thin filament.

in a muscle fiber at rest, **tropomyosin** [regulatory protein] and **troponin complex** [set of additional regulatory proteins], are bound to the **actin strands** of thin filaments. Tropomyosin covers the **myosin-binding sites** along the thin filament, preventing actin and myosin from interacting. Motor neurons enable actin and myosin to interact by triggering a release of calcium ions into the cytosol, where Ca^{2+} binds to the troponin complex, causing the troponin complex to change shape and dislodging the tropomyosin from the myosin binding sites, hence exposing the myosin-binding sites on actin.

arrival of AP at synaptic terminal of a motor neuron causes release of neurotransmitter **acetylcholine**; binding of ACh to receptors on muscle fiber leads to depolarization, initiates AP which propagates along plasma membrane and down T-tubules, triggering Ca^{2+} release from SR; Ca^{2+} stored in interior of SR flow through open channels into cytosol, bind to troponin complex, initiating muscle fiber contraction; motor neuron input stops, proteins in SR pump Ca^{2+} back into SR from cytosol, muscle relax as filaments slide back to initial position; regulatory proteins bound to thin filament shift back to initial position, block myosin-binding sites; Ca^{2+} pumped from the cytosol accumulates in the SR, providing stores needed to respond to the next AP.

each **muscle belly** is served by at least one **motor nerve**, consisting of a bundle of **motor neuron**; each having multiple axon branches that form synapses with multiple **muscle fibers**, where each muscle fiber is controlled by only one motor neuron. The **motor unit** consists of a single motor neuron and all the muscle fibers it controls. The contraction of a single skeletal muscle fiber is a brief all/none twitch, while contraction of a whole muscle, is graded; the extent and strength of its contraction can be altered by varying [1] ***the number of muscle fibers*** that contract and [2] the ***rate at which muscle fibers are stimulated*** [single stimulus signals for twitch contraction, second AP arrives before the muscle fiber has completely relaxed, summation [treppe] results in greater tension; when frequency is so high that the muscle fiber cannot relax between stimuli, the twitches fuse into one smooth, sustained contraction called tetanus; isometric vs isotonic contractions; concentric vs eccentric].

oxidative fibers rely mostly on aerobic respiration; specialised to use steady energy supply; many mitochondria, rich blood supply, large amount of myoglobin [oxygen-storing protein]; **glycolytic fibers** have a larger diameter, use glycolysis as their primary source of ATP and fatigue more readily than oxidative fibers.

the length-tension relation is the phenomenon whereby a muscle/muscle fibre displays different levels of maximum force production depending on the length at which it is tested; related to *extent to which individual sarcomeres within muscle fibre are overlapping*. Active length-tension relationship a result of degree of overlap between actin and myosin filaments within sarcomeres; passive length-tension relationship occurs as a result of elastic elements within muscle itself; more stretched higher tension.

muscle cells cannot divide; type II decrease faster than type I, exercise stimulates increase in myofibrils, increase in overall size of muscle cells, develop more mitochondria, myoglobin, glycogen, higher density of capillaries. **sarcoplasmic hypertrophy** is the increase in volume of sarcoplasmic fluid; **myofibrillar hypertrophy** is the growth of injured muscle fibers during repair. **agonist** [prime movers] function in pairs with **antagonist** muscles; **fixator synergistic** muscles stabilises a joint around which movement is occurring, **neutralizer synergist** muscle is one neutralizes an undesired joint action, aiding the agonist muscle.

afterburn [oxygen debt]: production of ATP, resynthesize glycogen from lactate, restore O_2 levels in venous/ skeletal muscle blood and myoglobin, repair damaged muscle tissue, restore body temperature to resting levels.

mechanisms of evolution

Carolus Linnaeus: binomial format [genus, species]; nested classification system; ***Georges Cuvier***: [paleontology [study of fossil]] older stratum [sedimentary rock layer] more dissimilar to current lifeform, across layers species appeared, disappeared; ***James Hutton***, ***Charles Lyell*** geologic changes result from gradual mechanisms; ***Jean-Baptiste de Lamarck***: use and disuse, inheritance of acquired inheritance [*organism have innate drive to become more complex*]; ***Alfred Russel Wallace***, ***Charles Darwin*** "*On the Origin of Species by Means of Natural Selection*": descent with modification; ***vestigial structures***: remnants of features that served a function in the organism's ancestors; organisms share characteristics due to common ancestor [***homology***], convergent evolution [***analogy***]; ***biogeography***: geographic distribution of species; ***natural selection***: population possess an enormous *reproductive potential* if all offspring survive, produce; *population size remain stable* [fluctuate around constant size]; *resources are limited* [do not increase as population grow larger]; individuals *compete for survival* [growing population exceed available resource]; *variation exist* among individuals in a population; *variation is heritable* [DNA passed down]; only the most fit individuals survive [*survival of the fittest*]; evolution occurs as *favorable traits accumulate* in the population [best adapted individuals, best adapted offspring, leave most offspring].

microevolution: evolutionary change in population [allele frequency] by ***natural selection*** [adaptative evolution], ***genetic drift*** [chance events that alter allele frequencies], ***gene flow*** [transfer of allele between populations], given ***genetic variation*** [at whole-gene level: average percentage of heterozygous loci; via production of new alleles and genes in *germ cells*] [environmental influence on phenotype: noninheritable variation]; ***Hardy-Weinberg equilibrium***: allele frequency remain constant across generation [no evolution] [*no mutation*, *no net migration*, *random mating*, *large population* [no genetic drift [***founder***, ***bottleneck effect***] [lose genetic variation, harmful alleles become fixed]], *isolated population* [no gene flow], *neutral trait* [no natural selection [*directional* [favour 1 extreme of distribution], *disruptive* [extremes], *stabilizing* [intermediate] selection] [*relative fitness*: relative contribution to gene pool] [***sexual selection*** in *sexual dimorphism*]]] [$p + q = 1$; $p^2 + 2pq + q^2 = 1$]; balancing selection: frequency dependent selection; heterozygote advantage.

speciation: species [*biological* [potential to interbreed], *morphological* [structural feature], *ecological* [ecological niche; interaction with environment] species concepts] splits into multiple; ***reproductive isolation***: [*prezygotic barrier*] ***habitat***, ***temporal*** [different mating periods], ***behavioral*** [courtship rituals], ***mechanical*** [morphological difference prevents successful mating], ***gametic isolation*** [sperms unable to fertilize egg; binding proteins, etc.]; [*postzygotic barrier*] ***reduced hybrid viability*** [impaired development], ***reduced hybrid fertility*** [mule [jack, mare], hinny [stallion, jenny]], ***hybrid breakdown*** [feeble, sterile next generation]; ***allopatric*** [population geographically divided, descendants become geographically isolated from parent population], ***sympatric speciation*** [gene flow reduced due to *polyploidy* [fertile allopolyploids], *sexual selection* [mate choice on physical appearance], *habitat differentiation* [exploit new habit/resource]; hybrid: *reinforcement* [cease to be formed], *fusion* [species merge], *stability* [continued production of hybrid]; disrupted gene flow, genetic diversity, speciation, formation of genus.

macroevolution [broad pattern of evolution above the species level]; origin of life: abiotic [nonliving] synthesis of small *organic molecules* [including RNA monomer] [***Oparin-Haldane hypothesis***: *reducing atmosphere*, oceans of organic material, energy from UV [tested by Miller – Urey]; ***hydrothermal vents***], join into *macromolecules*, [lipid in water], packaging into *protocells* [selectively permeable bilayer [montmorillonite clay particles coated with RNA], perform metabolic reactions using external source of reagents; divide, grow without dilution], origin of *self-replicating molecules* allowing inheritance [ribozyme [RNA catalyst]]; *stromatolite* [layered rocks] form when prokaryotes bind thin films of sediments together; *photosynthesis* produce oxygen that precipitate iron in water, saturation till gas enters atmosphere; *eukaryotes* form via endosymbiosis; *multicellular eukaryotes* form, *Cambrian explosion*, *colonization of land*; Permian [volcanism], Cretaceous [dust from asteroid collision] mass extinction, followed by adaptive radiation;

evolutionary history of biological diversity

taxonomy [systematics]: ***domains***, ***kingdom***, ***phylum***, ***class***, ***order***, ***family***, ***genus***, ***species*** [taxon]; *basal taxon* [branch that diverge near *common ancestor* of group]; shows *patterns of descent*, not phenotypical similarity, order of evolution; ***monophyletic*** [clade] [common ancestor, common descendants], ***paraphyletic*** [exclude some descendants], ***polyphyletic group*** [ancestor excluded]; ***homologous gene*** [ancestral]: ***orthologous*** [speciation], ***paralogous genes*** [gene duplication, divergence *within species*]; *molecular clock*: constant rate of evolution;

archaea [kingdoms: ***euryarchaeotes***, ***thaumarchaeotes***, ***aigarchaeotes***, ***crenarchaeotes***, ***korarchaeotes***]: *polysaccharide cell wall*; *glycerol isomer* as phospholipid components, *branched hydrocarbon* chain [fatty acid] with ***ether****-linkage*; DNA with *histone*, ribosome activity *uninhibited by antibiotic* streptomycin, chloramphenicol; ***methanogen*** [obligate *anaerobe*, energy from H_2 to fix CO_2, CH_4 by-product], ***extremophile*** [*halophile*: saline environment; most aerobic, heterotrophic; others anaerobic, photosynthetic with *bacteriorhodopsin* [pigment]; *thermophile*: sulfur-based chemoautotroph; high acid, base, pressure environments];

bacteria: *kingdom*: ***proteobacteria*** [$\boldsymbol{\alpha}$: N-fixing, eukaryotic host; $\boldsymbol{\beta}$: nitrogen recycling [oxidize NH_4^+, NO_2^- as waste product]; $\boldsymbol{\gamma}$: oxidize H_2S, S as waste product; some pathogenic; $\boldsymbol{\delta}$: slime secreting, under unfavorable condition form myxospore [endospore]; $\boldsymbol{\varepsilon}$: pathogenic], ***chlamydia*** [parasitic, walls lack peptidoglycan], ***spirochete*** [*helical*, *corkscrew motion*], ***cyanobacteria*** [photosynthetic; some specialised for N-fixation], ***gram-positive bacteria*** [mostly free-living]; *shape* [*cocci* [spherical], *bacilli* [rod-shaped], spiral; flagella: proton motive force.

eukaryote: ***excavata*** [excavated groove on 1 side of cell body; [clades] ***diplomonads***, ***parabasalids***: highly reduced mitochondria, ***euglenozoans***: spiral, crystalline structure in flagella], **SAR** [photosynthetic; ***stramenopila*** [hairy and smooth flagella], ***alveolata*** [membrane-enclosed sacs [alveoli] beneath plasma membrane], ***rhizaria*** [amoebas with threadlike pseudopodia]], ***archaeplastida*** [***red*** [phycoerythrin [photosynthetic pigment]]***, green algae*** [chloroplast] [unicellular, colonial, multicellular], ***plants***], ***unikonta*** [***amoebozoans*** [amoebas with lobe-shaped, tube-shaped pseudopodia; *sporangium* [harsh condition]], ***opisthokonts*** [*protist* [hairy], *animal*, *fungi*]];

plants: ***nonvascular plant*** [bryophyte] [***liverwort***, ***moss***, ***hornwort*** [lack seta]; [dominant: *haploid gametophyte*] spores develop into *protonemata* [n], apical meristem of "buds" produced generate *gametophore*; *antheridia* produce, release sperms that travel through film of moisture to reach, fertilize eggs within *archegonium* of female *gametophyte*; *zygote* [$2n$] form *sporophyte embryo*, grow *seta* [long stalk] [*attached to gametophyte at foot for nutrition*] that emerges from archegonium; *lid* of mature sporangium drops, haploid *spores* released], ***seedless vascular plants*** [***fern***; [dominant: *diploid sporophyte*] sporangia release spores which develop into *bisexual photosynthetic gametophyte*; sperm directed to egg by attractant secreted by *archegonia*, fertilization; *zygote* develops into *sporophyte*, underside of *reproductive leaves* are *sori* [clusters of *sporangia*]; ***lycophytes***: *microphylls*, other vascular plant have *megaphyll* [leaf supported by branched vascular tissue]], ***gymnosperms*** [flowerless seed plant; heterosporous: *megaspore* [female], *microspore* [male gametophyte]; ***conifer***: pollen cone contains *microsporangia*, *microsporocytes* divide by meiosis to form haploid *microspores*, develops into *pollen grain*; *pollen tube* digests into *megasporangium* in *ovule*, while *megasporocyte* undergoes meiosis, 1 [of 4] haploid cells survive as *megaspore*, which develops into *female gametophyte* that contains 2,3 *archegonia*; each forms an egg fertilized by sperm, *ovule* becomes *seed*], ***angiosperms*** [radial, bilateral symmetry of flowers].

fungi [cell wall of chitin]: continuous [*filamentous*] network of *hyphae* [fungi, subterranean *mycelium*; feed by absorption] [*septate hypha* [*septa* [cross-wall], pores allow organelles to flow], *coenocytic hypha* [continuous cytoplasmic mass]]; ***ectomycorrhizal fungi*** form sheaths of hyphae over surface of root, grow into extracellular spaces of root cortex, ***arbuscular mycorrhizal fungi*** extend *arbuscule* [branched hyphae, nutrition exchange] through root cell wall; ***sexual reproduction***: hyphae from 2 *mycelia* release pheromones that bind to receptors, hyphae extend toward source; fuse [*plasmogamy*: union of cytoplasm of parent mycelia]; *heterokaryotic stage* [genetically different nuclei coexist] [*dikaryotic mycelium*: two separate haploid nuclei in cell, divide in tandem]; *karyogamy* [nuclei fuse, meiosis of diploid cells restores haploid condition, form genetically diverse spores]; ***asexual reproduction*** [*deuteromycete*: lack sexual reproduction]: *fragmentation* [breaking up hyphae], *budding* [small hyphal outgrowth], *asexual spores* [*sporangiospores*: produced in sporangia borne on sporangiophore [stalk]; *conidia*: [produced at tips of conidiophores [specialized hyphae], not enclosed inside sac; groups: ***chytrids*** [ubiquitous in lake, soil; flagellated spore], ***zygomycete*** [rapid growth; decomposer, parasite, symbiont], ***glomeromycetes*** [mutualism with plant [roots]], ***ascomycetes***, ***basidiomycetes*** [long heterokaryotic stage].

neoproterozoic era [ediacaran biota: soft-bodied multicellular eukaryotes]; ***paleozoic era*** [cambrian explosion]; ***ordovician***, ***silurian***, and ***devonian*** period, increase in diversity punctuated by mass extinctions; ***mesozoic era*** [spread of habitats, first mammal appear]; ***cenozoic era*** [exploit of vacated ecological niche [large, non-avian dinosaur]; coelomate [true coelom [body cavity lined with only mesoderm [line internal organ]]; endoderm line digestive tract; ectoderm cover body]; pseudocoelomate [pseudocoelom between mesoderm, endoderm]; acoelomate [lack body cavity between digestive cavity, muscle]; metazoa clade: all animal; eumetazoan clade: animal with tissue; bilateria clade [lineages]: lophotrochozoa [ciliated tentacle; facilitate in feeding], ecdysozoa [external skeleton, most display molting], deuterostomia [chordata: only phylum with vertebrate];

porifera [sponge]: [filter-feeder] wall consists of *epidermis* [tightly-packed cells], *choanocytes* [flagellated cell; current draws water in through *pores* [doughnut-shaped cell], enter *spongocoel* [cavity], out through *osculum* [upper opening]], separated by *mesohyl* [gelatinous matrix]; *flagellum* projections trap food particle in *mucus*, engulfed by phagocytosis, digested or transferred to *amoebocyte* [transport nutrients to other cells, produce materials for skeletal fibers [spicules], or differentiate [act as stem cell]]; *hermaphrodites*: function as both sex.

cnidara: *gastrovascular cavity* [central digestive compartment; ***polyps*** [sessile]: *mouth/anus* at *aboral end*; ***medusa*** [mobile]: opening at *tentacles* [contain *cnidocytes* [defence]]] covered with *gastrodermis*; *mesoglea*, *epidermis layers*, *body stalk* [forms alternate]; ***medusozoan*** include ***scyphozoans*** [jellies], ***cubozoans*** [box jellies], ***hydrozoans*** [colony of interconnected *polyps* from budding; some equipped with tentacles for feeding, others specialised for reproduction produce *medusae* by budding; swim off, grow, reproduce sexually; zygote develop into planula [solid ciliated larva], settles, develops into new *polyp*]; ***anthozoan*** secrete exoskeleton [coral]

lophotrochozoan phyla: ***flatworms***, ***rotifers***, ***acanthocephalans***, ***ectoprocts***, ***brachiopods***, ***molluscs***, ***annelids***.
platyhelminthes [acoelomate flatworms]: free-living flatworms [planarians; carnivores in marine or freshwater]; flukes [parasites that suck tissue fluids, blood]; tapeworms [internal parasites; proglottids [segment in strobila contain sexually mature reproductive system]; no digestive tract, absorb pre-digested food]; others: saclike gut.
nematoda: roundworms: pseudocoelomate with complete digestive tract; free-living soil dwellers decompose, recycle nutrients [cause trichinosis when ingested via incompletely cooked meat].
rotifera: multicellular, specialized organs enclosed in pseudocoelom, complete digestive tract; filter-feeder.

mollusca: nerve ring around *oesophagus*, from which *nerve chords* extend; long *digestive tract* coiled in *visceral mass*; mouth region contains *radula* [backward-curved teeth]; [open circulatory system] dorsally located heart pump haemolymph [circulatory fluid] through arteries into *sinus* [body space]; *metanephridia* remove metabolic waste from haemolymph; [class] ***gastropoda***: snails [single shell]; ***cephalopoda***: octopus, squid [high O_2 demand, giant nerve fibers, closed circulatory system; developed NS]; ***bivalvia***: clams, mussels, [bivalves [2 part shells]].

annelida: [segmented worms] *cerebral ganglia* above *pharynx*; *nerve ring* connects to *subpharyngeal ganglion*, from which fused pair of *nerve cords* runs posteriorly; ventral nerve cords penetrate septa, run length of animal [as do digestive tract, longitudinal blood vessels]; closed circulatory system, dorsal, ventral vessels linked by segmental pairs of vessels [muscular vessel pump blood through system]; tiny blood vessels abundant in skin [function as respiratory organ]; segment contain 4 chaetae [bristles; traction for burrowing]; coelom partitioned by septa; metanephridium [excretory tubule] discharge waste from blood, coelomic fluid through exterior pore.

arthropoda [ecdysozoa]: ***spiders***, ***insects***, ***crustaceans***; jointed *appendages*, well-developed nervous system; specialized body segments, *exoskeleton* [chitin]; types of life cycles: ***nymphs*** [small version of adult]; ***larvae*** [*metamorphosis* into adults]; [classes] ***insects*** [nervous system consists of a pair of *ventral nerve cords* with several *segmental ganglia*; *mouthparts* formed from several pairs of modified appendages [specialised for chewing [mandibles], lapping, piercing, sucking]; metabolic wastes removed from haemolymph by *malpighian tubules* [outpocketings of digestive tract]; *tracheal system* of branched, chitin-lined tubes infiltrate the body, carry O_2 directly to cells, opens to outside of body through spiracles [pores that control air flow, water loss]; *heart* drives haemolymph through *open circulatory system*; 2 nerve cords meet in the head, where *ganglia* of several anterior segments fused into *brain*; *antennae*, *eyes*, other sense organs are concentrated on head; ***arachnids*** [4 pair of legs, book lungs [many fine lamellae, situated in abdomen, openings on underside]], ***crustaceans*** [subphylum] [segmented body with variable number of appendages, have gills].

echinodermata [coelomate deuterostome]: sea star, urchin; adults: radial; young: bilateral symmetry.

chordata: notochord [longitudinal, flexible rod located between digestive tube, nerve cord; define primitive axis of embryo]; dorsal, hollow nerve cord [develops from plate of ectoderm that rolls to neural tube located dorsal to notochord, develops into CNS]; pharyngeal slits/clefts [water entering mouth to exit body without passing through digestive system; gills, filter-feeding device]; muscular, post-anal tail; invertebrates: lancelets, tunicates.

ecology

organismal ecology [physiological, evolutionary, behavioral ecology] how structure, physiology, behavior meet environmental challenges; ***population ecology***: factors that affect population size, changes in time; ***community ecology***: how interactions between *species* affect community structure and organization; ***ecosystem ecology***: emphasizes energy flow and chemical cycling between *organisms and environment*; ***landscape ecology***: factors controlling exchanges of energy, materials, and organisms across *multiple ecosystems*; ***global ecology***: how regional exchange of energy and materials influence functioning, distribution of organisms across the *biosphere*.

tropical forest [equatorial, subequatorial]; ***desert*** [30˚ latitude, interior of continents]; ***savanna***: fire-resistance plants, forbs grow in response to seasonal rains; ***chaparral*** [midlatitude coastal regions]: shrubs, small trees; ***temperate grassland***; ***northern coniferous forest***; ***temperature broadleaf forest*** [northern midlatitude]: distinct vertical layers: closed canopy, understory trees, shrub, herb [epiphytes: air plant]; ***tundra*** [arctic]: frozen subsoil.

lakes [stratification [light decrease with depth], seasonal thermocline [summer]; oligotrophic [nutrient-poor]; eutrophic [O_2 poor]]; ***wetlands***; ***streams and rivers***; ***estuaries*** [transition area: river and sea]; ***intertidal zones***; oceanic ***pelagic zone*** [*photic* [light for photosynthesis], *aphotic*]; ***coral reefs***; marine ***benthic zone*** [ocean floor]; ***aquatic biome***: *abyssal zone* [deep ocean floor]; *neritic zone* [shallow waters], above *continental shelf*. ***ecological-evolutionary interaction***: distribution limited by dispersal, biotic, abiotic factors.

population size [mark-recapture method]: $x_{\mathrm{marked},2}/n_{\mathrm{captured},2} = s_{\mathrm{released},1}/x_{\mathrm{pop.size}}$;
patterns of distribution: ***clumped*** [resources]; ***uniform*** [territoriality]; ***random*** [physical conditions uniform].
survivorship curve: Type I [*low* mortality initially] [large mammals]; Type III [*high* mortality for young] [numerous offspring, little care]; Type II [*constant* death rate] [small mammals]; stair-stepped: mortality during molts.
reproductive rates: match of egg DNA to genetic profile of females [PCR]; percentage of females breeding.
change in population size: birth + imigrants – deaths – emigrants; $\dot{\mathrm{N}} = \mathrm{B} - \mathrm{D} = \mathrm{rN}|_{\mathrm{exp}} = \mathrm{rN(K-N)K^{-1}}|_{\mathrm{log}}$;
density-dependent regulation: *competition for resources*; *disease*; *predation* [rise in predator population]; *territoriality*; *intrinsic factors* [physiological factors, hormonal change that delay sexual maturation]; *toxic waste*.

interspecific interaction: *competition* [resource partitioning; niche]; *predation* [mechanical, chemical defense, *aposematic [warning]*, *cryptic coloration* [camouflage], *Batesian, Müllerian mimicry* [both harmful]]; *herbivory*; *parasitism* [endoparasites, ectoparasites]; *mutualism*; *commensalism*; *amensalism*.
Shannon diversity: $\mathrm{H} = -(p_A \ln p_A + p_B \ln p_B + \cdots)$, p is relative abundance [%] of each species; $\mathrm{S} = cA^z$.

water cycle: precipitation over land [evapotranspiration from land], percolation through soil, runoff and groundwater into ocean, evaporation from ocean [precipitation over ocean], movement over land by wind; ***carbon cycle***: CO_2 in atmosphere [burning of fossil fuels, cellular respiration, decomposition], photosynthesis by phytoplankton, plants; ***nitrogen cycle***: NO_3^- runoff to ocean from farmland, N fertilizers [industrial fixation]; denitrification of plants, reactive N gases released by factories, contribute to N_2 in atmosphere, dissociate to NO_3^- in ocean, decomposition and sedimentation release NH_4^+ nitrogen; ***phosphorous cycle***: weathering of rocks, runoff into dissolved PO_4^{3-}, uptake by plankton, decomposition form PO_4^{3-}, sedimentation, geographical uplift to land, windblown dust to atmosphere; leaching [into ocean], plant uptake of PO_4^{3-} from decomposed consumers.

biodiversity: ***habitat loss*** [***deforestation***, ***desertification*** [overgrazing]]; ***introduced species***; ***overharvesting***; ***global change*** [***acid precipitation*** [burning of fossil fuels that release SO_2, NO_2, react with water vapour to form sulfuric, nitric acid]; climate change [greenhouse effect [CO_2]; ozone depletion [$O_2 + \mathrm{UV} \rightarrow O_3$; CFC break down O_3; absorb radiation]; pollution [eutrophication [nutrient enrichment in lakes, increase in biomass [algal bloom], depletion of O_2, O_2 starvation]]; biological magnification [toxins [antibiotics, hormones, carcinogens, teratogens [cause birth defects]]]]; ***reduction in species diversity*** [minimum viable population $\mathrm{N_e} = 4\mathrm{N_f} \cdot \mathrm{N_m}/(\mathrm{N_m} + \mathrm{N_f})$].