1 Cell biology

Introduction

- eukaryotes have a much more complex cell structure than prokaryotes; evolution allowed cell specialization and cell replacement
- cell division is essential but is carried out differently in pro- and eukaryotes
- biological world is very diverse; cells have universal features

1.1 Introduction to cells

The cell theory

- internal structure is built up from very small individual parts
- large organs are made up from number of different tissues: microscope allows examination
- with microscope certain features were seen again and again: cell theory was developed to explain the basic features of structure: cells are fundamental building blocks of living organisms
- smallest organism is unicellular, larger organisms are multicellular
- cells vary in size but share following features: surrounded by membrane, contain genetic material, many activities are chemical reactions catalyzed by enzymes, own energy release system: cells thought to be smallest living structures, nothing smaller can survive

Unicellular organisms

- functions of life: things an organism has to do to survive
- in unicellular organisms a cell has to carry out all functions of life: structure of unicellular organisms is more complex than most cells in multicellular organisms
- 7 functions: nutrition, metabolism, growth, response, excretion, homeostasis, reproduction
- many unicellular organisms have a method of movement (some remain fixed)

Limitations on cell size

- metabolic rate of the cell is proportional to the volume of the cell
- substances must be absorbed and waste products removed for metabolism to continue
- substances move through plasma membrane: rate at which they cross the membrane depends on surface area
- surface area to volume ratio is important: if it is too small substances will not enter as quickly as needed and waste products won't leave fast enough
- if the ratio is too small then cells may overheat because the metabolism produces heat faster than it is lost over the cell's surface

Multicellular organisms

- some unicellular organisms live together in colonies: they cooperate but are not fused together to form a single cell mass and so are not a single organism
- organisms consisting of a single mass of cells fused together are multicellular
- intensively researched multicellular organisms is worm *Caenorhabditis elegans*
- *C. elegans* cells called neurons (most located in front: like brain): though the brain coordinates responses to worm's environment to does not control how individual cells develop: cells in this and other multicellular organism can be regarded as cooperative groups without leader
- characteristics of whole organism, including that it is alive, are known as emergent properties
- emergent properties arise from interaction of the component parts of a complex structure

Cell differentiation in multicellular organisms

- different cells perform different functions: division of labour
- group of cells specialize in the same way to perform the same function: called a tissue
- becoming specialized they can carry out their function more efficiently: develop ideal structure
- development of cells in different ways to carry out specific functions is called differentiation

Gene expression and cell differentiation

- multicellular organisms have different cell types but all have the same set of genes

- cells have the genes needed to specialize in every possible way; in most cell types less than half of the genes will ever be used (expressed)
- development of cell involves switching on particular genes, expressing them, but not others
- cell differentiation happens because different sequence of genes is expressed in different cell types

Stem cells

- new animal life starts when a sperm fertilizes an egg cell to produce a zygote; embryo is formed when zygote divides repeatedly; at early stages cells are capable of dividing many times
- embryo cells are extremely versatile and can differentiate along different pathways into any of the cell types found in that particular animal: all adult tissues stem from them: stem cells
- stem cells have two key properties: can divide again and again, not fully differentiated
- embryonic stem cells could be used to produce regenerated tissue, might even grow whole organs: types of use are therapeutic (provide therapies for diseases, other health issues)
- non-therapeutic uses: produce large quantities of meat for human consumption
- stem cells are most versatile in early embryonic stage; during embryo development cells commit themselves to a pattern of differentiation, once committed the cell can still divide but all of these will differentiate in same way: no longer stem cells
- small number of stem cells remain present in adult body (found in bone marrow, skin, liver): considerable powers of regeneration and repair; stem cells in other tissues only allow limited repair (e.g. brain, kidney, heart)

1.2 Ultrastructure of cells

The resolution of electron microscopes

- unaided eye can see things with size of 0.1 mm as separate objects, but no smaller
- light microscope allows to see cells, size 0.2 µm (limited by wavelength of light)
- resolution: making separate parts of an object distinguishable by eye
- electron beams have shorter wavelength: electron microscopes have higher resolution (1 nm)
- light microscopes reveal structure of cells, electron microscopes reveal ultrastructure
- Millimetres x 1'000 = Micrometers (µm); Micrometers x 1'000 = Nanometers (nm)

Prokaryotic cell structure

- all organisms are divided into two groups according to cell structure: eukaryotes have a compartment within cell (nucleus with chromosomes), prokaryotes don't have a nucleus
- prokaryotes were first organisms to evolve as they have the simplest cell structure
- all cells have a cell membrane, but some have cell wall (including prokaryotes)
- prokaryote's cytoplasm is not divided into compartments: one uninterrupted chamber
- prokaryotes don't have cytoplasmic organelles apart from ribosomes; these are smaller than in eukaryotes: 70S (Svedberg units)
- part of cytoplasm appears lighter: region contains DNA, usually in form of one circular DNA molecule; not associated with proteins; region is called nucleoid

Cell division in prokaryotes

- all living organisms need to produce new cell: only possible by division of pre-existing cells
- cell division in prokaryotes is called binary fission (asexual reproduction): circular chromosome is replicated, copies move to opposite cell ends, cytoplasm divides
- daughter cells are genetically identical

Eukaryotic cells structure

- much more complicated internal structure: eukaryotic cells are compartmentalized
- divided into partitions: partitions are single or double membranes
- most important compartment is nucleus (contains chromosomes)
- compartments in cytoplasm are organelles: each organelle has a distinctive structure and function
- advantages of compartmentalization: enzymes and substrates can be more concentrated, substances causing damage can be kept inside membrane of organelle, pH can be maintained at ideal level, organelles and contents can be moved around in cell

1.3 Membrane structure

Phospholipid bilayer

- hydrophilic: substances attracted to water; hydrophobic: not attracted to water
- phospholipids have both properties: amphipathic (phospholipid molecule is hydrophilic, two hydrocarbon tails are hydrophobic)
- when mixed with water phospholipids arrange in double layers (hydrocarbon tails facing inwards, phosphate heads facing outwards): phospholipid bilayer
- stable structure and forms basis of all cell membranes

Membrane proteins

- cell membranes have wide range of functions; primary function is forming a barrier through which ions and hydrophilic molecules cannot easily pass: carried out by phospholipid bilayer
- almost all other functions are carried out by proteins: hormone binding sites (hormone receptors), immobilized enzyme with active site on outside (e.g. intestine), cell adhesion (form tight junctions), cell-to-cell communication (receptors for neurotransmitters in synapses), channels for passive transport (for hydrophilic particles, facilitated diffusion), pumps for active transport (use ATP)
- varied functions lead to very diverse structure and position in membrane of membrane proteins
- integral proteins: hydrophobic on at least one part, embedded, many are transmembrane
- peripheral proteins: hydrophilic on surface, not embedded, most are attached on surface of integral proteins (attachment often reversible), some have single hydrocarbon chain holding them to membrane surface
- proteins are orientated to fulfill functions correctly
- protein content of membranes is very variable: depending on function

Cholesterol in membranes

- in addition to phospholipids and proteins animal cell membranes contain cholesterol
- type of lipid but not fat or oil, is a steroid
- most of it is hydrophobic, attracted to hydrocarbon tails in centre of membrane; on end it has a hydroxyl group (-OH) which is hydrophilic: cholesterol is positioned between phospholipids
- amount of cholesterol varies

1.4 Membrane transport

Endocytosis

- vesicle: small sac of membrane with fluid inside; spherical, dynamic
- easily constructed and destructed due to fluidity of membrane
- to form a vesicle small region of membrane is pinched off, done by proteins using ATP
- vesicle formed inside of cell, containing fluid from outside of cell: method of taking materials into the cell: endocytosis
- vesicles from endocytosis contain water and solutes, but also larger molecules that cannot pass across plasma membrane

Vesicle movement in cells

- vesicles can be used to move materials in the cell
- example: protein synthesized by ribosomes on rough endoplasmic reticulum, vesicles bud off and move to Golgi apparatus (fuse with it) which processes it into its final form, vesicle buds off again and moves to place where protein is secreted
- example: growing cell: area has to increase: ribosomes synthesize membrane proteins, vesicles bud off the rough endoplasmic reticulum, move to plasma membrane and fuse with it
- this method can also be used for increase of organelles (lysosomes, mitochondria) in cell

Exocytosis

- release of material from cells using vesicles: process of getting the contents out of the cell
- example: digestive enzymes released by gland cells by exocytosis; synthesized, moved to Golgi apparatus, then to membrane; this case called secretion (useful substance released)

- exocytosis used to expel waste products and unwanted material: removal of excess water from unicellular organisms (e.g. Paramecium)

Simple diffusion

- one of the four methods of moving particles across membrane
- diffusion: spreading of particles due to continuous random motion
- particles move from area of high concentration to low conc.: down the concentration gradient
- diffusion is a passive process (no need of energy)
- simple diffusion across membranes: particles passing between phospholipids in membrane
- inner part of membrane hydrophobic: non-polar particles move easily through (e.g. Oxygen) but positively or negatively charged (polar) can only diffuse at low rates (smaller ones faster)

Facilitated diffusion

- ions and other particles that cannot diffuse between phospholipids can pass through channels
- channels are holes with very narrow diameter, consist of protein, chemical properties ensure that only one type of particle can pass: cell decides which channels to synthesize and place
- channels help particles move from a high to a low concentration

Osmosis

- water can mostly move freely in and out of cells; if more water moves into one direction than the other it is called osmosis
- occurs due to differences in solutes (substances dissolved in water); intermolecular bonds between substance and water, restrict water to move freely
- regions with a higher solute concentration have lower free water molecules: movement of water from regions with lower solute concentration to region of higher solute concentration
- despite water molecules being hydrophilic they can move through phospholipid bilayer because they are small enough; some cells have channels called aquaporins (e.g. kidney)

Active transport

- cells take in substances, though the concentration in the cell is higher: against the concentration gradient, is not diffusion
- ATP is used as energy source
- carried out by globular proteins: pump proteins
- once the ion or molecule enters the middle chamber ATP is used for conformational change of protein: opens up into the cell

1.5 The origin of cells

Cell division and the origin of cells

- since 1880s: theory that cells can only be produced by division of a pre-existing cell
- there is a continuity of life from its origins on Earth to the cells in our body today

Origin of the first cells

- tracing back should eventually lead to the earliest cell to have existed
- cells must have arisen from non-living material (unless they arrived from outer space)
- hardest question for biology: how could a structure as complex as the cell have arisen by natural means from non-living material?
- complex structures cannot arise by evolution; evidence that it could have formed over millions of years in a series of small steps; hypotheses how main steps could have occurred
- 1. Production of carbon compounds such as sugars and amino acids: Miller and Urey create atmosphere of early Earth (methane, hydrogen, ammonia), electrical discharges simulate lightning, amino acids and other carbon compounds needed for life were produced
- 2. Assembly of carbon compounds into polymers: origin of first carbon compounds around deep-sea vents, hot water carrying reduced inorganic chemicals (e.g. iron sulphide), chemicals represent readily accessible supplies of energy
- 3. Formation of membranes: if phospholipids or other amphipathic carbon compounds were among first, they would have naturally assembled into bilayers, allows different internal chemistry from that of the surrounding to develop

- 4. Development of a mechanism for inheritance: genes are made of DNA, to pass them on enzymes are needed, but to produce enzymes genes are needed; solution is that an earlier phase of evolution had RNA as genetic material, it is self replicating

Endosymbiosis and eukaryotic cells

- theory of endosymbiosis helps explaining evolution of eukaryotic cells: states that mitochondria were once free-living prokaryotic cells that had developed process of aerobic cell respiration
- larger prokaryotes that could only respire anaerobically took them in by endocytosis
- rather than killing and digesting them, they allowed them to continue to live in their cytoplasm
- as long as the smaller prokaryotes grew and divided as fast as the larger ones, they could persist indefinitely inside the larger cells: evolution made them the mitochondria of today
- the larger and smaller prokaryotes were in symbiotic relationship, both benefited (mutualistic relationship): smaller is supplied with food and carries out aerobic respiration to supply energy efficiently to the larger cell: natural selection favored cells with endosymbiotic relationship
- endosymbiotic theory also explains origin of chloroplasts: prokaryote that develops photosynthesis that was taken in by larger cell
- chloroplasts and mitochondria are no longer capable of living independently, but have features suggesting they evolved from independent prokaryotes: have own genes (circular DNA), own 70S ribosomes, transcribe their DNA and use mRNA to synthesize some own proteins, can only be produced by division of pre-existing mitochondria and chloroplasts

1.6 Cell division

The role of mitosis

- nucleus can divide to form two genetically identical nuclei by mitosis
- before mitosis, all of the DNA in the nucleus must be replicated (happens during interphase): each chromosome is converted into two identical DNA molecules (chromatids)
- mitosis is involved in embryonic development, growth, tissue repair, asexual reproduction
- mitosis is divided into four phases: prophase, metaphase, anaphase, telophase

Interphase

- cell cycle has two main phases: interphase and cell division
- interphase is a very active phase, many metabolic reactions occur
- DNA replication (in nucleus) and protein synthesis (in cytoplasm) only happen during interphase
- during interphase the number of mitochondria increases; in plants the same with chloroplasts
- interphase consists of three phases: G_1 phase, S phase, G_2 phase
- in S phase cell replicates all genetic material in its nucleus
- some do not progress beyond G_1 because they are never going to divide: enter G_0 which may be temporary or permanent

Supercoiling of chromosomes

- two chromatids making up each chromosome must be separated during mitosis
- DNA in chromosomes are immensely long: essential to package chromosomes into much shorter structures: condensation of chromosomes during first stage of mitosis
- condensation: repeatedly coiling DNA molecule (chromosome shorter and wider): supercoiling
- histone proteins associated with DNA help with supercoiling and enzymes are involved

Cytokinesis

- cells divide after mitosis when two genetically identical nuclei are present in cell
- process of division is cytokinesis: happens differently in plant and animal cells
- in animal cells plasma membrane is pulled inwards using contractile protein (actin, myosin)
- when cleavage furrow reaches centre, cell is pinched apart into two daughter cells
- in plant cells vesicles are moved to equator, they fuse to form tubular structures across equator
- then more vesicles fuse with tubular structures and form two layers of membrane, completing division of cytoplasm; next, pectins and other substances are deposited by exocytosis between two new membranes (forms middle lamella, links cell walls)
- cellulose is brought adjacent to lamella; each cell builds its own cell wall adjacent to equator

Cyclins and the control of the cell cycle

- each phase of cell cycle involves many important tasks: cyclins (proteins) ensure that tasks are performed at correct time and cell only moves to next stage when appropriate
- cyclins bind to cyclin-dependent kinases (enzymes): these become active and attach phosphate groups to other proteins: phosphorylation triggers proteins to carry out tasks
- four main types of cyclin in humans; unless cyclins reach threshold concentration, the cell does not progress: cyclins control cell cycle

Tumour formation and cancer

- tumours are abnormal groups of cells that develop at any stage of life in any part of body
- in some cases cells adhere, do not invade nearby tissues, unlikely to cause harm: benign
- other tumours become detached, move elsewhere and develop into secondary tumours: malignant and very likely to be life-threatening: cancers
- chemicals and agents causing cancer are known as carcinogens; all mutagens are carcinogenic
- mutagens are agents that cause gene mutations and mutations cause cancer
- mutations are random changes to base sequence of genes; the few genes that can become cancer-causing after mutating are oncogenes; in normal cell oncogenes are involved in control of cell cycle: this is why mutations can result in uncontrolled cell division
- several mutations must occur in same cell for it to become tumour cell: chance of happening is small but there are many cells in body so total chance in lifetime is significant
- when tumour cell has been formed it divides repeatedly: primary tumour; metastasis is movement of cells form primary tumour to set up secondary tumours in other part of body

2 Molecules to metabolism

Introduction

- living organisms control their composition by complex web of chemical reactions that occur within water
- compounds of carbon, hydrogen and oxygen are used to supply and store energy
- proteins act as enzymes, genetic information is stored in DNA

2.1 Molecules to metabolism

Molecular biology

- explaining of living processes in terms of chemical substances involved
- discovery of DNA structure (1953) started revolution in biology
- possibility of explaining biological processes from structure of molecules and how they interact
- many molecules are important: some as simple as water, most varied and complex are nucleic acids and proteins
- nucleic acids comprise DNA and RNA: used to make genes
- proteins are varied in structure and carry out huge range of tasks
- relationship between genes and proteins is at the heart of molecular biology
- approach to molecular biology is reductionist

Carbon compounds

- carbon can be used to make huge range of different molecules; organisms have limitless possibilities for chemical composition
- carbon atoms can form four covalent bonds (strongest bond between atoms), more than most other atoms: molecules can have complex structures
- bonds between carbon atoms, also other elements (hydrogen, oxygen, nitrogen, phosphorus)
- four bonds can be single covalent bonds or two single and one double

Classifying carbon compounds

- four main classes of carbon compounds, have different properties: different purposes
- carbohydrates: characterized by composition: carbon, hydrogen, oxygen (hydrogen to oxygen ratio is 2:1)
- lipids: insoluble in water, include steroids, waxes, fatty acids, triglycerides
- proteins: composed of one or more chains of amino acids, all contain carbon, hydrogen, oxygen, nitrogen; two of the 22 contain additionally sulphur
- nucleic acids: chains of subunits called nucleotides, contain carbon, hydrogen, oxygen, nitrogen, phosphorus; two types: ribonucleic acid (RNA), deoxyribonucleic acid (DNA)

Metabolism

- organism carry out many different chemical reactions which are catalyzed by enzymes
- most reactions happen in cytoplasm, some are extracellular
- metabolism is the sum of all reactions that occur in an organism
- consists of pathways, happens in small steps; mostly chains of reactions, can be cycles

Anabolism

- build up larger molecules from smaller parts
- anabolic reactions require energy, usually in form of ATP
- includes: protein & DNA synthesis, photosynthesis, synthesis complex of carbohydrates

Catabolism

- larger molecules are broken down into smaller ones
- catabolic actions release energy
- includes: digestion of food, cell respiration, digestion of complex carbon compounds

2.2 Water

Hydrogen bonding in water

- water molecule: covalent bonds between oxygen and two hydrogen atoms
- bond involves unequal sharing of electron: polar covalent bond: hydrogen atoms have a partial positive charge, oxygen has a partial negative charge
- attraction between water molecules is a hydrogen bond (intermolecular force)
- Hydrogen bond is weak, collectively they give water unique properties

Properties of water

- <u>cohesive properties</u>: binding of molecules of the same type
- water molecules stick to each other due to hydrogen bonding: useful for water transport in plants: water sucked trough xylem vessels at low pressure: only works when water isn't separated by suction forces
- <u>adhesive properties</u>: hydrogen bonds can form between water and other polar molecules: water sticks to them
- useful in leaves: water adheres to cellulose in cell walls, water evaporates, water drawn from nearest xylem vessel, keeps cell wall moist: absorb carbon dioxide for photosynthesis
- <u>thermal properties</u>: high specific heat capacity, latent heat of vaporization and boiling point
- high specific heat capacity: hydrogen bonds restrict motion of molecules and increase temperature required to break them; energy needed to raise temperature of water is large, to cool down water must lose large amounts of energy: thermally stable habitat
- high latent heat of vaporization: when molecule evaporates it separates from molecules in liquid (heat needed for process is latent heat): evaporation has a cooling effect: sweating as example
- high boiling point: highest temperature it can reach in liquid state; water is liquid over broad range of of temperatures
- <u>solvent properties</u>: polar nature of water forms shells around charged molecules preventing them to clump (keeping them in solution); partially negative oxygen pole attracted to positively charged ions, partially pos. hydrogen pole attracted to negatively charged ions: both dissolve

Hydrophilic and hydrophobic

- hydrophilic: substances that are chemically attracted to water
- all substances that dissolve in water are hydrophilic, as do substances that water adheres to
- some substances are insoluble, molecules are hydrophobic if they don't have a negative or positive charges (nonpolar); all lipids are hydrophobic
- two nonpolar molecules surrounded by water brought together by random movement will behave as if they were attracted to each other
- water molecules are more attracted to each other than to the nonpolar molecules: nonpolar molecules join together in water: hydrophobic interactions

2.3 Carbohydrates and lipids

Carbohydrates

- glucose, fructose, ribose are monosaccharides (single sugar units)
- monosaccharides can be linked to make larger molecules: disaccharides (two monosaccharides, e.g. maltose (2x glucose), sucrose (glucose, fructose); polysaccharides (many monosaccharides), e.g. starch, glycogen, cellulose (linked glucose molecules)
- condensation reaction (anabolic process, uses ATP): when linking monosaccharides, one loses -OH and the other -H which forms water, reaction yields water

Lipids

- all lipids are insoluble in water
- triglycerides (three fatty acids with one glycerol) as one of principal groups
- fats are liquid at body temperature but solid at room temperature, oils are liquid at both
- triglyceride is made by condensation reaction, three water molecules produced, ester bond created (-OH group on glycerol reacts with -COOH of fatty acid)
- triglycerides act as energy stores, can be released by anaerobic respiration, also conduct heat badly and are used as insulators

Fatty acids
- basic structure: chain of carbon atoms, hydrogen linked by single covalent bonds: hydrocarbon chain: one end is the acid part (carboxyl group: -COOH)
- most living organisms have length of hydrocarbon chain between 14 and 20 carbon atoms
- some fatty acids have carbon atoms linked by single covalent bonds, other have one ore more double covalent bonds (can bond only with one hydrogen)
- fatty acid with single bonds contains as much hydrogen as possible: saturated fatty acid
- with one double bond it is a monounsaturated and more than one it's polyunsaturated fatty acid

Unsaturated fatty acids
- in living organisms hydrogen atoms nearly always on the same side of double bonded carbon atoms: these are cis-fatty acids; hydrogens on opposite sides are trans-fatty acids
- cis-fatty acids: hydrocarbon chain has a bend, bad for packing in regular arrays, lower melting point, liquid at room temperature: oils
- trans-fatty acids: no bend, higher melting point, solid at room temperature, produced artificially

2.4 Proteins
Amino acids and polypeptides
- polypeptides are chains of amino acids linked by condensation reactions: happens on ribosomes during translation
- polypeptides are the main component of proteins
- condensation reaction involves amine group ($-NH_2$) and carboxyl group (-COOH), water is eliminated, new bond is called peptide bond
- dipeptide consists of two molecules; oligopeptides have less than 20; over 20 is polypeptide

The diversity of amino acids
- amino acids linked by ribosomes share some identical features: carbon atom in the centre of molecule is bonded to amine group, carboxyl group and hydrogen atom and R group (this is different in each amino acid)
- twenty different amino acids are used by ribosomes
- amine and carboxyl groups are used for forming peptide bond, R group gives its character
- the twenty amino acids are chemically very diverse due to differences in R groups
- some proteins contain amino acids not in the basic 20; in most cases it is one of these 20 being modified after a polypeptide has been synthesized (e.g. collagen: polypeptides contain proline which is changed to hydroxoproline to stabilize)

Polypeptide diversity
- ribosomes link amino acids one at a time until polypeptide is fully formed
- peptide bonds can be made between any amino acid so any sequence is possible
- huge range of possible polypeptides

Genes and polypeptides
- living organisms produce small fraction of possible amino acid sequences, still an organism produces polypeptides with thousands of different sequences: information has to be stored
- amino acid sequence of each polypeptide is stored in coded form in base sequence of a gene
- most genes in a cell store amino acid sequence of a polypeptide: genetic code used for it: three bases code for each amino acid (polypeptide with 400 amino acids = 1200 bases, but in reality always longer: extra base sequences at both ends and sometimes at certain points in middle)
- base sequence coding for polypeptide is known as "open reading frame": open reading frames only occupy small proportion of total DNA of species (puzzle to molecular biologists)

Proteins and polypeptides
- integrin: membrane protein with two polypeptides, like folding knife: can be adjacent or unfold when working
- collagen: three long polypeptides, wound together into rope-like molecule giving greater tensile strength, winding also allows small amount of stretch
- hemoglobin: four polypeptides, associated non-polypeptide structures: transport oxygen better

Protein conformations
- conformation of protein is the three-dimensional structure, determined by amino acid sequence
- fibrous proteins (collagen) are elongated (often repeating structure), many proteins are globular
- amino acids added one by one to form polypeptide; always added in same sequence for particular polypeptide
- in globular proteins polypeptides fold up to develop final conformation, stabilized by R groups
- globular proteins soluble in water have hydrophilic R groups on outside and hydrophobic inside
- membrane proteins have hydrophobic regions on outside which attract to centre of membrane
- in fibrous proteins amino acid sequence prevents folding and ensures that it is elongated

Protein functions
- no other carbon compound can compare with versatility of proteins
- functions: catalysis, muscle contraction, cytoskeleton, tensile strengthening, blood clotting, transport of nutrients and gases, cell adhesion, membrane transport, hormones, receptors, packing of DNA, immunity
- proteins have many biotechnological uses; expensive, still not easy to synthesize artificially

Proteomes
- proteome: all of the proteins produced by a cell, tissue or organism
- genome: all of the genes in a cell, tissue or organism
- genome of organism is fixed, proteome is variable (different cells make different proteins, also may vary in one cell over time)
- proteome reveals what is actually happening in an organism
- each person has a unique proteome due to differences of activity and small differences in amino acid sequence of proteins

2.5 Enzymes
Active sites and enzymes
- catalysts: speed up chemical reactions without being altered themselves
- found in all living cells and can be secreted to work outside of cell
- enzyme-substrate specificity: one enzyme can only catalyze one biochemical reaction
- active site: special region where substrates bind to (shape and chem. properties must match)
- substrates are converted into products while bound to active site, then released, freeing the active site for the next reaction

Enzyme activity
- substrate molecule can only bind if it moves very close to active site: collision
- with most reactions the substrates are dissolved into water: all molecules are in contact with each other and in continual motion
- most substrate molecules are smaller than enzyme: move faster
- random movement of substrate and enzyme cause collisions: orientation is important too

Factors affecting enzyme activity
- temperature increase: particles are given more kinetic energy: higher chance of colliding: enzyme activity increases
- temperature increase: bonds in enzyme vibrate more: bonds can break: structure including active site changes: enzyme is denatured: enzyme activity decreases
- pH scale for acidity (logarithmic): acidity due to hydrogen ions
- pH: enzymes have optimum at highest activity: if pH is increased or decreased activity decreases, eventually stops
- pH: hydrogen ions change structure of enzyme: beyond certain concentration structure is irreversibly altered: denaturation
- not all enzymes have same pH optimum
- enzyme cannot catalyze until substrate binds to active site
- substrate concentration: decrease of concentration decreases number of collisions: enzyme activity decreases and vice versa

- substrate concentration: increase of concentration: increasing occupation of enzymes: rate of reaction decreases: with increasing concentration enzyme activity rises less but never reaches maximum

Denaturation

- structure of enzyme (protein) can be irreversibly altered: high temperature, high or low pH
- substrate either cannot bind or when it binds the reaction isn't catalyzed
- in many cases enzymes get insoluble in water

Immobilized enzymes

- Buchner brothers (1897): show that enzymes can catalyze reactions outside of living cells
- over 500 enzymes have commercial uses: enzymes are usually immobilized
- immobilization: attachment of enzyme to another material or into aggregation which restricts enzyme movement
- advantages: enzyme can be separated from products, after take-out of reaction mixture they can be recycled, increases stability of enzyme to changes in temperature and pH, enzyme can be exposed to higher substrate concentrations

2.6 Structure of DNA and RNA

Nucleic acids and nucleotides

- materials extracted from nuclei of cells
- two types: DNA and RNA: large molecules that are constructed by linking nucleotides to form a polymer
- consist of three parts: sugar (five C-atoms: pentose), phosphate (acidic, negatively charged), base (contains nitrogen, one or two rings in structure)
- base and phosphate are linked by covalent bonds to pentose sugar
- phosphate of one nucleotide and sugar of another are linked by covalent bonds and form a strong backbone
- four different bases which can be linked in any sequence
- base sequence stores information and backbone ensures stability and security

Differences between DNA and RNA

- sugar in DNA is deoxyribose, sugar in RNA is ribose: DNA has one oxygen atom less
- two polymers of nucleotides in DNA, only one in RNA; polymers are referred to as strands: DNA is double stranded and RNA is single stranded
- bases in DNA are adenine, cytosine, guanine and thymine; in RNA thymine is replaced by uracil

Structure of DNA

- strand consists of chain of nucleotides linked by covalent bonds
- strands are parallel but in other directions: antiparallel: one in 5' to 3', the other 3' to 5'
- strands are held together by hydrogen bonds between nitrogenous bases
- adenine always paired with thymine and cytosine with guanine: complimentary base pairing

2.7 DNA replication, transcription and translation

Semi-conservative replication of DNA

- before cell division: strands of double helix separate: each serves as a template for the new strand: result is two DNA molecules, both of one original and one newly synthesized: semi-conservative replication
- complimentary base pairing: base sequence on the template strand determines the base sequence on the new strand

Helicase

- DNA strands must separate in order to be replicated
- helicases, a group of enzymes, separate and unwind the strands using ATP
- ATP is used to be able to break hydrogen bonds

DNA polymerase

- carries out the assembly of the new strands
- moves along the strand, adding one nucleotide at a time
- brings nucleotides into region where hydrogen bonds could form but unless it is the correct base the nucleotide breaks away again and no hydrogen bond is formed
- links the new nucleotide to the strand once a hydrogen bond has formed
- nucleotide is added by covalent bonds: phosphate group is 5’ terminal, pentose sugar 3’: adds 5’ of free nucleotide to 3’ end of existing strand
- very high degree of fidelity

Transcription

- two processes are needed to produce a specific polypeptide using the base sequence of a gene: transcription is the first process
- synthesis of RNA, using DNA as a template
- RNA is single stranded, hence transcription only occurs along one DNA strand
- outline: RNA polymerase binds on DNA at the beginning of a gene, RNA polymerase separates DNA and adds RNA nucleotides with complimentary bases (uracil instead to thymine), RNA polymerase forms covalent bonds between RNA nucleotides, RNA separates from DNA and double helix reforms, transcription stops at the end of a gene
- product is RNA molecule with base sequence complimentary to DNA: base sequence is identical to the other DNA strand (exception uracil)
- to make a RNA copy of one DNA strand, the other strand is transcribed
- DNA strand with same base sequence as RNA strand is the sense strand, the template strand is the antisense strand

Translation

- second process to produce specific polypeptide is translation
- synthesis of polypeptide with amino acid sequence determined by the base sequence of a RNA molecule
- takes place on ribosomes
- ribosomes are complex structures consisting of a large and small subunit with binding sites for each molecule that takes part in translation
- each subunit is composed of RNA molecules and proteins
- part of the large subunit makes the peptide bonds between amino acids to link them into polypeptides

Messenger RNA and the genetic code

- RNA carrying the information for synthesizing a polypeptide is called messenger RNA (mRNA)
- average mRNA length is 2’000 nucleotides
- only certain genes will be transcribed when they are used so only certain mRNA will be available in the cytoplasm
- if a cell needs a lot of a particular polypeptide it will make many mRNA copies
- other types of RNA are transfer RNA (tRNA, involved in decoding base sequence of mRNA into amino acid sequence during translation) and ribosomal RNA (rRNA, part of the structure of the ribosome)

Codons

- genetic code: enables to convert base sequence on mRNA into an amino acid sequence
- living organisms use triplet code: three bases code for an amino acid
- different codons can code for the same amino acid: code is degenerate
- three codons are „stop“ codons that code for the end of translation
- amino acids are carried on tRNA: each amino acid is carried by a specific tRNA which has a three base anticodon complimentary to the mRNA codon for that particular amino acid

Codons and anticodons

- three components work together to synthesize polypeptides by translation: mRNA (sequence of codons for the amino acid sequence), tRNA (anticodon of three bases binding to a

complimentary codon on mRNA and carry the amino acid corresponding to that codon), ribosomes (binding site for mRNA and tRNA and catalyst the assembly of the polypeptide)
- main events of translation: mRNA to small subunit of ribosome, tRNA with anticodon binds to ribosome, another tRNA binds to ribosome (two are maximum), ribosome binds first amino acid to second amino acid with a new peptide bond, ribosome moves along and first tRNA is released, another tRNA binds, ribosome makes a new peptide bond between the amino acids
- the process of adding further amino acids is repeated until a stop codon is reached
- accuracy depends on complementary base pairing: mistakes are very rare

2.8 Cell respiration

Release of energy by cell respiration

- all living cells perform cell respiration: organic compounds are broken down to release energy
- example: energy is released in muscle fibers by breaking down glucose into CO_2 and water
- carbohydrates and lipids are often used, but amino acids and proteins may also be used
- plants use carbohydrates or lipids previously made by photosynthesis
- cell respiration is carried out using enzymes to retain as much as possible of energy in usable form: adenosine triphosphate (ATP); to make it a phosphate group is linked to adenosine diphosphate (ADP); the energy required comes from the breakdown of organic compounds
- ATP is not transferred from cell to cell, all cells need continuous supply: cell respiration is an essential function of life in all cells

ATP is a source of energy

- ATP is used for synthesizing large molecules (DNA, RNA, proteins), active transport, moving things in cell (chromosomes, vesicles, protein fibers in muscles)
- energy from ATP is immediately available: it is split to ADP and phosphate
- ultimately all energy is converted to heat; heat cannot be reused
- cells require a continual source of ATP for cell activities

Anaerobic respiration

- glucose is broken down in anaerobic respiration without using oxygen; yield of ATP is small but quick: useful in short but rapid burst of ATP, oxygen supplies running out, oxygen-deficient environments (waterlogged soils)
- products of anaerobic respiration are not same in all organisms
- in animals glucose is converted to lactic acid which dissolves to lactate
- in yeast and plants glucose is converted to ethanol and carbon dioxide
- lactate and ethanol are toxic in excess and must be removed or produced in small quantities

Aerobic respiration

- with oxygen, glucose can be fully broken down to release more energy than in anaerobic cell respiration: anaerobic respiration yields 2 ATP per glucose while aerobic yields over 30
- aerobic cell respiration involves series of chemical reactions, water and CO_2 are produced
- water is useful while carbon dioxide is a waste product
- in eukaryotic cells most reactions happen in the mitochondrion

2.9 Photosynthesis

What is photosynthesis?

- living organisms require complex carbon compounds: some can make them only using light energy and simple inorganic substances: photosynthesis
- photosynthesis is an example of energy conversion

Wavelengths of light

- sunlight is made up of all wavelengths of electromagnetic radiation our eyes can detect
- other wavelengths are invisible to us
- shorter wavelengths (X-rays, ultraviolet radiation) have high energy; longer wavelengths (infrared radiation, radio waves) have low energy
- visible light (400-700nm) has wavelengths longer than ultraviolet but shorter than infrared
- violet and blue are the shortest wavelengths, red is the longest

- wavelengths detected by our eyes are those used for photosynthesis: penetrate Earth's atmosphere in larger quantities than others, so are particularly abundant

Light absorption by chlorophyll

- first stage in photosynthesis is light absorption which involves chemical substances (pigments)
- pigments absorb light and appear colored to us; pigments absorbing all colors appear black
- main photosynthetic pigment is chlorophyll, all appear green to us because they absorb red and blue light very effectively

Oxygen production in photosynthesis

- in photosynthesis water molecules are split (photolysis) to release electrons for other stage
- all oxygen generated in photosynthesis comes from photolysis of water
- oxygen is a waste product and diffuses away

Effects of photosynthesis on the Earth

- prokaryotes were first organisms to perform photosynthesis
- one consequence of photosynthesis is rise in oxygen concentration of atmosphere
- Great Oxidation Event (2'400 - 2'200 million years ago) oxygen concentration to 2%
- first glaciation happened at same time: probably due to reduction of greenhouse effect, rise in oxygenation decreased methane levels and photosynthesis decreased carbon dioxide
- increase in oxygen caused oxidation of dissolved iron in water: precipitates in water: distinctive rock formation is produced (banded iron formation)
- 750-635 million years ago there is a significant rise from 2% to 20% of oxygen: period when many groups of multicellular organisms were evolving

Production of carbohydrates

- plants convert carbon dioxide and water into carbohydrates by photosynthesis: require energy
- endothermic: chemical reaction that involves putting in energy
- reactions combining smaller molecules to make larger ones are also often endothermic
- energy for conversion of carbon dioxide into carbohydrates is obtained from light
- energy from light is converted to chemical energy in carbohydrates

Limiting factors

- rate of photosynthesis is affected by temperature, light intensity, carbon dioxide concentration
- each of the factors can limit the rate if they are below the optimum: limiting factor
- only one of the factors is actually limiting the rate: factor the furthest from optimum

3 Genetics

Introduction

- living organism inherits blueprint for life from parents
- chromosomes carry genes in linear sequence
- during meiosis alleles segregate allowing new combinations

3.1 Genes

What is a gene?

- gene: heritable factor consists of length of DNA and influences specific characteristic
- genetics: storage of information in living organisms and how information is passed on
- question about composition of genes: strong evidence it is DNA
- few DNA molecules in cell (46), yet thousands of genes: gene consists of shorter length of DNA than a chromosome and each chromosome carries many genes

Where are genes located?

- genes are linked in groups, each group corresponds to one type of chromosome in a species
- each gene occupies specific position on chromosome it is located: locus of a gene

What are alleles?

- Mendel: differences between varieties of peas he crossed together were due to different heritable factors
- pairs of heritable factors are alternative forms of same gene: alleles
- alleles occupy the same position on one type of chromosome; same locus
- only one allele can occupy the locus of the gene on a chromosome
- most animals have two of each type of chromosome: two alleles (either same or different)

Differences between alleles

- different alleles of gene have slight variations in base sequence; usually one or couple of bases
- positions in gene where more than one base may be present: single nucleotide polymorphisms (SNPs) several snips can be present in gene; even then alleles of gene differ by few bases

Mutation

- new alleles are formed from other alleles by gene mutation; mutations are random changes: no particular mechanism; most significant type is base substitution
- unlikely to be beneficial: mutations are either neutral or harmful, some are lethal
- mutations in body cells are eliminated when individual dies; mutations in gametes can be passed on to offspring causing genetic disease

What is a genome?

- genome: whole of genetic information of an organism
- living organism's genome is entire base sequence of each of its DNA molecules
- humans: 46 chromosomes in nucleus and DNA molecule in mitochondrion
- plant species: genome is DNA and DNA molecules in mitochondrion and chloroplast
- prokaryotes: DNA in circular chromosome and present plasmids

The Human Genome Project

- aim to find base sequence of entire human genome
- project drives rapid improvements in base sequencing techniques
- possible to predict which base sequences that are protein-coding genes
- most of the genome is not transcribed: affect gene expression and highly repetitive sequences
- example of a human genome
- vast majority of base sequences are shared by all humans; many snips contribute to diversity
- comparisons between genomes reveal aspects of evolutionary history

3.2 Chromosomes

Bacterial chromosomes

- prokaryotes have one chromosome consisting of circular DNA containing genes needed for basic life process; it is not associated with proteins, it is naked
- usually only a single copy of each gene (only after replication there are two before cell splits)

Plasmids

- plasmids are small extra DNA molecules, usually in prokaryotes, very unusual in eukaryotes
- contains few genes that may be useful to cell, but not essential e.g. antibiotic resistance
- plasmids are not always replicated at same time as chromosome
- copies can be transferred from one cell to another
- can cross the species barrier: when plasmid is released when prokaryote dies, another takes up
- are used by biologists to transfer genes artificially

Eukaryote chromosomes

- eukaryotic chromosomes are composed of DNA and protein
- long linear DNA molecule associated with histone protein
- adjacent histones separated by short stretches of DNA molecule, not in contact with histone

Differences between chromosomes

- eukaryote chromosomes are too narrow to be visible during interphase in light microscope; during mitosis and meiosis they are fatter and shorter by supercoiling and visible (with stains)
- two chromatids with identical DNA molecules are produced by replication
- chromosomes examined during mitosis show different types
- centromere holding chromatids together can be placed anywhere on chromosome
- every eukaryote has at least two types of chromosomes, most have more (humans: 23)
- every gene in eukaryotes occupies specific position on one type of chromosome: locus
- each chromosome type carries specific sequence of genes
- genes arranged in standard sequence allows parts to be swapped during meiosis

Homologous chromosomes

- carry the same sequences of genes but are not identical because alleles are different
- two eukaryotes of same species will have each chromosome homologous to a chromosome form the other: this allows members of a species to interbreed

Haploid nuclei

- haploid nucleus has one chromosome of each type, one full set of chromosomes
- gametes have haploid nuclei

Diploid nuclei

- diploid nucleus: has two chromosomes of each type, two full sets of chromosomes
- haploid gametes fuse together and produce zygote with diploid nucleus
- many plants/animals consist entirely of diploid cells apart of gametes for sexual reproduction
- two copies of every gene: effects of harmful recessive mutations can be avoided if a dominant allele is present; organisms are often more vigorous

Chromosome numbers

- most fundamental characteristic of species is number of chromosomes: can interbreed
- number of chromosomes can change during evolution of species: decrease of chromosomes fuse or increase if they split; there are some mechanisms doubling the number (rare)

Sex determination

- two sex chromosomes: X (relatively large) and Y (much smaller)
- all other chromosomes are autosomes
- X chromosomes has many genes essential for males and females; all humans have one
- Y chromosome has small number of genes; small part are same as on X chromosome
- remainder of Y chromosome cannot be found on X, not important for female development

- Y causes fetus to develop into male (SRY or TDF); initiates development of male features
- X does not have TDF gene, ovaries develop and female sex hormones are produced
- all offspring inherit a X from their mother; gender is determined at moment of fertilization
- formation of sperm produces half with X and half with Y chromosome

Karyograms

- chromosomes of organism are visible in cells that are in mitosis
- dividing cells stained and placed under microscope slide which bursts the cell
- chromosomes are arranged according to size and structure; distinguished by position of centromere and pattern of banding
- homologous pairs are arranged by size starting with longest, ending with smallest

3.3 Meiosis

Meiosis in outline

- one of the two ways a eukaryotic nucleus divides
- in meiosis the nucleus divides twice: meiosis I and meiosis II
- first division produces two nuclei each of which divides again creating total of four nuclei
- the four nuclei are haploid: meiosis is a reduction division
- halving of chromosome number happens in first division: two nuclei produced by meiosis I have haploid number but each chromosome consist of two chromatids; these separate in meiosis II

Meiosis and sexual life cycles

- cycles of organisms can be sexual or asexual; asexual offspring genetically identical to parent
- sexual life cycle: differences between chromosomes of offspring and parents: genetic diversity
- sexual reproduction involves process of fertilization which is the union of gametes
- fertilization doubles the number of chromosomes
- in animals meiosis happens during process of creating gametes
- evolution of meiosis is a critical step to origin of eukaryotes: sexual life cycle could not occur

Replication of DNA before meiosis

- DNA is replicated during interphase before meiosis, chromosome has two sister chromatids
- two chromatids are genetically identical
- DNA is not replicated between first and second division of meiosis

Bivalents formation and crossing over

- before supercoiling the homologous chromosomes pair up (4 DNA molecules because replication already happened), process is called synapsis
- pair of homologous chromosomes is a bivalent
- after synapsis crossing over takes place: junction is created where one chromatid in each of the homologous chromosomes breaks and rejoins with the other chromatid
- crossing over occurs at random positions; at least one crossover happens in each bivalent
- crossing over is a mutual exchange of genes
- some alleles of exchanged genes are different: chromatids with new combinations are created

Random orientation of bivalents

- after nuclear membrane breaks down, spindle microtubules attach to centromeres
- attachment is different than in mitosis: each chromosome attached to one pole only, two homologous chromosomes in bivalent attached to different poles, orientation (pole to which chromosome is attached to), orientation of bivalents is random, orientation of one bivalent does not affect other bivalents

Halving the chromosome number

- in meiosis the centromere does not divide, whole chromosomes move to poles
- chromosomes in bivalent held together by chiasmata; these slide to end of chromosome and then they separate (disjunction): halves chromosome number of cell
- nuclei formed in first division contain one of each chromosome type: haploid

Meiosis and genetic variation
- a child will inherit unpredictable mixture of characteristics of both parents: unpredictability due to meiosis: every gamete has new combination of alleles: genetic variation
- meiosis can result in gametes with different combinations of genes: two processes for diversity
- random orientation of bivalents: generates genetic variation among genes which are on different chromosome types
- crossing over: without crossing over combinations of alleles on chromosomes would be forever linked: allows that genes are reshuffled, producing new combinations

Fertilization and genetic variation
- fusion of gametes is a significant event
- alleles from two different individuals are combined in one new individual
- combination is unlikely ever to have existed before
- fusion of gametes promotes genetic variation which is essential for evolution

3.4 Inheritance
Mendel and the principles of inheritance
- organisms pass on characteristics when they reproduce
- acquired characteristics cannot be inherited
- early theories: blending inheritance: characters are intermediate of parents
- Mendel creates an alternative theory using pea plants
- Mendel repeated each cross many times and with seven different characteristics
- rediscovering Mendel's work: cross-breedings are done with plants and animals: confirmed

Gametes
- fuse together to form zygote; sex cells
- male and female gametes are different in size and motility: male is smaller and can move, female is larger but moves less or not at all
- gametes contain one chromosome of each type: haploid; nucleus has one allele of each gene
- male and female parents make an equal genetic contribution to their offspring

Zygotes
- gametes fuse and nuclei join together: doubling chromosome number: diploid
- some genes have more than two alleles (ABO blood groups)

Segregation of alleles
- meiosis: diploid nucleus into four haploid nuclei
- if two copies of one allele are present, the gametes receive one copy of it
- if two different alleles are present, 50% of gametes receive one and the other half the other
- segregation: separation of alleles into different nuclei; breaks up existing combinations, creates new combinations

Dominant, recessive and co-dominant alleles
- dominant alleles mask the effects of recessive alleles
- pairs of alleles where both have an effect when they are present together: co-dominant
- usual reason for dominance of one allele is that it codes for a protein that is active and carries out a function while the recessive allele codes for a non-functional protein

Genetic diseases due to recessive alleles
- most genetic diseases are caused by recessive alleles of a gene
- carrier: has one allele for genetic disease, can pass it on
- genetic diseases by recessive alleles appear unexpectedly, parents are unaware that they are carriers; cystic fibrosis as an example

Other causes of genetic diseases
- small proportion of genetic diseases are caused by dominant alleles: not possible to be carrier
- Huntington's disease as an example

- very small proportion of genetic diseases are caused by co-dominant alleles (sickle-cell anemia)
- some genetic diseases show a different pattern of inheritance in males and females: sex linkage
- red-green color-blindness and hemophilia as examples of sex linked genetic diseases

Sex-linked genes
- inheritance pattern where ratios are different in males and females: sex linkage
- geneticists observe that inheritance of genes and of chromosomes show clear parallels and so genes are likely to be located on chromosomes
- Y chromosome might not carry the gene that is present on X chromosome
- in crosses involving sex linkage, alleles should always be shown as superscript letters on X

Genetic diseases in humans
- sickle-cell anemia, cystic fibrosis, hemophilia, Huntington's disease, phenylketonuria (PKU), Tay-Sachs, Marfan's syndrome as examples
- large number of genetic diseases; most are caused by rare recessive alleles
- two alleles must be inherited and the chance is extremely small
- cheaply and quickly sequence of genome: reveals number of rare recessive alleles
- individual can only produce child with genetic disease due to one of the recessive alleles if the other partner has the same rare allele

Causes of mutation
- new alleles are formed from other alleles by gene mutation: random change
- two types of factor can increase mutation rate: radiation (enough energy to cause chemical changes in DNA), chemical substances (chemical changes in DNA)
- no mechanism for mutations; mutation is unlikely to be beneficial, either neutral or harmful
- mutations of genes controlling cell division can cause cell to divide endlessly: tumour: cancer
- mutations are eliminated when individual dies; mutations in gametes can be passed to offspring: origin of genetic diseases

3.5 Genetic modification and biotechnology
Gel electrophoresis
- separation of charged molecules in an electric field according to their size and charge
- gel is immersed in a conducting fluid and an electric field is applied: charged molecules move through the gel: molecules with negative and positive charges move in opposite directions
- proteins may be positively or negatively charged so can be separated according to charge
- eukaryotic DNA molecules must be broken up as they are too long: all DNA molecules are negatively charged and will move in the same direction but not at the same rate
- small DNA fragments move faster than large ones so DNA fragments can be separated by size

DNA amplification by PCR
- polymerase chain reaction is used to make large numbers of copies of DNA
- small samples can be replicated into millions of copies: makes the studying of DNA possible without using up a limited sample
- PCR is used to copy specific DNA sequences: a sequence is selected by using a primer that binds to the beginning of the desired sequence

DNA profiling
- stages: sample of DNA is obtained, sequences that vary considerably between individuals are amplified by PCR, copied DNA is split into fragments using restriction endonucleases (restriction enzymes), fragments are separated using gel electrophoresis, produces a pattern of bands which is the individual's DNA profile, profiles can be compared to see which bands are same and which different

Genetic modification
- molecular biologists developed techniques to transfer genes between species
- the transfer of genes is known as genetic modification
- possible because the genetic code is universal: same polypeptide is produced after translation

- used to treat human diseases, introduce new characteristics in an animal species, producing a variety of crop plants (GM crops)

Clones

- zygote is the first cell of a new organism, produced by the fusion of a male and female gamete
- it is produced by sexual reproduction and will be genetically different
- if an organism reproduces asexually, the offspring is genetically identical
- production of genetically identical organisms is cloning a group of genetically identical organisms is called a clone
- identical twins are the smallest clone that can exist; a better term is monozygotic as not all of their characteristics are identical

Natural method of cloning

- many plants have a natural method of cloning
- natural methods of cloning are less common in animals

Cloning animal embryos

- embryonic cells are pluripotent in their early stages and could theoretically be divided into two different groups of cells which would become two separate individuals
- formation of identical twins could be called cloning, but most animals don't do this naturally
- in livestock, an egg can be fertilized in vitro, cells separated and transplanted into a surrogate mother, this is only possible for a limited number of clones
- this method isn't popular because it can't be seen whether the new individual has desirable characteristics

Cloning adult animals using differentiated cells

- easy to clone an embryo but its characteristics are unknown at that point
- when they're old it is harder to clone them: cells are differentiated
- John Gurdon: nuclei from adult frogs were put into egg cells where the nucleus was removed, the egg cells developed as if they were normal zygotes
- for mammals this is more difficult to achieve, Dolly is the first example
- would have benefits of regrowing human tissue which would not be rejected by the body

4 Ecology

Introduction

- ecosystems require continuous supply of energy
- continued availability depends on cycles
- survival depends on sustainable ecological communities
- concentrations of gases in the atmosphere have significant effects on climates

4.1 Species, communities and ecosystems

Species

- group of organisms that can potentially interbreed to produce fertile offspring
- distinctive courtship dances: show that they are fit, suitable partner, same type of bird
- each type remains distinct; hybrids between types (species) rarely produced
- most species have method ensuring that they reproduce with other members of their species
- interbreeding: two members of same species mating and producing offspring
- cross-breeding: members of different species mating, almost always infertile
- reproductive separation is reason for each species being a recognizable type of organism

Populations

- population: group of same species who lives in same area at the same time
- if two populations live in different areas they are unlikely to interbreed
- if two populations never interbreed they may gradually develop differences: are same species until they cannot interbreed and produce fertile offspring

Autotrophic and heterotrophic nutrition

- organisms need supply of organic nutrients: growth, reproduction
- autotrophic: self-feeding: organisms make own carbon compounds from simple substances
- heterotrophic: feeding on others: obtaining carbon compounds from other organisms
- mixotrophic: some unicellular organisms use both methods: *euglena gracilis* has chloroplast when sufficient light but can feed by endocytosis

Consumers

- heterotrophs that feed off other organisms which are still alive or shortly dead
- ingest their food: absorb the products of digestion
- trophic groups: primary consumers feed on autotrophs, secondary consumers feed on primary consumers; does not always fit

Detritivores

- dead organic matter rarely accumulates in ecosystems: nutrition for two groups of heterotrophs
- detritivores ingest dead organic matter, then digest it internally, absorb products of digestion

Saprotrophs

- secrete digestive enzymes into dead organic matter and digest it externally
- also known as decomposers
- many bacteria and fungi are saprotrophic

Communities

- relationship between organisms are complex and varied: interaction between two species is of benefit to one species and harms the other; in other cases both benefit
- all species are dependent on relationships with others for long-time survival: population of one species can never live in isolation
- community: group of populations living together in an area and interacting with each other

Ecosystems

- abiotic environment: community depends on its non-living surrounding of air, water, soil or rock

- some cases abiotic environment exerts powerful influence over organisms: wave action on rocky shore creates very specialized habitat
- many cases where organisms influence abiotic environment: plants growing in sand, roots stabilize and encourage more dunes
- many interactions between organisms and the abiotic environment
- ecosystem: community and its abiotic environment are highly complex interacting system

Inorganic nutrients
- living organisms need supply of carbon, hydrogen, oxygen, other carbon compounds, nitrogen, phosphorus and 15 other elements
- autotrophs obtain all elements as inorganic nutrients from abiotic environment
- heterotrophs obtain some of the elements in their food, others still from abiotic environment

Nutrient cycles
- limited supplies of chemical elements on Earth: they can be endlessly recycled
- cycles for different elements vary

Sustainability of ecosystems
- concept of sustainability due to current human unsustainable uses of resources
- it is sustainable if it can continue indefinitely
- natural ecosystems can teach us: three requirements for sustainability: nutrient availability, detoxification of waste products, energy availability
- nutrients can be recycled indefinitely; usually waste products of one species are exploited as resource by another species
- energy cannot be recycled: sustainability depends on continued supply (mostly light by sun)

4.2 Energy flow
Sunlight and ecosystems
- initial source of energy is sunlight by photosynthesis
- three groups of autotroph carry out photosynthesis: plants, eukaryotic algae, cyanobacteria: are called producers
- heterotrophs don’t use light energy directly, depend on it: consumers, saprotrophs, detritivores
- in most ecosystems almost all energy in carbon compounds will have been harvested by photosynthesis by producers
- percentage of energy that is harvested by producers and is available to other organisms varies

Energy conversion
- producers convert light energy to chemical energy using chlorophyll: create carbon compounds
- producers can release energy from carbon compounds by cell respiration and is lost as heat
- largest part of energy remains in cell and tissues of producers which is available to heterotrophs

Energy in food chains
- food chain: sequence of organisms each of which feeds on the previous one
- usually between two and five organisms in a food chain
- producers are always the first organism; subsequent organisms are consumers
- no consumers feed on the last organism of a food chain
- consumers obtain energy from the carbon compounds in the organisms on which they feed

Respiration and energy release
- living organisms need energy for synthesis of large molecules (DNA, RNA, protein), active transport, moving things in cell: ATP supplies this energy
- every cell produces its own ATP supply by cell respiration
- during cell respiration carbon compounds are oxidized: oxidation reactions are exothermic and the energy released is used in endothermic reactions to make ATP
- cell respiration transfers chemical energy from carbon compounds to ATP
- energy transformations are never 100% efficient: remainder from cell respiration is converted to heat (e.g. muscles warm when hey contract)

Heat energy in ecosystems

- energy conversions: light to chemical (photosynthesis), chemical to kinetic (muscle contraction), chemical to electrical (nerve cells), chemical to heat (heat-generating adipose tissue)
- organisms cannot convert heat energy into any other form of energy

Heat losses from ecosystems

- heat from cell respiration makes living organisms warmer
- heat produced in living organisms is all eventually lost to abiotic environment

Energy losses and ecosystems

- biomass: total mass of a group of organisms, biomass has energy
- the energy added to biomass by each successive trophic level is less
- energy in sec. consumers per year per square meter is always less than in prim. consumers
- loss of energy between trophic levels
- most of energy in food that is digested and absorbed by organisms in trophic level is released by cell respiration, lost as heat: only energy available to organisms in next trophic level is chemical energy
- organisms in a trophic level are usually not entirely consumed; energy in uneaten material passes to saprotrophs or detritivores rather than passing to organisms to next trophic level
- not all parts of food ingested are digested and absorbed; energy in feces does not pass along the food chain and passes to saprotrophs and detritivores
- only small proportion of energy in biomass of one trophic level will ever become part of biomass of organism in next trophic level (ca. 10%)
- less and less energy available to each successive trophic level: after a few stages remaining energy would not support another level: number of trophic levels is restricted
- generally a higher biomass of producers, the lowest rank of all

4.3 Carbon cycling

Carbon fixation

- autotrophs absorb carbon dioxide from atmosphere and convert it into carbon compounds
- they reduce carbon dioxide concentration in atmosphere, mean is at 0.039% or 390 μmol/mol

Carbon dioxide in solution

- carbon dioxide is soluble in water: either dissolved or combines with water to form carbonic acid (H_2CO_3) which dissociates into hydrogen and hydrogen carbonate ions (H^+, HCO_3^-)
- hydrogen and hydrogen carbonate explain how carbon dioxide reduce pH of water
- dissolved carbon dioxide and hydrogen carbonate are absorbed by aquatic plants and other autotrophs which they use for creating carbon compounds

Absorption of carbon dioxide

- autotrophs use carbon dioxide which reduces the concentration of carbon dioxide in the atmosphere and sets up concentration gradient between cells and water/air: carbon dioxide diffuses from atmosphere or water into autotroph
- in land plants it diffuses through stomata under leaf; in water all parts are permeable

Release of carbon dioxide from cell respiration

- carbon dioxide is waste product of aerobic cell respiration and diffuses out of cells
- non-photosynthetic cells in producers (root cells), animal cells, saprotrophs (fungi) are groups which produce carbon dioxide

Methanogenesis

- methane is produced in anaerobic environments; waste product of anaerobic respiration
- three groups of bacteria are involved: bacteria convert organic matter into organic acids, alcohol, hydrogen, carbon dioxide; bacteria use organic acids and alcohol to produce acetate, carbon dioxide, hydrogen; archaeans produce methane from carbon dioxide, hydrogen, acetate ($CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$; $CH_3COOH \rightarrow CH_4 + CO_2$)

- archaeans are methanogenic: they carry out methanogenesis in anaerobic environments: mud along shores, swamps, guts of ruminant mammals, landfill sites
- some methane produced by archaeans diffuses into atmosphere (conc. at 1.7-1.85 μmol/mol)

Oxidation of methane

- molecules of methane persist in atmosphere around 12 years: naturally oxidized in stratosphere

Peat formation

- in soils organic matter is digested by saprotrophic bacteria or fungi: saprotrophs obtain oxygen from air spaces in soil
- some environments water is unable to drain out, so become waterlogged and anaerobic: saprotrophs cannot thrive and dead organic matter is not fully decomposed: acidic conditions
- accumulated partially decomposed matter becomes compressed and forms dark brown acidic material called peat

Fossilized organic matter

- carbon and some carbon compounds are chemically stable and remain unchanged in rock for hundreds of million years: large deposits of carbon from past geological eras
- deposits are results from incomplete decomposition
- coal is formed when peat is compressed and heated
- oil and natural gas are formed in mud at bottom of seas and lakes: conditions are anaerobic so decomposition is often incomplete; when compressed and heated chemical changes occur producing mixtures of liquid carbon compounds or gases: crude oil and natural gas

Combustion

- if organic matter is heated in presence of oxygen it will set light and burn
- combustion: oxidation reaction that occurs
- products of complete combustion are carbon dioxide and water
- coal, oil, natural gas are different forms of fossilized organic matter: all burned as fuels

Limestone

- some animals have hard body parts from calcium carbonate ($CaCO_3$): mollusk shells, hard corals that build reefs
- when they die, soft parts are decomposed; in acid calcium carbonate dissolves away, in neutral or alkaline condition is stable and hard parts deposit on sea bed
- result of animal hard parts is limestone; hard parts can be seen as fossils

4.4 Climate change

Greenhouse gases

- earth is kept much warmer than without the gases
- greenhouse gases with largest warming effect are carbon dioxide and water vapor
- carbon dioxide is released by cell respiration and combustion of biomass and fossil fuels
- carbon dioxide is removed by photosynthesis and dissolving into oceans
- water vapor is formed by evaporation from oceans and transpiration in plants
- water vapor is removed by rainfall and snow
- water continues to retain heat after condensing to form droplets in clouds
- water absorbs heat energy and radiates it back to Earth’s surface and reflects heat energy

Other greenhouse gases

- other greenhouse gases have a smaller but still significant effect
- methane is the third most significant gas; emitted from waterlogged habitats and released during extraction of fossil fuels and from melting ice polar regions
- nitrous oxide is naturally released by bacteria and by agriculture and vehicle exhausts
- two most abundant gases in atmosphere (oxygen, nitrogen) are not greenhouse gases and do not absorb longer-wave radiation
- all greenhouse gases make up less than 1% of atmosphere

Assessing the impact of greenhouse gases

- two effects determine warming effect: ability to absorb long-wave radiation and concentration
- methane causes much more warming than carbon dioxide but is at much lower concentration
- concentration of gas depends on rate at which it is released and how long on average it remains in the atmosphere
- water vapor enters immensely rapid but only stays for nine days

Long-wavelength emissions from Earth

- warmed surface absorbs short-wave energy from sun; re-emits it at much longer wavelength
- most of re-emitted radiation is infrared (peak at 10'000nm); solar peaks at 400nm

Greenhouse gases

- 25-30% of short-wavelength radiation from sun is absorbed before it reaches surface: most of it is ultraviolet absorbed by ozone
- 70-75% reaches surface and most of it is converted to heat
- 70-85% of longer-wavelength is captured by greenhouse gases: effect is global warming
- greenhouse gases in atmosphere only absorb energy in specific wavebands
- water vapor, carbon dioxide, methane, nitrous oxide absorb some wavelengths and are greenhouse gases

Global temperatures and carbon dioxide concentrations

- if concentration of gas changes we can expect the size of contribution to greenhouse effect to change and global temperature to rise or fall
- ice columns were drilled in Antarctic to deduce past carbon dioxide concentrations
- bubbles of air were trapped in the ice
- global temperatures can be deduced from ratios of hydrogen isotopes in water molecules
- repeating pattern of rapid periods of warming followed by longer period of cooling
- periods of higher carbon dioxide concentration coincide with periods Earth was warmer
- rises in carbon dioxide concentration increases greenhouse effect

Greenhouse gases and climate patterns

- Earth's surface is warmer than without greenhouse gases: if concentration of greenhouse gases rises more heat will be retained and an increase in global average temperature is expected
- global average temperature are not directly proportional to greenhouse gas concentrations
- global temperature influence other aspects of climate: higher temperature increase evaporation of water so rain is more in mass and more frequent
- consequences of rise in average global temperature are unlikely to be evenly spread
- predictions are uncertain, but it is clear that warming would cause profound changes to climate

Industrialization and climate change

- the rise to concentration nearing 400 parts per million is unprecedented (usually to 300ppm)
- concentrations started to rise above natural levels in late 18th century
- much of the rise happened since 1950
- industrial revolution stared in late 18th century but main impact was in second half of 20th
- combustion of coal, oil, natural gases increased rapidly
- since start of industrial revolution, correlation between rising atmospheric carbon dioxide and average global temperatures is very marked

Burning fossil fuels

- increasing quantities of coal were mined and burned causing carbon dioxide emissions after industrial revolution
- energy from combustion provided heat and power; later oil and natural gas were added
- hard to doubt that burning of fossil fuels has been major contributor in rise of atmospheric carbon dioxide concentrations
- steepest rises coincide with increases in burning of fossil fuels

5 Evolution and biodiversity

Introduction

- theory that diversity of life evolved by natural selection
- ancestry of groups of species can be deduced by comparing base or amino acid sequences

5.1 Evidence for evolution

Evolution in summary

- strong evidence for characteristics of species changing over time: evolution
- difference between acquired (developed during lifetime) and heritable characteristics
- evolution only concerns heritable characteristics passed form parents
- mechanism for evolution is natural selection
- strong disbelief from different groups: important to look at evidence

Evidence from fossils

- fossils found in various rock layers were different
- radioisotope dating revealed ages of rock strata and of fossils in them (paleontology)
- sequence of fossils matches sequence in which they would evolve (bacteria first, etc.)
- sequence fits with ecology of groups (plant fossils before animal fossils)
- many sequences of fossils are known which link existing organisms to likely ancestors

Evidence from selective breeding

- humans deliberately breed animal species for thousands of years
- domesticated breeds have not existed in their current form: artificial selection: changes were achieved by repeatedly selecting and breeding individuals most suited for human uses
- effectiveness of artificial selection is shown by considerable changes in short time
- artificial selection shows that selection can cause evolution but not vice versa

Evidence from homologous structures

- some similarities in structure are superficial (e.g. tail fins in whales and fishes): analogous structure: have different origins and became similar because they perform the same or similar function: convergent evolution
- homologous structure: may look superficially different and perform different function but have "unity of type": same bones in same relative positions: have same origin
- adaptive radiation: homologous structures became different as they perform different functions
- homologous structures do not prove evolution but are difficult to explain without it
- vestigial organs: reduced structures that serve no function: easily explained by evolution: no longer have a function and so are being gradually lost

Speciation

- if two populations separate they do not interbreed, natural selections acts differently: evolve in different ways: characteristics will gradually diverge
- if they have chance of interbreeding but don't they evolved into separate species: speciation
- speciation often occurs when species migrates to an island: explains large numbers of endemic species on islands
- endemic species: found only in a certain geographical area

Evidence from patterns of variation

- if populations gradually diverge to become separate species, we would expect to find examples of all stages of divergence at any moment
- species can gradually diverge over long periods of time and there is no sudden switch
- continuous range in variation does not match belief that species were created as distinct types or that they are unchanging
- continuous range in variation provides evidence for evolution of species and origin of new ones

5.2 Natural selection

Variation

- theory of evolution by natural selection is based on variation
- typical populations vary in many respects
- natural selection depends on variation within populations; if all individuals were same there would be no way of some individuals being favored more

Sources of variation

- causes of variation are mutation, meiosis, sexual reproduction
- mutation is the original source of variation, new alleles are produced
- meiosis produces new combinations, every cell produced has different combination due to crossing over and independent orientation of bivalents
- sexual reproduction fuses two gametes from different parents, bring mutations together
- species without sexual reproduction only get variation from mutation; generally assumed that such species will not generate enough variation to evolve quickly enough for survival during times of environmental change

Adaptations

- adaptation: characteristics that make an individual suited to its environment or way of life: close relationship between structure and function
- characteristics develop over time and thus species evolve
- adaptations develop by natural selection, not with the direct purpose of making an individual suited to its environment
- adaptations do not develop during lifetime of an individual (= acquired characteristics); acquired characteristics cannot be inherited

Overproduction of offspring

- living organisms vary in the number of offspring they produce
- overall trend that living organisms produce more offspring than the environment can support
- causes struggle for existence within population

Differential survival and reproduction

- chance plays part in deciding which individual survives and reproduces and which not
- characteristics of an individual also have an influence
- less adapted individuals tend to die or fail to reproduce; best adapted tend to survive and produce many offspring: natural selection

Inheritance

- variation between individuals can be passed on to offspring: it is heritable
- variation in behavior can be heritable
- not all features are passed on to offspring: acquired characteristics are not passed on and are not significant in the evolution of a species

Progressive change

- well adapted individuals survive, reproduce, pass on characteristics to offspring
- less well adapted have lower survival rates and less reproductive success
- increase in proportion of individuals with well adapted characteristics: gradually change
- major evolutionary changes are likely to occur over long periods of time and many generations
- there are examples of smaller but significant changes (e.g. dark wing moths in polluted areas, changes in beaks of finches on Galapagos, antibiotic resistance in bacteria)

5.3 Classification of biodiversity

Development of the binomial system

- congresses are held so that all biologists use same system of names of living organisms
- separate congresses for animals and for plants and fungi

- International Botanical Congress (IBC) proposed that 1753 is starting point for genera and species of plants and fungi (in that year Linnaeus published book that gave consistent binomials for all species known)
- International Zoological congress accepted rules for naming and classifying animal species from 1758 (Linnaeus)

The binomial system

- biologists use binomial nomenclature; it consists of two words (genus, species/specific name)
- genus: group of species that share certain characteristics
- rules: genus name is upper-case, species name is lower-case, binomial is shown in italics, after it was used in a text the genus can be abbreviated to initial letter, earliest published name (plants: 1753; animals: 1758) is the correct one

The hierarchy of taxa

- taxon in Greek is group of something
- species are arranged into taxa
- species classified into genus, genera into families, families into orders, orders into classes, etc. until level of kingdom or domain
- going up hierarchy, taxa include more species which share fewer features

The three domains

- traditional classification systems (based on cell type): eukaryotes and prokaryotes
- prokaryotes are very diverse: esp. after RNA sequence was determined
- prokaryotes have two distinct groups: Eubacteria and Archaea
- all organisms are classified into three domains: Eubacteria, Archaea, Eukaryota
- archaeans live in broad range of habitats
- archaeans are obligate anaerobes and give off methane as waste product
- viruses are not classified into any of the three domains: have genes coding for proteins but have too few characteristics of life to be living organisms

Eukaryote classification

- principal taxa for classifying eukaryotes are divided into kingdoms, then phyla, classes, orders, families, genera, species
- biologists recognizes four kingdom of eukaryote: plants, animals, fungi, protoctista
- protoctista are most controversial as they are very diverse and should be divided further

Natural classification

- goal to classify spices so they follow the way a species evolved
- natural classification: all members of a genus or higher taxon should have a common ancestor
- natural classification is problematic as it is not always clear which groups of species share a common ancestor: causes unnatural or artificial classification
- convergent evolution can make distantly related organisms appear superficially similar
- adaptive radiation can make closely related organisms appear different
- molecular methods have been introduced: significant changes to classification

Reviewing classification

- new evidence may show that members of a group do not share common ancestor: group is split into two or more taxa
- species in different taxa are found to be closely related, two or more taxa are united or species moved from one genus to another
- classification of humans caused most controversy: humans are in order Primates and family Hominidae: debate to include great apes
- research shows that chimpanzees and gorillas are closer to humans than orang-utans and so should be in the same family

Advantages of natural classification

- natural classification of species is helpful in research into biodiversity

- identification of species is easier: species can be identified by assigning to kingdom, phylum, until species level: dichotomous keys are helpful for the process
- members of group in natural classification have evolved from common ancestor: inherit similar characteristics: allows predictions of characteristics of species found in that group

5.4 Cladistics

Clades

- species can evolve and split to form new species; happened repeatedly so now there is a large groups of species all derived from a common ancestor
- clade: group of organisms evolved from common ancestor
- clade includes: all species alive today, common ancestral species, species that evolved from it and then became extinct
- clades can include thousands of species or only a few

Identifying members of a clade

- not always obvious which species evolved from common ancestor, should be included in clade
- most objective evidence from base sequence of genes and amino acid sequences of proteins
- species with recent common ancestor are expected to have few differences in these sequences
- species diverging form common ancestor long ago will have many differences in sequences

Molecular clocks

- differences in base sequence of DNA and amino acid sequence of proteins are result of mutations: accumulate over time at roughly constant rate
- mutations can be used as a molecular clock

Analogous and homologous traits

- similarities between organisms can be either homologous or analogous
- homologous: similar ancestry
- analogous: convergent evolution, evolved independently
- problems between distinguishing led to mistakes in classification
- morphology (form and structure) of organisms is rarely used for identifying; base and amino acid sequences are trusted more

Cladograms

- tree diagram based on similarities and differences between the species in a clade
- principle of parsimony: how species in a clade could have evolved with the smaller number of changes of base or amino acid sequence: most probable sequence of divergence
- node: branching point: usually two clades branch off but it can be three or more
- node represents a hypothetical ancestral species that split to form two or more species

Cladograms and reclassification

- construction of cladograms based on base and amino acid sequences only became possible towards end of 20th century
- cladistics: construction of cladograms and identification of clades
- traditional classification based on morphology does not always match evolutionary origins: some groups have been classified, merged, split, or species transferred
- reclassification is time-consuming but worthwhile: new classification based on cladistics are likely to be much closer to truly natural classification, predictive value will be higher

6 Human physiology

Introduction
- body functions are carried out by organ systems
- structure of small intestine allows it to move, digest, absorb
- blood system continuously transports substances to cells and collects waste products
- skin and immune system resist threat of invasion by pathogens
- lungs are actively ventilated to ensure gas exchange
- neurons transmit the message; synapses modulate it; hormones are for widely spread signals

6.1 Digestion and absorption

Peristalsis
- circular and longitudinal muscles in wall of gut is smooth rather than striated; short cells, not elongated fibers; exerts continuous force with short periods of more vigorous contractions
- peristalsis: waves of muscle contractions passing along intestine, occurs in one direction
- circular muscles behind food constricts gut to prevent it being pushed back
- contraction of longitudinal muscle moves food along gut
- contractions are controlled unconsciously by enteric nervous system
- during vomiting, abdominal muscles force food out rather than muscles in gut
- overall progression through intestine is slower, allowing digestion
- peristalsis churns food with enzymes to speed up digestion

Pancreatic juice
- pancreas contains two types of gland tissue: small cell groups secreting insulin and glucagon into blood and remainder secreting digestive enzymes into gut
- hormones from stomach and enteric nervous system mediate pancreas to production
- groups of gland cells cluster around ends of tubes (ducts) into which enzymes are secreted
- digestive enzymes are synthesized in pancreatic gland cells in ribosomes on rough endoplasmic reticulum, processed by Golgi apparatus and released by exocytosis
- pancreatic juice contains amylase (for starch), lipase (for triglycerides, phospholipids), proteases (for proteins, peptides)

Digestion in the small intestine
- enzymes carry out hydrolysis reactions: starch to maltose (amylase), triglycerides to fatty acids and glycerol or fatty acids and monoglycerides (lipase), phospholipids to fatty acids, glycerol and phosphate (phospholipase), proteins and polypeptides to shorter peptides (protease)
- wall of small intestine produces variety of other enzymes which digest more substances, most remain immobilized in plasma membrane of epithelium cells; continue to work when abraded
- DNA and RNA to nucleotides (nucleases), maltose to glucose (maltase), lactose to glucose and galactose (lactase), sucrose to glucose and fructose (sucrase), peptides to dipeptides (exopeptidases, remove single amino acids), dipeptides to amino acids (dipeptidases)
- cellulose is left undigested: humans cannot synthesize necessary enzymes

Villi and the surface area for digestion
- absorption: taking substances into cells and blood, takes place in small intestine
- rate of absorption depends on surface area: increased with villi
- villi: finger-like projections of mucosa to inside of intestine

Absorption by villi
- epithelium covering villi must form barrier to harmful substances
- villus cells absorb: glucose, fructose, galactose, monosaccharides, amino acids (any of 20), fatty acids, monoglycerides, glycerol, bases from nucleotides, mineral ions (calcium, potassium, sodium), vitamins (ascorbic acid (vitamin C))
- harmful substances passing through are removed from blood by liver
- some bacteria pass: quickly removed by phagocytic cells in liver

Methods of absorption
- nutrients must pass from lumen of small intestine to capillaries or lacteals in villi
- exposed part of plasma membrane is enlarged with microvilli
- two examples for mechanisms moving nutrients in and out of villus epithelium cells
- triglycerides: must be digested to fatty acids and monoglycerides beforehand, are absorbed by simple diffusion, fatty acids also by facilitated diffusion (transporters in membrane), once in cell fatty acids are combined with monoglycerides to produce triglycerides, these coalesce with cholesterol to form droplets which are coated in phospholipids and proteins, lipoprotein released by exocytosis through inner plasma membrane, either enter lacteal and carried away by lymph or enter blood capillaries in villi
- glucose: cannot pass through plasma membrane (polar), sodium-potassium pumps sodium ions by active transport to interstitial spaces in villus and potassium ions in opposite direction (low concentration of sodium in villus), sodium-glucose co-transporter proteins in microvilli transfer sodium ion and glucose from interstitial lumen to cytoplasm of epithelium cells (passive facilitated diffusion, but energy needed for concentration gradient), glucose channels allow it to move by facilitated diffusion to blood capillaries

6.2 The blood system
Arteries
- convey blood from heart to tissue of body; elastic and muscle tissue in walls facilitate and control blood flow
- main pumping chambers of heart are ventricles: thick strong muscles pumping blood into arteries reaching high pressure at peak of each pumping cycle
- recoil of elastic tissue helps propel blood down artery
- contraction of smooth muscle determines diameter and controls overall flow through them
- elastic and muscular tissues contribute to toughness of walls which have to withstand constantly changing and intermittently high blood pressure: progress is pulsatile
- active muscles of heart itself are supplied with blood by coronary arteries

Artery walls
- tunica externa (outer layer), tunica media (thick layer with muscle and elastin), tunica intima (smooth endothelium forming the lining)

Arterial blood pressure
- systolic pressure: peak pressure reached in artery, widens lumen (store of potential energy)
- stretched elastic fibers squeeze blood in lumen at end of heartbeat: prevents minimum pressure (diastolic pressure) becoming too low
- blood flow in arteries is relatively steady
- vasoconstriction: contraction of circular muscles in artery wall, increases blood pressure
- arterioles have high density of muscle cells responding to hormone and neural signals to control blood flow to tissue
- vasoconstriction reduces supply; vasodilation increases supply

Capillaries
- narrowest blood vessels; branch and rejoin to form network with huge total length
- transport blood through almost all tissues in body (exceptions: lens tissues and cornea in eye)
- all active cells are close to a capillary
- wall consists of very thin endothelium cells, coated with filter-like protein gel, pores between cells: wall is very permeable: allow part of plasma leak out and form tissue fluid
- tissue fluid contains oxygen, glucose, all other substances in blood plasma
- proteins cannot pass through capillary wall
- fluid flows between cells in tissue, allows cells to absorb useful substances and excrete waste
- then the tissue fluid re-enters capillary network
- permeabilities differ between tissues, enables particular proteins and other large particles to pass but not others; this may change over time and capillaries remodel to needs of tissue

Veins
- transport blood from capillary networks back to atria of heart at lower pressure

- have thinner walls than arteries and less muscle and elastin fibers
- can dilate and contain more blood than arteries
- blood flow is assisted with contraction of muscle squeezing on adjacent veins
- hepatic portal vein is unusual, carries blood from stomach and intestines to liver

Valves in veins

- pressure in veins is so low that there is danger of backflow: pocket valves (three cup-shaped flaps of tissue) maintain circulation and allow blood flow in one direction
- blood flowing back is caught in flaps, filling them with blood and blocking lumen
- blood flowing towards heart pushes flaps to sides of veins
- valves efficiently use intermittent and transient pressures from muscular and postural changes

The double circulation

- mammalian lungs are supplied with blood by separate circulation
- blood capillaries in lungs cannot withstand high pressures, blood pumped at lower pressure
- blood coming from lungs is at such low pressure that it must go to heart again
- humans have pulmonary circulation (for lungs) and systemic circulation (for organs)
- pulmonary circulation receives deoxygenated blood from systemic circulation
- systemic circulation receives oxygenated blood from pulmonary circulation
- important that blood from two systems is not mixed: heart is double pump

The sinoatrial node

- heart muscles contract without stimulation from motor neurons; contraction is called myogenic (generated by muscle itself)
- membrane of heart muscle cell depolarizes when cell contracts, activating adjacent cells
- region of fastest rate of spontaneous beating is in sinoatrial node (in wall of right atrium)
- sinoatrial node initiates each heartbeat as membranes are first to depolarize in each cardiac cycle; specialized cells in sinoatrial node have extensive membranes but few proteins which cause contractions in other cells

Initiating the heartbeat

- sinoatrial node sets pace for beating of heart: pacemaker
- if defective, it may be replaced by artificial pacemaker

Atrial and ventricular contraction

- heartbeat initiated by contracting and simultaneously sending of electrical signal that spreads throughout wall of atria: possible with interconnections between adjacent fibers
- fibers are branched so each fiber passes signal to several others
- after delay of 0.1 seconds, electrical signal is conveyed to ventricles: delay allows time for atria to pump blood into ventricle; then signal is propagated through ventricle to make it contract

Changing the heart rate

- sinoatrial node responds to signals from outside of heart including signals from branches of two nerves (one for in other for decrease) coming from medulla of brain called cardiovascular center
- cardiovascular center receives input form receptors monitoring blood pressure, pH (reflecting carbon dioxide concentration) and oxygen concentration
- all parameters being low suggests increase in heart rate and vice versa

Epinephrine

- sinoatrial node responds to epinephrine in blood to increase heart rate
- epinephrine (adrenalin) is hormone produced in adrenal glands, secretion controlled by brain
- secretion rises when vigorous physical activity may be necessary (“fight or flight”)

6.3 Defense against infectious disease

Skin as barrier to infection

- many different microbes in environment that can cause disease (pathogens)
- primary defense is skin: outermost layer is tough and provides physical barrier

- sebaceous glands (associated with hair follicles) secrete chemical sebum which maintains skin moisture and lowers skin pH (inhibits growth of bacteria and fungi)
- mucous membranes are thinner and softer type of skin (nasal passages, penis, vagina)
- mucus (sticky solution of glycoproteins) secreted, acts as physical barrier: pathogens and harmful particles are trapped in it and either swallowed or expelled
- mucus has antiseptic properties due to presence of anti-bacterial enzyme lysozyme

Cuts and clots

- when skin is cut, blood vessels are severed and start to bleed; stops due to clotting
- emerging blood changes from liquid to semi-solid gel: seals wound, prevents further loss of blood and blood pressure; cut is breach barrier to infection provided by skin
- clots prevent entry of pathogens until new tissue has grown to heal cut

Platelets and blood clotting

- blood clotting involves cascade of reactions, each producing catalyst for next reaction
- important that clotting is under strict control; if it occurred in blood vessels it would block it
- clotting only occurs if platelets (cellular fragments circulating blood) release clotting factor
- after cut, platelets aggregate at site forming temporary plug, then release clotting factors

Fibrin production

- cascade of reactions after platelets release clotting factors leads to production of enzyme thrombin; this converts soluble protein fibrinogen to insoluble fibrin
- fibrin forms mesh trapping more platelets and blood cells
- resulting clot is initially gel but when exposed to air it dries to hard scab

Phagocytes

- after physical barriers, white blood cells (many different types) provide next line of defense
- some squeeze through pores in capillary walls and move to sites of infection: engulf pathogens by endocytosis and digest them

Antibody production

- proteins and other molecules on surface of pathogens are recognized as foreign by body: stimulates specific immune response: production of antibodies
- lymphocytes (type of white blood cell) produce antibodies; each lymphocyte only one type
- normally have small numbers of lymphocytes for each of antibody
- antigens on pathogen stimulate cell division of small group of specific lymphocytes
- plasma cells (large clone of lymphocytes) are produced within few days
- antibodies are large proteins with two functional regions: hyper-variable region (binds to specific antigen) and region that helps body to fight pathogen (making it recognizable, preventing viruses from docking to host cells)
- antibodies only persist for few weeks but some lymphocytes are not active plasma cells but became memory cells (very long-lived): remain inactive unless same pathogen infects again
- immunity is either having antibodies or memory cells that allow for rapid production of antibody

Antibiotics

- chemical that inhibits growth of microorganisms, mostly antibacterial
- block processes occurring in prokaryotes but not in eukaryotes: do not harm human cells
- processes targeted are bacterial DNA replication, transcription, translation, ribosome function, cell wall formation
- many antibacterial antibiotics found in saprotrophic fungi as these compete with saprotrophic bacteria for dead organic matter: fungi inhibit growth of bacterial competitors

Viruses and antibiotics

- viruses: non-living and only reproduce in living cells: use chemical processes of living host
- processes virus uses cannot be targeted by drugs as the host cell would also suffer
- commonly used antibiotics are ineffective against viruses
- few viral enzymes can be targeted by drugs to control virus without harming host cell: antivirals

Resistance to antibiotics
- bacteria develop resistance to antibiotics by natural selection
- bacteria with resistance are usually discovered shortly after introduction of new antibiotic; not a huge concern unless strain develops multiple resistance
- methicillin-resistant Staphylococcus aureus or multi-drug-resistant tuberculosis
- measures to avoid antibiotic resistance: prescription only for serious infections, completing courses of antibiotics, high standards of hygiene in hospitals, no antibiotics in animal feeds, pharmaceutical developing new types of antibiotic

6.4 Gas exchange
Ventilation
- gas exchange: all organisms absorb one gas form environment and release different one
- leaves absorb carbon dioxide for photosynthesis; humans absorb oxygen for cell respiration
- terrestrial organisms exchange gases with the air; in humans this happens in small air sacs called alveoli inside lungs
- gas exchange happens by diffusion between air in alveoli and blood flowing through adjacent capillaries: gas diffuses due to concentration gradient: air in alveolus has more oxygen and blood capillary has more carbon dioxide
- ventilation: fresh air pumped into alveoli, stale air removed to maintain concentration gradient

Type I pneumocytes
- lung contains large numbers of alveoli with very large total surface area for diffusion
- wall of each alveolus consists of single layer of cells: epithelium
- most cells in epithelium are Type I pneumocytes which are flattened cells
- air in alveolus and blood in alveolar capillaries are less than 0.5 μm apart: distance the gas has to diffuse is very small: adaptation to increase rate of gas exchange

Type II pneumocytes
- rounded cells that occupy about 5% of alveolar surface area
- secrete fluid which coats inner surface of alveoli: allows oxygen in alveolus to dissolve and diffuse to blood and provides area from which carbon dioxide can evaporate into air
- fluid contains a pulmonary surfactant: form monolayer on surface of moisture lining alveoli: reduces surface tension and prevents water from causing sides of alveoli to adhere exhaling
- this helps to prevent collapse of lungs
- premature babies are often born with insufficient pulmonary surfactant

Airways for ventilation
- air enters ventilation system through mouth or nose; passes down trachea
- trachea has rings of cartilage in its wall: keeps it open even when air pressure inside is low or pressure in surrounding tissues is high
- trachea divides into two bronchi (also strengthened with cartilage)
- one bronchus leads to each lung; bronchi divided repeatedly (tree-like) to narrower airways called bronchioles (have smooth muscle fibers in walls allowing width to vary)
- at the end of narrowest bronchioles are groups of alveoli for gas exchange

Pressure changes during ventilation
- if gas is free to move, it will always flow from regions of higher to regions of lower pressure
- inspiration: muscle contractions cause pressure inside thorax to drop below atmospheric pressure, air is drawn into the lungs until lung pressure is same to atmospheric
- expiration: muscle contractions cause pressure in thorax to rise above atmospheric, so air is forced out

Antagonistic muscles
- muscles can be contracting or relaxing
- muscles perform work when contracting and become shorter
- muscles lengthen while relaxing (happens passively); requires the contracting of another muscle
- muscles can only cause movement in one direction

- when one muscle contracts and causes movement, second muscle relaxes and is elongated
- antagonistic pair of muscles: when muscles work together: inspiration and expiration

6.5 Neurons and synapses

Neurons

- two systems for internal communication: endocrine system and nervous system
- endocrine system: glands that release hormones
- nervous system: consist of nerve cells (neurons) that transmit electrical signals (nerve impulses)
- neurons have a cell body with cytoplasm, nucleus, narrow outgrowths (nerve fibers) along which nerve impulses travel, dendrites (short branched nerve fibers, in brain), axons (very elongated nerve fibers, from toes to spinal chords)

Myelinated nerve fibers

- basic structure of nerve fiber: cylindrical in shape, with plasma membrane enclosing narrow region of cytoplasm: conducts nerve impulses at around 1m per second
- some nerve cells are coated by myelin: consists of many layers of phospholipid bilayer
- Schwann cells deposit myelin by growing around nerve fiber many times
- node of Ranvier: gap between adjacent Schwann cells
- saltatory conduction: in myelinated nerve fibers, nerve impulse can jump form one node of Ranvier to the next one; quicker than continuous transmission (up to 100m per second)

Resting potentials

- resting potential: neuron not transmitting a signal has a potential difference across membrane
- sodium-potassium pumps pump sodium ions (Na^+) out and potassium ions (K^+) in; number of ions pumped is unequal (3 Na^+ out, 2 K^+ in), creating concentration gradients for both
- membrane is a lot more permeable to K^+ ions than Na^+ ions, so K^+ leak back across membrane faster; Na^+ concentration gradient is steeper than K^+ gradient: charge imbalance
- proteins in nerve fibers are negatively charged, increase imbalance
- neuron has a resting membrane potential of about -70mV

Action potentials

- rapid change in membrane potential consisting of two phases: depolarization (change from negative to positive) and repolarization (change back from positive to negative)
- depolarization is due to opening of sodium channels in membrane, allowing Na^+ ions to diffuse into neuron: reverses charge imbalance across membrane: inside is positive relative to outside (membrane potential increases to +30mV)
- repolarization happens rapidly after depolarization: closing of sodium channels and opening of potassium channels: potassium ions diffuse out of cell until potential close to -70mV is reached
- diffusion of potassium repolarizes neuron but does not restore resting potential: concentration gradients of sodium and potassium not re-established: this takes a few milliseconds and the neuron can then transmit another nerve impulse

Propagation of action potentials

- nerve impulse: action potential that starts at one end of neuron and is propagated along axon
- propagation of action potential happens because ion movement in one part of neuron triggers depolarization in neighboring part of neuron
- nerve impulses always travel in one direction along neurons: impulse can only be initiated at one terminal of neuron
- refractive period after depolarization preventing propagation of impulse backwards

Local currents

- propagation of action potential is due to movements of sodium ions
- sodium entering through sodium channels reduces concentration of sodium ions outside of axon and increases inside
- depolarized part has different sodium concentration than neighboring part: sodium ions diffuse between these regions
- inside axon sodium ions diffuse from depolarized part to region which is still polarized; outside the axon, concentration gradient goes in opposite direction: movements are local currents

- local currents reduce concentration gradient in part of neuron that has not yet depolarized: resting potential is changed from -70mV to -50mV
- sodium channels in axon membrane are voltage-gated: -50mV as threshold potential
- opening of sodium channels causes depolarization
- local currents cause wave of depolarization and also repolarization

Synapses
- junctions between cells in the nervous system; in sense organs they are between sensory receptor cells and neurons, in brain and spinal cord they are immense numbers of them between neurons, in muscles and glands they are between neurons and muscle fibers or secretory cells
- effectors: muscles and glands: they carry out a response to a stimulus
- neurotransmitters are used to send signals across synapses
- in all synapses: there is pre-synaptic and post-synaptic cells, separated by a fluid-filled gap (synaptic cleft) so electrical impulses cannot pass

Synaptic transmission
- synaptic transmissions occur very rapidly
- nerve impulse is propagated along neuron up to pre-synaptic membrane, pre-synaptic membrane depolarizes which causes diffusion of calcium ions (Ca^{2+}) into neuron
- calcium entering causes vesicles containing neurotransmitter to move to pre-synaptic membrane and fuse with it, releasing neurotransmitter into synaptic cleft by exocytosis
- neurotransmitter diffuses across synaptic cleft and binds to receptors on post-synaptic membrane causing adjacent sodium ion channels to open, sodium ions diffuse down concentration gradient into post-synaptic neuron causing post-synaptic membrane to reach threshold potential: action potential is triggered in post-synaptic membrane
- neurotransmitter is rapidly broken down and removed form synaptic cleft

Acetylcholine
- is used as neurotransmitter in many synapses
- produced in pre-synaptic neuron; combining choline (diet) and acetyl group (aerobic respiration)
- is loaded into vesicles and released into synaptic cleft during synaptic transmission
- acetylcholine remains bound to receptor of post-synaptic membrane for short time during which one action potential is initiated
- enzyme acetylcholinesterase is present in synaptic cleft and rapidly breaks acetylcholine down into choline and acetate (choline is reabsorbed by pre-synaptic neuron)

Threshold potentials
- nerve impulses follow all-or-nothing principle: action potential is only initiated if threshold potential is reached; only at this potential do sodium channels open, causing depolarization
- positive feedback effect of sodium channels: if threshold potential is reached, there will always be a full depolarization
- at synapse, amount of neurotransmitter secreted of pre-synaptic membrane may not be enough to cause threshold potential to be reached in post-synaptic membrane; post-synaptic membrane does not depolarize and sodium ions are pumped back out
- typical post-synaptic neuron in brain or spinal chord has synapses with many pre-synaptic neurons; may be necessary for several of these to release neurotransmitter at same time to reach threshold potential and cause nerve impulse to be initiated

6.6 Hormones, homeostasis and reproduction
Control of blood glucose concentration
- cells in pancreas respond to changes in blood glucose levels; if it deviates, homeostatic mechanisms mediated by pancreatic hormones insulin an glucagon are initiated
- pancreas: two glands in one organ: most is exocrine gland tissue (digestive enzymes to small intestine), small regions of endocrine tissue (islets of Langerhans; hormones to bloodstream)
- two cell types in islets of Langerhans secrete different hormones
- α cells: synthesize and secrete glucagon if blood glucose levels fall below set point; hormone stimulates breakdown of glycogen into glucose in liver cells

- β cells: synthesize and secrete insulin if blood glucose rises too much; hormone stimulates uptake of glucose by various tissues (esp. skeletal muscle and liver), in liver it stimulates conversion of glucose to glycogen
- insulin is broken down by cells acting upon it, so secretion must be ongoing

Thyroxin
- secreted by thyroid gland in neck; molecule contains four atoms of iodine
- prolonged deficiency of iodine prevents synthesis of thyroxin
- almost all cells in the body are targets; regulates body's metabolic rate so all cells need to respond, most active are liver, muscle and brain
- higher metabolic rate supports more protein synthesis, growth and generation of body heat
- importance of thyroxin is shown by effects of thyroxin deficiency (hypothyroidism): lack of energy, forgetfulness, weight gain despite loss of appetite (less glucose and fat are being broken down for energy), feeling cold, constipation, impaired brain development in children

Leptin
- protein hormone secreted by adipose cells (fat storage cells); controlled by food intake and amount of adipose tissue in body
- target of hormone is group of cells in hypothalamus of brain that contribute to appetite control
- if adipose tissue increases, blood level concentrations increase, causing long-term appetite inhibition and reduced food intake
- importance of hormone shown in experiment with mice that cannot produce leptin

Melatonin
- circadian rhythms: 24-hour cycle and behavior rhythms adapted to this cycle
- cycle continues when person is placed into continuous light or darkness: internal system
- circadian rhythms depend on two cell groups in hypothalamus (suprachiasmatic nuclei, SCN)
- SCN set the daily rhythm, even without external clues
- in the brain, SCN control secretion of hormone melatonin in pineal gland
- melatonin increases in evening and drops to low level at dawn (rapidly removed by liver)
- most obvious effect is sleep-wake cycle; falling levels encourage waking
- contributes to night-time drop in core body temperature
- melatonin receptors in kidney suggest decreased urine production at night
- SCN and pineal gland maintain rhythm of slightly over 24h: timing of rhythm is normally adjusted by few minutes each day
- ganglion cell in retina of eye detects light (wavelength 460-480nm) and passed impulses to cells in SCN, indicating to SCN the timing of dusk and dawn

Sex determination in males
- human reproduction involves fusion of a sperm and egg
- development of embryo is initially same in all embryos and embryonic gonads develop which can either become ovaries or testes
- development pathway of embryonic gonads depends on presence or absence of gene
- if SRY is present, embryonic gonads develop into testes; gene is located on Y chromosome
- SRY codes for a DNA-binding protein (testis determining factors, TDF) which stimulates the expression of other genes that cause testis development
- embryos with two X chromosomes do not have SRY gene, TDF is not produced and embryonic gonads develop as ovaries

Testosterone
- testes develop form embryonic gonads in about 8th week of pregnancy
- testes develop testosterone-secreting cells in early stage and produce it by 15th week
- testosterone causes male genitalia to develop
- at puberty, testosterone secretion increases: stimulates sperm production (primary sexual characteristic) and secondary sexual characteristics such as penis enlargement, growth of pubic hair and deepening of voice due to growth of larynx

Sex determination in females

- in absence of SRY, embryonic gonads develop as ovaries
- no testosterone is secreted, but estrogen and progesterone are always present in pregnancy; at first they are secreted by mother's ovaries, later by placenta
- during puberty, secretion of estrogen and progesterone increases: development of female secondary sexual characteristics including enlargement of breasts and growth of pubic hair

Menstrual cycle

- occurs from puberty until menopause, apart from pregnancies
- each time the cycle occurs, it gives the chance of a pregnancy
- first half: follicular phase: group of follicles is developing in the ovary, in each follicle an egg is stimulated to grow, lining of uterus (endometrium) is repaired and thickens
- the most developed egg breaks open, releasing its egg into oviduct; other follicles degenerate
- second half: luteal phase: wall of follicle which released egg becomes corpus luteum, endometrium prepares for implantation of embryo
- if fertilization does not occur, corpus luteum in ovary breaks down; thickening of endometrium in uterus breaks down and is shed during menstruation
- four hormones control menstrual cycle by negative and positive feedback
- FSH and LH are protein hormones, produced by pituitary gland, bind to receptors in membranes of follicle cells; estrogen and progesterone are ovarian hormones, produced by wall of follicle and corpus luteum
- FSH rises to peak at end of menstrual cycle, stimulates development of follicles, each containing an oocyte and follicular fluid, and stimulates secretion of estrogen by follicle wall
- estrogen rises to peak at end of follicular phase, stimulates repair and thickening of endometrium, increase in FSH receptors, making follicles more receptive to FSH (positive feedback); in high levels, estrogen inhibits FSH (negative feedback) and stimulates LH secretion
- LH rises to sharp peak at end of follicular phase, stimulates completion of meiosis in oocyte, partial digestion of follicle wall (allows it to burst open), promotes development of wall of follicle after ovulation into corpus luteum, secreting estrogen (positive feedback) and progesterone
- progesterone levels rise at start of luteal phase, promotes thickening and maintenance of endometrium, inhibits FSH and LH secretion by pituitary gland (negative feedback)

7 Nucleic acids

7.1 DNA structure and replication

The Watson and Crick model suggested semi-conservative replication

- DNA structure suggests mechanism for DNA replication
- several lines of experimental evidence play role: X-Ray diffraction patterns, Rosalind Franklin's photographs, base composition studies of Erwin Chargaff
- Watson and Crick's first model has sugar-phosphate strands wrapped around each other and nitrogen bases facing outwards; Rosalind Franklin says that nitrogen bases are relatively hydrophobic in comparison to phosphate backbone: nitrogen bases point inwards
- Franklin's X-Ray diffraction suggests DNA is tightly packed
- packing occurs if purine pairs with pyrimidine and bases are upside down to one another
- adenine has a surplus negative charge and thymine a positive one: electrically compatible
- cytosine and guanine can bond by three hydrogen bonds
- complementary base-pairing suggest mechanism for DNA replication: hypothesis of semi-conservative replication

The role of nucleosomes in DNA packing

- nucleosomes help supercoiling DNA
- eukaryotic DNA is associated with histone proteins; prokaryotic DNA is naked (=no proteins)
- histones package DNA into nucleosomes
- nucleosomes are 8 histones (octamer 2x4 different histones) in the core with DNA coiled around
- short „linker" DNA connects nucleosomes
- additional histone protein molecule (H1) binds DNA to core particle
- association of histones with DNA is supercoiling: allows great length of DNA packed into small space
- nucleosome facilitates packing of large genomes; H1 further enhances packing

The leading strand and the lagging strand

- DNA in anti-parallel fashion: synthesis of strands occurs differently
- leading strand is made continuously following the fork
- lagging strand is made in fragments moving from the fork
- lagging strands creates fragments called Okazaki fragments

Proteins involved in replication

- complex system of enzymes carry out DNA replication
- replication involves formation and movement of replication fork and synthesis of leading and lagging strands
- helicase unwinds the DNA
- topoisomerase releases strain developing ahead of helicase
- single-stranded proteins keep strands apart long enough for template stand to be copied
- primers start replication (only one in leading strand, many on lagging strand)
- DNA primase creates RNA primers which initiate DNA polymerase
- DNA polymerase covalently links deoxyribonucleotide monophosphate to 3' of growing strand
- different organisms have different DNA polymerases with different functions as proof-reading, polymerization and removal of RNA primers once no longer needed
- DNA ligase connects gaps between fragments

The direction of replication

- DNA polymerases can only add to 3' end of primer
- DNA replications starts at sites called origins of replication (prokaryotes have one, eukaryotes many)
- replication occurs in both directions from origin
- five carbons of deoxyribose sugar have a number
- phosphate group of new DNA nucleotides is added to 3' carbon of sugar of nucleotide at end of chain: replication occurs in 5' to 3' direction

Non-coding regions of DNA have important functions

- DNA is used as guide for production of polypeptides (only some DNA sequences do: coding sequences)
- many non-coding sequences are found in the genome
- functions of non-coding sequences: act as guide to produce tRNA and rRNA, play role in regulation of gene expression (enhancers and silencers), introns
- most of eukaryotic genome is non-coding
- repetitive sequences can be common in genome, especially in eukaryotes
- two types of repetitive sequences: moderately repetitive and highly repetitive (satellite DNA)
- these sequences can form from 5 to 60% of genome (humans: nearly 60%)
- one area of rep. sequences occurs on ends of eukaryotic chromosomes called telomeres
- telomeres have a protective function: during interphase enzymes cannot replicate DNA until the end of chromosome; without telomeres genes would be lost; they sacrifice repetitive sequence

7.2 Transcription and gene expression

Regulation of gene expression by proteins

- gene expression is regulated by proteins binding to specific base sequences on DNA
- some proteins are always necessary for survival and are expressed in unregulated fashion
- other proteins need to be produced at certain times in certain amounts: regulated expression
- in prokaryotes gene expression is a consequence of variations of environmental factors (e.g. lactose in *E.coli*: genes expressed in presence of lactose, not expressed absence: regulation of gene expression by negative feedback; repressor is deactivated in presence of lactose)
- eukaryotic genes are regulated by variations in environmental conditions; each cell of a multicellular eukaryotic organism expresses only a fraction of its genes
- regulation of eukaryotic gene expression is a critical part of cellular differentiation and process of development
- number of proteins whose bonding to DNA regulates transcription: enhancers, silencers, promoter-proximal elements; sequences linked to regulatory transcription are unique to gene
- enhancers increase rate of transcription when proteins bind to them
- silencers decrease rate of transcription when proteins bind to them
- enhancers and silencers can be distant from promoter, unlike promoter-proximal elements
- binding of proteins to promoter-proximal elements is necessary to initiate transcription

The impact of the environment on the gene expression

- environment of cell and organism has an impact on gene expression
- influence of environment on gene for some traits is unequivocal: environmental factors can affect gene expression such as production of skin pigmentation
- embryo contains an uneven distribution of chemicals called morphogens
- morphogens affect gene expression contributing to different patterns of gene expression

Nucleosomes regulate transcription

- chemical modification of histone tails as important factor in determining expression of a gene
- modifications can be addition of acetyl, methyl or phosphate group
- example: residues of amino acids lysine on histone tails add or remove acetyl groups, lysine residues bear positive charge binding to negative DNA forming a condensed structure inhibiting transcription, acetylation neutralizes positive charges causing higher transcription levels
- chemical modification activates or deactivates genes by decreasing or increasing accessibility of gene to transcription factors

The direction of transcription

- transcription occurs in a 5' to 3' direction
- synthesis of mRNA in three stages: initiation, elongation, termination
- transcription begins at promoter; once RNA polymerase binds, DNA is unwound by RNA polymerase, RNA polymerase slides along DNA synthesizing single strand of RNA

Post-transcriptional modification

- mRNA is modified after transcription in eukaryotes

- Regulation of gene expression can occur at several points: transcription, translation, post-translational regulation in eu- and prokaryotes
- in prokaryotes mostly at transcription
- eukaryotes additionally use post-transcriptional modification of RNA
- prokaryotes lack a nuclear membrane: transcription and translation can be coupled
- separate locations for transcription and translation in eukaryotes allows significant post-transcriptional modification before mature transcript exits nucleus (e.g. removal of intervening sequences (introns) from RNA transcript)
- prokaryotic DNA does not contain introns
- immediate product of mRNA transcription is called pre-mRNA (several stages until it's mature)
- one stage is RNA splicing: RNA contains sequences not contributing to formation of polypeptide: introns: must be removed: remaining parts are called exons
- exons will be spliced together to form mature mRNA
- post-transcriptional modification includes addition of 5'-cap (occurs before transcription) and poly-A tail (occurs after transcript has been made)

mRNA splicing

- splicing mRNA increases number of different proteins an organism can produce
- alternative splicing: process when a single gene codes from multiple proteins (occurs in genes with multiple exons)
- proteins translated from alternatively spliced mRNAs will differ in their amino acid sequence and possibly in their biological functions
- example in mammals: Tropomyosin is encoded by gene that has 11 exons
- example in fruit flies: potential 38'000 different mRNAs possible based on number of introns

7.3 Translation

Initiation of translation

- involves assembly of components that carry out the process
- beginning of process is the binding of mRNA to small ribosomal subunit at mRNA binding site
- initiator tRNA molecule carrying methionine binds to start codon AUG
- large ribosomal subunit then binds to small one
- Initiator tRNA is in P site, next codon signals binding to A site, peptide bond is formed between amino acids in P and A site

Elongation of the polypeptide

- synthesis of polypeptide involves a repeated cycle of events
- elongation occurs after initiation
- ribosome translocates three bases along mRNA, moving tRNA to E site: this frees the A site and allows the new tRNA with appropriate anticodon to bind

Termination of translation

- process of elongation continues until a stop codon is reached
- movement along the mRNA is from 5' end to 3' end

Free ribosomes

- in eukaryotes, proteins are synthesized in cytoplasm or at endoplasmic reticulum, depending on final destination of protein
- proteins used in cell (cytoplasm, mitochondria, chloroplasts) are synthesized by free ribosomes

Bound ribosomes

- proteins perform a function within specific compartment of the cell or are secreted
- proteins must be sorted to end up in correct location
- proteins destined for use in endoplasmic reticulum, Golgi apparatus, lysosomes, plasma membrane or outside the cell are synthesized by ribosomes bound to endoplasmic reticulum
- whether a ribosome is bound or free depends on presence of signal sequence on polypeptide; in the first part of sequence: if signal sequence is created it binds to signal recognition protein stopping translation until bound to receptor on surface of endoplasmic reticulum
- translation begins again and polypeptide is created into lumen of endoplasmic reticulum

The coupling of transcription and translation in prokaryotes
- eukaryotes have compartmentalized cellular functions while prokaryotes do not
- as soon as mRNA is transcribed, translation begins

Primary structure
- chain of amino acids is a polypeptide; 20 different common amino acids can be combined in any sequence: huge diversity of proteins
- sequence of amino acids in a polypeptide is the primary structure

Secondary structure
- chain of amino acids in polypeptide has polar covalent bonds within its backbone: chain folds so hydrogen bonds form between carboxyl group (C=O) and amino group (N-H)
- folding creates α-helix and β-pleated sheet and are the secondary structure

Tertiary structure
- overall three-dimensional shape of protein: happens through interaction of R-groups between one another and surrounding water medium
- different types of interaction: positively and negatively charged R-groups, hydrophobic amino acids orientate inwards while hydrophilic turn outwards, polar R-groups form hydrogen bonds between themselves, R-group of amino acid cystine can form covalent bond with another cystine (bond is called disulphide bridge)

Quartenary structure
- proteins can be formed from single polypeptide chain or multiple chains
- quartenary structure is the way polypeptides fit together when there is more than one chain
- biological activity of protein is related to primary, secondary, tertiary and quartenary structure
- treatments as high temperatures, changes in pH can cause alterations in structure of protein and therefore its biological activity; permanent loss of structure is called denaturation

8 Metabolism, cell respiration and photosynthesis

Introduction

- life sustained by web of chemical reactions in cells: regulated by needs of cell and organism
- energy converted to usable form in cell respiration; photosynthesis converts light energy to chemical energy and huge diversity of carbon compounds is produced

8.1 Metabolism

Metabolic pathways

- consist of chains and cycles of enzyme-catalyzed reactions
- metabolism refers to chemical changes taking place in living cell
- metabolism is very complex, but there are some common patterns: chemical changes happen in sequence of small steps (metabolic pathway), metabolic pathways involve a chain of reactions, some metabolic pathways form a cycle (end product is also reactant starting it)

Enzymes and activation energy

- enzymes lower activation energy of chemical reaction they catalyze
- chemical reactions are not single-step processes: substrates pass through transition state
- energy is required to reach transition state (activation energy); though from transition state to product energy is released
- activation energy is used to break or weaken bonds
- enzyme catalyzing reaction: substrate binds to active site, enzyme alters substrate to reach transition state, converted into products, separate from active site
- binding to active site lowers overall energy level of transition state: activation energy reduced
- net amount of energy released stays unchanged by enzyme's involvement
- reduced activation energy greatly increases rate of reaction (typically by factor million+)

Types of enzyme inhibitors

- some chemical substances bind to enzymes and reduce its activity: inhibitors
- inhibitors can be competitive and non-competitive
- competitive: interfere with active site so the substrate cannot bind
- non-competitive: bind at different location than active site causing change in shape of enzyme so the substrate cannot bind

End-product inhibition

- allosteric interactions: many enzymes regulated by chemical substances binding to special sites away from active site (allosteric site)
- in many cases the regulated enzyme is one of first reactions in metabolic pathway and the substance binding to allosteric site is end product of pathway
- reactions often do not reach completion: equilibrium is reached with substrate-product ratio: if product concentration increases reaction slows and eventually stops: end-product inhibition prevents build-up of intermediate products

8.2 Cell respiration

Oxidation and reduction

- oxidation and reduction are chemical processes that always occur together; involves a transfer of electrons: oxidation is the loss of electrons, reduction is the gain of electrons
- electron carriers: substances that can accept and give up electrons as required
- main electron carrier in respiration is NAD, in photosynthesis it is NADP (phosphorylated NAD)
- NAD initially has one positive charge and exists as NAD^+
- NAD^+ accepts two electrons: two hydrogen atoms are removed from substance being reduced, one hydrogen atom is split into proton and electron, NAD^+ accepts the electron and the proton is released, NAD accepts electron and proton of other hydrogen atom creating NADH and H^+

- reduction can be achieved by accepting atoms of hydrogen; oxidation by loss of hydrogen
- oxidation and reduction can also occur through loss or gain of atoms of oxygen
- adding oxygen atoms is oxidization because oxygen atoms have a high affinity for electrons and tend to draw electrons from other molecules

Phosphorylation

- addition of a phosphate molecule (PO_4^{3-}) to an organic molecule
- purpose of phosphorylation is to make a molecule more unstable: activates the molecule
- hydrolysis of ATP releases energy: exergonic reaction; many reactions in body are endergonic
- reactions in body do not proceed unless coupled with exergonic reaction releasing more energy
- many metabolic reactions are coupled to the hydrolysis of ATP

Glycolysis and ATP

- most significant consequence of glycolysis is production of small ATP yield without oxygen
- glycolysis converts sugar into pyruvate: is not done in one step (metabolic pathway)
- first step of glycolysis: ATP is used to phosphorylate sugar: reduces activation energy: makes the reaction much more likely to occur

Pyruvate is a product of glycolysis

- fructose bisphosphate is split from two molecules of triose phosphate: each is oxidized to glycerate-3-phosphate in reaction that yields enough energy to make ATP, oxidization is made by removing hydrogen atoms, hydrogen is accepted by NAD^+ which becomes NADH and H^+
- in final stage of phosphate is transferred to ADP to produce more ATP and pyruvate

The fate of pyruvate

- two pyruvate are produced per glucose in glycolysis
- if oxygen is available, pyruvate is absorbed into mitochondrion where it is fully oxidized
- carbon and oxygen are removed as carbon dioxide in decarboxylation
- oxidation of pyruvate is achieved by removal of pairs of hydrogen atoms: NAD and FAD accept hydrogen atoms and pass them to electron transport chain for oxidative phosphorylation

The link reaction

- after pyruvate is shuttled into mitochondrial matrix, it is decarboxylated and oxidized to form an acetyl group (acetyl coenzyme A); two high energy electrons are removed and react with NAD^+ to produce reduced NAD
- whole process is link reaction as it links glycolysis with Krebs cycle

The Krebs cycle

- link reaction involves one decarboxylation and one oxidation; in Krebs cycle two decarboxylations and four oxidations follow
- energy released in oxidations of link reaction and Krebs cycle is used to reduce hydrogen carriers (NAD^+, FAD): energy is used in final part of aerobic cell respiration
- for every turn of Krebs cycle, it produces three reduced NAD, two decarboxylations occur, one reduced FAD is produced, one ATP molecule is generated

Oxidative phosphorylation

- reduced NAD is generated in glycolysis, link reaction, Krebs cycle, $FADH_2$ is produced during Krebs cycle
- final part of aerobic respiration is oxidative phosphorylation because ADP is phosphorylated to produce ATP using energy released by oxidation
- NAD and $FADH_2$ are used to carry the energy released to the mitochondrial cristae

The electron transport chain

- main substance oxidized is NAD
- energy is released in series of small steps, carried out by chain of electron carriers
- reduced NAD and $FADH_2$ donate their electrons to electron carriers
- as electrons pass from carrier to carrier, energy is used to transfer protons across inner membrane form matrix into intermembrane space

- protons flow through ATP Synthase down their concentration gradient providing energy for the production of ATP

Chemiosmosis

- mechanism used to couple release of energy by oxidization to ATP production
- happens in the inner mitochondrion membrane
- chemical substance (H^+) moves across a membrane, down the concentration gradient: releases energy needed for enzyme ATP synthase to make ATP
- main steps: NADH and H^+ supplies pair of hydrogen atoms to first carrier (NAD+ returns to matrix), hydrogen atoms are split to release two electrons, electrons pass from carrier to carrier and energy is released, energy transfers protons (H^+) across inner mitochondrial membrane, concentration gradient builds up quickly, gradient is store of potential energy, to allow electrons to flow they must be transferred to terminal electron acceptor (in aerobic respiration it is oxygen), the oxygen combines with two H^+ ions from matrix to become water, protons pass back from intermembrane space to matrix through ATP synthase, this releases energy and is used to phosphorylate ADP

The role of oxygen

- oxygen is final electron acceptor in mitochondrial electron transport chain
- reduction of oxygen molecule involves accepting electrons and forming covalent bond with H
- by using hydrogen, proton gradient is maintained so that chemiosmosis can continue

Structure and function in the mitochondrion

- clear relationship between structures in organism and their function: natural selection, evolution
- mitochondria which produced most ATP would have an advantage
- adaptation: change in structure so that something carries out its function more efficiently
- mitochondrion is semi-autonomous organelle: can grow and reproduce itself
- mitochondrion is site of aerobic respiration; outer membrane separates contents of mitochondrion from rest of cell: creates compartment specialized for biochemical reactions
- inner mitochondrial membrane is site of oxidative phosphorylation: contains electron transport chains and ATP synthase
- cristae are tubular projections which increase surface available for oxidative phosphorylation
- intermembrane space is where protons build up after electron transport chain
- volume of intermembrane space is small so concentration gradient can be built up rapidly
- matrix fluid contains enzymes necessary for Krebs cycle and link reaction

8.3 Photosynthesis

Location of light-dependent reactions

- photosynthesis consists of two different parts: one which uses light directly (light-dependent reactions) and the other that uses light indirectly (light-independent reactions)
- light-dependent reactions can only carry on in darkness for few seconds
- chloroplast has outer and inner membrane; inner membrane encloses third system of interconnected membranes: thylakoid membranes; within these is thylakoid space
- light-dependent reactions take place in thylakoid space and across thylakoid membranes

The products of the light-dependent reactions

- light energy is converted to chemical energy in the form of ATP and reduced NADP
- ATP and reduced NADP are energy sources for the light-independent reactions

The location of the light-independent reactions

- inner membrane of chloroplast encloses a compartment called stroma which is a protein-rich medium containing enzymes for light-independent reactions (Calvin cycle)
- Calvin cycle is an anabolic pathway that requires endergonic reactions to be coupled to hydrolysis of ATP and oxidation of reduced NADP

Photoactivation

- Chlorophyll and accessory pigments are grouped into large arrays called photosystems

- photosystems are located in the thylakoids; there are two types: Photosystems I and II
- photosystems have reaction centers
- both photosystems contain many chlorophyll molecules, which absorb light energy and pass it to two special chlorophyll molecules in the reaction centre of the photosystems
- when the special chlorophyll molecules absorb energy from a photon of light, an electron within the molecule becomes excited: the chlorophyll is photoactivated
- chlorophyll at reaction centre can donate their excited electrons to an electron acceptor
- light-dependent reactions begin in Photosystem II; electron acceptor in this photosystem is called plastoquonine: collects two excited electrons from Photosystem II and moves to another position in membrane
- plastoquonine is hydrophobic so it remains within the membrane
- absorption of two photons of light causes production of one reduced plastoquonine with one of chlorophyll at reaction centre having lost two electrons
- Photosystem II can do this twice so chlorophyll at reaction centre loses four electrons and two plastoquonine molecules have been reduced

Photolysis

- when plastoquonine is reduced, chlorophyll in reaction centre is a powerful oxidizing agent: causes water molecules to split (photolysis) and give up electrons, replacing the ones it lost
- photolysis is how oxygen is generated and diffuses away as a waste product
- useful product of Photosystem II is reduced plastoquonine, carrying electrons and light energy
- the light energy drives all the subsequent reactions of photosynthesis

The electron transport chain

- photophosphorylation: production of ATP using energy from light, carried out by thylakoids
- thylakoids are stacks of membranes with very small fluid-filled spaces; contain Photosystem II, ATP synthase, chain of electron carriers, Photosystem I
- plastoquonine carries electrons to start chain of electron carriers

The proton gradient

- electrons are passed from carrier to carrier in the electron transport chain
- energy is released as they pass which pumps protons across thylakoid membranes into space inside the thylakoids
- concentration gradient of protons develops which stores potential energy; photolysis contributes to this gradient

Chemiosmosis

- protons travel back across membrane, down concentration gradient, through enzyme ATP synthase: energy released is used for making ATP from ADP and inorganic phosphate
- when electrons reach end of carrier chain they are passed to plastocyanin
- plastocyanin: water-soluble electron acceptor in fluid in thylakoids
- reduced plastocyanin is used in the next step of photosynthesis

Reduction of NADP

- remaining parts of light-dependent reactions involve Photosystem I: reduced NADP is important product: needed in light-independent reactions; carries a pair of electrons
- chlorophyll in Photosystem I passes light energy to special chlorophyll molecules in reaction centre: raises electron to high energy level: photoactivation
- excited electron passes through carrier chain and is passed at the end to ferredoxin
- ferredoxin is a protein in fluid outside of thylakoid
- two molecules of reduced ferredoxin are used to reduce NADP
- electron lost from Photosystem I to carrier chain is replaced by electron from plastocyanin
- Photosystem II and I are linked: excited electrons from Photosystem II are passed through chain of carriers to plastocyanin which gives them to Photosystem I, electrons are re-excited with light energy and are used to reduce NADP
- when NADP runs out, electrons return to electron transport chain that links the photosystems: as electrons flow back along electron transport chain to Photosystem I, they cause pumping of protons which allows ATP production: cyclic photophosphorylation

Carbon fixation

- carbon fixation reaction: carbon dioxide is converted into other carbon compounds
- in plants and algae this happens in stroma (fluid surrounding thylakoids in chloroplast)
- product of reaction is glycerate-3-phosphate
- carbon dioxide reacts with five-carbon compound (ribulose bisphosphate, RuBP) to produce two molecules of glycerate-3-phosphate
- enzyme catalyzing reaction is ribulose bisphosphate carboxylase (rubisco)
- stroma contains large amounts of rubisco to maximize carbon fixation

The role of reduced NADP and ATP in the Calvin cycle

- RuBP is 5-carbon sugar derivative; when it is converted to glycerate-3-phosphate amount of hydrogen in relation to oxygen is reduced
- hydrogen has to be added using ATP and reduced NADP (from light-dependent reactions) by reduction reaction to produce carbohydrate
- ATP provides energy and reduced NADP provides hydrogen atoms
- product is a three-carbon sugar derivative: triose phosphate

The fate of triose phosphate

- first carbohydrate produced by light-independent reactions is triose phosphate
- two triose phosphate molecules can be combined to hexose phosphate; hexose phosphate can be combined by condensation reaction to starch
- if all triose phosphate was converted, supplies of RuBP would run out
- some triose phosphate in chloroplast is used to regenerate RuBP; conversion of 3-carbon sugar into 5-carbon sugar cannot be done in one step
- RuBP is consumed and produced in light-independent reactions: Calvin cycle
- three RuBP form six triose phosphates: five of these are needed to regenerate three RuBP molecules: only one triose phosphate is left for conversion to hexose, starch, other products
- to produce glucose, six turns of Calvin cycle are needed, each of which contributes one of the fixed carbon atoms

RuBP regeneration

- in last phase of Calvin cycle, series of enzyme-catalyzed reactions convert triose phosphate to RuBP using ATP
- after RuBP is regenerated it can serve to fix carbon dioxide and begin cycle again

Chloroplast structure and function

- double membrane forms chloroplast envelope
- thylakoids: extensive system of internal membranes, intense green color
- small fluid-filled samples inside thylakoids
- stroma: colorless fluid around thylakoids containing many different enzymes; may contain starch grains or lipid droplets if chloroplasts synthesize rapidly
- grana: stacks of thylakoids

9 Plant biology

Introduction

- plants are highly diverse in structure and physiology
- act as producers in almost all terrestrial ecosystems
- plants have sophisticated methods of adapting growth to environment
- reproduction is influenced by biotic and abiotic environment

9.1 Transport in the xylem of plants

Transpiration

- plant leaves are primary organ of photosynthesis; involves synthesis of carbohydrates using light energy: carbon dioxide is raw material, oxygen is waste product
- waxy cuticle has very low permeability to essential carbon dioxide: has pores through epidermis: stomata
- transpiration: loss of water vapor from leaves and stems of plants
- plants minimize water losses through stomata using guard cells
- guard cells are in pairs and control aperture of stoma and adjust from wide open to closed
- guard cells found in all groups of land plants except in group liverworts

Xylem structure helps withstand low pressure

- xylem vessels: long continuous tubes with thickened walls; allow efficient transport of water
- thickened walls are impregnated with polymer lignin: strengthens walls to withstand very low pressures without collapsing
- mature xylem cells are nonliving; flow of water must be passive
- pressure inside xylem vessels is usually much lower than atmospheric pressure but rigid structure prevents collapsing
- cohesion: polar water molecules holding together (neg. oxygen part attracted to pos. hydrogen)
- adhesion: water attracted to hydrophilic parts of cell walls of xylem
- cohesion and adhesion ensure that water can be pulled up from xylem in continuous stream

Tension in leaf cell walls maintaining the transpiration stream

- water is drawn from nearest xylem vessel in veins of leaf due to adhesion when it evaporates
- even if pressure in xylem is low, adhesion is strong enough to suck it out of xylem
- low pressure generates a pulling force going down the stem to ends of roots: transpiration-pull: strong enough to move water against gravity: all energy is from thermal energy by transpiration
- pulling of water depends on cohesion; many liquids are unable to resist the pulling force
- cavitation: column of water breaking in xylem vessels, happens occasionally with water
- though water is liquid, it transmits pulling forces in same way as a solid rope

Active transport of minerals in the roots

- solute concentration inside root cells is greater than in soil: water uptake by osmosis
- most solutes in roots and soil are mineral ions
- concentration gradient between soil and root is established by active transport using protein pumps in plasma membranes; separate pumps for each type of ion
- mineral ions can only be absorbed if they make contact with appropriate pump protein: occurs by diffusion or mass flow when water carrying ions moves through soil
- some ions move through soil very slowly (bind to soil particles)
- certain plants developed relationship with fungus growing on surface of roots (sometimes into cells of root): thread-like hyphae of fungus grow into soil and absorb mineral ions (e.g. phosphate) and supply them to roots
- most plants supply sugars and other nutrients to fungus: mutualistic relationship (both benefit)

Replacing losses from transpiration

- water leaves through stomata by transpiration which is released by water from xylem
- transpiration, adhesion, cohesion forces pull water from roots which take in water by osmosis
- when water is in roots, it travels to xylem through cell walls (apoplast pathway) and cytoplasm (symplast pathway)

9.2 Transport in the phloem of plants

Translocation occurs from source to sink

- phloem tissue is found throughout plants; it is composed of sieve tubes which are made from specialized sieve tube cells which are separated by perforated walls called sieve plates
- sieve tube cells are closely associated with companion cells
- translocation: transport of organic solutes in plants (happens in phloem)
- phloem links part that need a supply of sugars and other solutes with parts that have a surplus
- source: areas where sugars and amino acids are loaded into phloem
- sink: areas where sugars and amino acids are unloaded and used
- sometimes sinks turn into sources and vice versa: phloem must be able to transport biochemicals in either direction; no valves or central pump
- fluid in phloem flows due to pressure gradients; energy is used so it is an active process

Phloem loading

- sucrose is most prevalent solute in phloem sap; not available for plant tissues to metabolize in respiration: good transport form of carbohydrate: will not be metabolized during transport
- plants differ in mechanism by which they bring sugars into phloem: process is phloem loading
- some species: significant amount travels in cell wall from mesophyll cells to cell walls of companion cells
- sometimes travels in sieve cells where sucrose transport protein actively transports sugar in (apoplast route): gradient is achieved by H^+ ions are transported out of companion cell from surrounding cells using ATP; H^+ flow down concentration gradient through co-transporter protein; energy released is used to carry sucrose into companion cell-sieve tube complex
- other species: sucrose travels between cells in plasmodesmata (symplast route); once sucrose reaches companion cell it is converted to oligosaccharide to maintain sucrose gradient

Pressure and water potential differences play a role in translocation

- build up of sucrose and other carbohydrates draws water into companion cells by osmosis: rigid cell walls and incompressibility of water result in build-up of pressure
- water flows from area of high pressure to area of low pressure
- at sink end, sucrose is withdrawn from phloem: either converted to starch or used as energy: loss of solute causes reduction in osmotic pressure so water that carried solute to sink is drawn back into transpiration stream in xylem

9.3 Growth in plants

Growth in plants

- most animals and some plant organs undergo determinate growth: defined embryonic period or growth stops when certain size is reached
- indeterminate growth: cells continue to divide indefinitely: usually plants
- many plant cells have totipotent cells: is what sets plant cells apart from most animals
- growth in plants is confined to regions called meristems (undifferentiated cells undergoing active cell division)
- primary meristems: found in tips of stems and roots: called apical meristems
- root apical meristem is responsible for growth of root; shoot apical meristem is at tip of stem
- many dicotyledonous (2 leaves in embryo of seed) plants develop lateral meristems

Role of mitosis in stem extension and leaf development

- cells in meristems undergo cell cycle (mitosis, cytokinesis) to produce more cells
- new cells absorb nutrients and water: increase in volume and mass
- shoot apical meristem throws off cells needed for growth of stem and produces groups of cells that develop into leaves and flowers
- with each division, one cell remains in meristem, other increases size and differentiates as it is pushed away from meristem region
- each apical meristem can give rise to additional meristems
- protoderm gives rise to epidermis; procambium gives rise to vascular tissue; ground meristem can give rise to pith

- chemical influences play role in determining which specialized cell is made from unspecialized plant cells
- young leaves: produced at sides of shoot apical meristems, are small bumps (leaf primordia)

Plant hormones affect shoot growth

- auxins are hormones with many functions: initiating growth of roots, influencing development of fruits, regulating leaf development
- most abundant auxin is indole-3-acetic-acid (IAA): controls growth in shoot apex, promotes elongation of cells in stems; very high concentrations inhibit growth
- IAA is synthesized in apical meristem of shoot and transported down stem for growth
- axillary buds are shoots that form at junction or node of stem and base of leaf
- regions of meristem are left behind at node; growth is inhibited by auxin from shoot apical meristem: apical dominance; the further distant a node is from shoot apical meristem, the lower concentration of auxin and its inhibition of growth is; additionally, cytokinin produced by root promote axillary bud growth
- gibberellins are another category of hormones that contribute to stem elongation

Plant tropisms

- rate and direction of stem and root growth are controlled by hormones
- two external stimuli (tropisms): light (phototropism) and gravity (gravitropism)
- stems grow towards source of brightest light (in absence of light: upwards)

Auxin influences gene expression

- first stage of phototropism is absorption of light by photoreceptors (proteins: phototropins)
- when phototropins absorb light of appropriate wavelength they change conformation: bind to receptors within cell which control transcription of specific genes: code for group of glycoproteins (PIN3 proteins) that transport auxin from cell to cell

Intracellular pumps

- position and type of PIN3 proteins can be varied to transport auxin where growth is needed
- phototropins detect light on one side of tip: auxin is transported laterally from side with brighter light to shaded side: stem grows into curve towards source of light
- leaves attached to stem receive more light and are able to photosynthesize at greater rate
- gravitropism is also auxin dependent; gravity from one side of root causes cellular organelles (statoliths) to accumulate on lower side of cells: PIN3 accumulate on bottom of cells
- high auxin concentrations inhibit root cell elongation so top cells elongate at faster rate causing root to bend downward
- pattern of auxin is opposite in root and shoot: in shoot promotes elongation, in root inhibits

9.4 Reproduction in plants

Flowering and gene expression

- vegetative structures: roots, stems, leaves grow after germination
- plant is in vegetative phase until trigger causes to change into reproductive phase (flowering)
- change happens when shoot meristems start producing parts of flowers instead of leaves
- flowers allow sexual reproduction, are produced by shoot apical meristem (reproductive shoot)
- temperature can play role in transforming leaf to flower-production; day length is main trigger, but plants measure duration of dark period
- short-day plants flower when dark period becomes longer (autumn)
- long-day plants flower during long days of summer when nights are short
- light either inhibits or activates genes that control flowering; in long-day plants the active form of pigment phytochrome leads to transcription of flowering time (FT gene)
- FT mRNA is transported to phloem to shoot apical meristem where it is translated to FT protein
- FT protein binds to transcription factor, leads to activation of many flowering genes

Photoperiods and flowering

- long-day plants flower in summer the nights have become short enough
- short-day plants flower in autumn when nights have become long enough
- length of darkness matters: pigment phytochrome measures length of dark periods

- phytochrome can switch between two forms: P_R and P_{FR}
- when P_R absorbs red light of wavelength 660nm it is converted into P_{FR}
- when P_{FR} absorbs far-red light (730nm) it is converted to P_R
- sunlight contains more light of wavelength 660nm (P_R to P_{FR}) but P_R is more stable so in darkness it changes gradually
- P_{FR} is active form of phytochrome and receptor proteins (for P_{FR}) are present in cytoplasm
- in long-day plants large amounts of P_{FR} remain at end of short nights to bind which promotes transcription of genes needed for flowering
- in short-day plants receptor inhibits transcription when P_{FR} binds; at end of long nights very little P_{FR} remains inhibition fails and plant flowers

Mutualism between flowers and pollinators

- sexual reproduction depends on transfer of pollen from stamen to stigma of another plant
- commonly transferred by animals (pollinators); wind and water are also possible
- mutualism: close association between two organisms where both benefit from relationship
- pollinators gain food (nectar) and plant gains means to transfer pollen

Pollinators, fertilization and seed dispersal

- after pollination comes fertilization: from each pollen grain on stigma a pollen tube containing male gametes grows down the style to ovary which is located inside ovule
- fertilized ovule develops into seed, ovary develops into fruit
- seed dispersal: seeds cannot move but travel long distances from parent plant, reduces competition between offspring and parent and helps spreading species
- type of seed dispersal depends on structure of fruit: dry and explosive, fleshy and attractive for animals to eat, feathery/winged to catch wind, covered in hooks to catch onto coats of animals

10 Genetics and evolution

Introduction

- genes may be linked or unlinked
- meiosis leads to independent assortment of chromosomes and unique composition of alleles
- gene pools change over time

10.1 Meiosis

Chromosome replication

- meiosis follows a period of interphase with cell cycle phases G_1, S and G_2
- DNA is replicated in S phase so each chromosome consists of two chromatids
- synapsis occurs where homologous chromosomes align beside each other: tetrad/bivalent
- synaptonemal complex: protein-based structure forming between homologous chromosomes

Exchange of genetic material

- during prophase I breaks in DNA occur: non-sister chromatids exchange homologous sequence: after crossing over they continue to adhere at connection points called chiasmata

Chiasmata formation

- consequences of chiasmata are increased stability of bivalents and increased genetic variability
- exchanges DNA between maternal and paternal chromosomes: decouples linked combinations
- crossing over can occur multiple times and between different chromatids within same homologous pair

New combinations of alleles

- crossing over produces new combinations of alleles on chromosomes of haploid cells

Meiosis I

- first meiotic division is unique, second round resembles mitosis
- differences between meiosis I and II: sister chromatids remain associated with each other, homologous chromosomes exchange DNA (genetic recombination), reduction division
- creation of genetic variety of gametes; segregation of homologous chromosomes (anaphase I)

Independent assortment

- homologous chromosomes pair up and then separate to poles; pole to which it moves depends on which pole the pair is facing; is random; irrespective of other pairs: independent orientation

Meiosis II

- daughter cells enter meiosis II after meiosis I without passing through interphase
- meiosis II is similar to mitosis
- sister chromatids are separated, but likely to be non-identical sister chromatids (crossing over)

10.2 Inheritance

Segregation and independent assortment

- segregation: separation of two alleles of every gene that occurs in meiosis
- genes found on different chromosomes are unliked; genes on the same are linked: do not segregate independently
- crossing over between genes occurs more frequently the further the separation of the genes

Linked genes

- Morgan shows that genes are arranged in linear sequence along X chromosome
- each particular gene is found in a specific position on one chromosome type: locus of a gene
- chromosomes with same sequence of genes are homologous; alleles will be different
- all genes on a chromosome are part of one DNA molecule
- diploid have two of each type of autosome

- two types of linkage: autosomal gene linkage and sex linkage

Types of variation

- variation: differences between individual organisms
- variation is discrete or discontinuous when individuals fall into number of distinct categories
- blood types are an example of discrete variation; there are no in-between categories

Continuous variation

- when two or more genes affect the same character they have an additive effect
- Mendel's expected 3:1 ratio did not occur and he had variety of flower colors: two unlinked genes with co-dominant alleles
- number of frequency variants can be predicted with alternate rows of Pascal's triangle
- as number of genes increases, distribution becomes increasingly close to normal distribution
- closeness to normal distribution suggests more than one gene involved: polygenic inheritance

Chi-squared tests are used to determine whether the difference between observed and expected frequency distribution is statistically significant

- are differences between observed and expected due to sampling error or are differences statistically significant
- method: table of observed frequencies, calculate expected frequencies (assuming independent assortment), determine degrees of freedom (one less than total number of classes), find critical region from chi-squared values, calculate X^2 = sum of $(obs\text{-}exp)^2/exp$, if calculated value is equal to or below the chi-squared value H_0 is not rejected

10.3 Gene pools and speciation

Gene pools

- gene pool: all genes and their different alleles present in an interbreeding population
- species is a group of potentially interbreeding populations with common gene pool that is reproductively isolated from other species
- some populations are geographically isolated: multiple gene pools for same species
- genetic equilibrium exists when all members of population have equal chance of contributing to the future gene pool

Allele frequency and evolution

- evolution: cumulative change in heritable characteristics of a population over time
- evolution occurs because: mutations introducing new alleles, selection pressures favoring reproduction of some varieties, barriers to gene flow emerging between different populations
- if a population is small, random events can also have a significant effect on allele frequency

There are different categories of reproductive isolation

- speciation is the formation of a new species by the splitting of an existing population
- allopatric speciation: isolation occurs because of geographic separation
- sympatric speciation: isolation of gene pools within same geographic area, e.g. behavioral
- temporal isolation: populations may mate/flower at different seasons or different times of day

Gradualism in speciation

- gradualism: species slowly change through a series of intermediate forms
- gradualism is dominant framework in paleontology but there are gaps in the fossil record

Punctuated equilibrium

- long periods of relative stability in a species are punctuated by periods of rapid evolution
- gaps in fossil record might not be gaps at all
- geographic isolation and opening of new niches within shared geographic range can lead to rapid speciation
- rapid change is much more common in organisms with short generations (prokaryotes, insects)

11 Animal physiology

Introduction

- immunity based on recognition of self and destruction of foreign material
- all animals excrete nitrogenous waste products
- sexual reproduction involves development and fusion of haploid gametes

11.1 Antibody production and vaccination

Antigens in blood transfusion

- antigen: any foreign molecule that can trigger immune response; most common are proteins and very large polysaccharides (found on surface of cancer cells)
- surface of own cells contain proteins and polypeptides which are distinguished by immune system as “self”; others are “foreign” antigens
- antigens on surface of pollen are trigger for immune responses “allergies” and “hay fever”

The specific immune response

- immune systems uses “challenge and response”: antigens on surface of pathogens are “challenge”; response is in multiple stages
- pathogens ingested by macrophages, their antigens are displayed on surface of macrophages, lymphocytes (helper T cells) have antibody-like receptor protein in plasma membrane which bind, only few lymphocytes have receptor protein, these helper T cells bind and are activated by macrophage, these bind to B cells
- B cells have receptor protein to which antigen binds; helper T cell activates selected B cell by means of binding and release of signaling protein

The role of plasma cells

- plasma cells: mature B lymphocytes that produce and secrete large number of antibodies during immune response
- cell’s cytoplasm contains extensive network of rough endoplasmic reticulum which manufactures, modifies and transports antigens

Clonal selection and memory cell formation

- activated B cells divide many times by mitosis; clonal selection: large number of plasma cells that produce one specific antibody type
- antibodies only persist in body for few weeks and plasma cells producing them are gradually lost after infection is overcome
- most of clone B cells become active plasma cells, small number become memory cells which remain long after infection; remain inactive unless same pathogen appears again
- immunity involves either having antibodies or memory cells allowing rapid production

The role of antibodies

- antibodies aid in destruction of pathogens in number of ways
- opsonization: make pathogen more recognizable to phagocytes, more readily engulfed
- neutralization of viruses and bacteria: prevent viruses from docking to host cells
- neutralization to toxins: bind to toxins produced by pathogens, preventing them from affecting susceptible cells
- activation of complement: complement system is collection of proteins which lead to perforation of membranes of pathogens
- agglutination: cause sticking together of pathogens, so prevented of entering cells and easier for phagocytes to ingest

Immunity

- either due to presence of antibodies or memory cells
- immunity develops when immune system is challenged by specific antigen and produces antibodies and memory cells in response

- memory cells ensure that second time antigen is encountered, body is ready to respond rapidly by producing more antibodies at faster rate

Vaccines lead to immunity
- vaccine is introduced to body usually by injection
- vaccine may contain a live attenuated (weakened) version of pathogen or some derivative that contains antigens form pathogen: stimulates primary immune response

Zoonosis are a growing global health concern
- pathogens often highly specialized with narrow range of hosts
- some bacterial pathogens only cause disease in humans
- zoonosis: pathogen which can cross species barrier: emerging global health concern
- cause is growth of contact between animals and humans

The immune system produces histamines
- mast cells are immune cells found in connect tissue that secrete histamine in response to infection which causes dilation of small blood vessels in infected area which causes the vessels to become leaky: increases flow of fluid containing immune components

Effects of histamines
- histamine as contributor to number of symptoms of allergic reactions
- cells in variety of tissues have membrane-bound histamine receptors
- histamine plays role in bringing symptoms of allergy in nose, formation of allergic rashes and in dangerous swelling (anaphylaxis)
- to lessen effects, anti-histamines can be taken

The process for creating hybridoma cells
- monoclonal antibodies are highly specific; only recognize one antigen
- to produce clone of cells that will manufacture a monoclonal antibody, the antigen recognized by antibody is injected into a mammal; mammal's immune system makes plasma B cells that are capable of producing desired antibody
- B cells fused with cancer cells (myeloma cells): fusion of these two is hybridoma cell

Production of monoclonal antibodies
- full diversity of B cells are fused with myeloma cells: many different hybridomas are produced and individually tested to find the one that produces required antibody
- once identified, desired hybridoma cell is allowed to decide to secrete huge amounts of monoclonal antibodies
- hybridoma cell is multiplied in fermenter to produce large numbers of genetically identical copies, each secreting antibody produced by original lymphocyte
- monoclonal antibodies used for treatment and diagnosis of diseases

11.2 Movement
Bones and exoskeletons anchor muscles
- exoskeletons are external skeletons that surround and protect most of body surface of animals such as crustaceans and insects
- bones and exoskeletons facilitate movement by providing anchorage for muscles and acting as levers; levers change size and direction of forces; in a lever there are: pivot point (fulcrum), effort force, resultant force; relative positions of these three determine the class of lever
- spine acts as first-class lever when nodding backwards (fulcrum between effort and resultant)
- grasshopper leg acts as third-class lever
- muscles are attached to inside of exoskeletons, but to outside of bones

Skeletal muscles are antagonistic
- skeletal muscles occur in pairs that are antagonistic: when one contracts, the other relaxes
- antagonistic muscles produce opposite movements at a joint

Different joints allow different ranges of movement

- structure of a joint, including joint capsule and ligaments, determines the possible movements
- knee joint can act as hinge joint (only two movements: flexion, extension) or can act as pivot joint when flexed: knee has greater range of movement when it is flexed
- hip joint is a ball and socket joint: it can flex, extend, rotate, move sideways and back
- moving sideways and back are called abduction and adduction respectively

Structure of muscle fibers

- muscles used to move our body are attached to bones: skeletal muscles/ striated muscles
- two other types of muscles are smooth and cardiac
- striated muscle is composed of bundles of muscle cells known as muscle fibers
- single plasma membrane (sarcolemma) surrounds each muscle fibre: but many nuclei are present in muscle fibers and are much longer than typical cells
- embryonic muscle cells fuse together to form muscle fibers
- modified version of endoplasmic reticulum (sarcoplasmic reticulum) extends throughout muscle fibre: wraps around every myofibril conveying signal to contract to all parts of muscle at once
- sarcoplasmic reticulum stores calcium
- between myofibrils are large number of mitochondria which provide ATP for contractions

Myofibrils

- myofibrils: within each muscle many parallel, elongated structures: have alternating light and dark bands; in centre of each light band is a disc shaped structure (Z-line)

Structure of myofibrils

- number of repeating units alternating between light and dark bands are visible; in centre of light band is Z-line: part of a myofibril between one Z-line and the next is called a sarcomere
- pattern of light and dark bands is due to precise and regular arrangement of two types of protein filaments: thin actin and thick myosin filaments
- actin filaments are attached to Z-line at one end; myosin filaments are interdigitated with actin filaments on both ends and occupy the centre of sarcomere
- myosin filament is surrounded by six actin filaments, forms cross-bridges during contraction

Mechanism of skeletal muscle contraction

- during muscle contraction, myosin filament pull actin filaments towards centre of sarcomere
- process shortens each sarcomere and therefore overall length of muscle fibre
- contraction of skeletal muscle occurs by sliding of actin and myosin filaments: myosin filaments cause this sliding: have heads binding to special sites on actin filaments, create cross-bridges through which they excerpt force using ATP
- heads are regularly spaced along actin filaments so many cross-bridges can form at once

The control of skeletal muscle contraction

- tropomyosin in relaxed muscle blocks binding sites on actin
- when motor neuron sends signal to muscle fibre to contract, sarcoplasmic reticulum releases calcium ions, these bind to protein troponin which moves tropomyosin: exposes actin's binding sites: myosin heads bind and pull actin filaments to centre of sarcomere

The role of ATP in the sliding of filaments

- for significant contraction, myosin heads must carry out action repeatedly: happens in sequence of stages
- ATP causes breaking of the cross-bridges by attaching to myosin heads
- hydrolysis of ATP to ADP and P provides energy for myosin heads to move from centre
- new cross-bridges form by binding of myosin heads to actin binding sites, each head binds one position further from centre of sarcomere
- energy is stored in myosin head from hydrolyzing ATP
- sequence of stages continues until motor neuron stops sending signals; calcium ions are pumped back to sarcoplasmic reticulum, regulatory protein covers binding sites on actin, muscle fibre relaxes

11.3 The kidney and osmoregulation

Different responses to changes in osmolarity in the environment

- osmolarity: solute concentration of a solution
- many animals are osmoregulators (maintain constant internal solute concentration, usually at third of seawater): all terrestrial animals, freshwater animals and some marine organisms
- osmoconformers have same internal solute concentration as concentration of environment

The Malpighian tubule system

- arthropods have circulating fluid (hemolymph) that combines characteristics of tissue and blood
- osmoregulation is a form of homeostasis
- breakdown of amino acids causes nitrogenous waste which is toxic and needs to be excreted: in insects excreted as uric acid and in mammals as urea
- Malpighian tubules: tubes in insects branching off from intestinal tract; cells lining tubules actively transport ions and uric acid from hemolymph into lumen of tubules, draws water by osmosis into lumen, tubules empty contents into gut, water and salts are reabsorbed, uric acid is excreted with feces

Comparing the composition of blood in the renal artery and the renal vein

- kidneys function in osmoregulation and excretion: remove substances from blood that are not needed or harmful
- composition of renal artery (entering kidney) is different to renal vein (leaving kidney)
- substances in higher amounts in renal artery: toxins and other substances ingested but not fully metabolized and excretory waste (nitrogenous waste, mainly urea) and removed things that are not excretory products (excess water and salt)
- water and salt aren’t excretory products because they are produced by body cells
- water and salt content may vary in renal artery, but more constant in renal vein: osmoregulation
- kidneys filter around fifth of volume of plasma from blood flowing through; filtrate contains all substances from plasma membrane apart from large protein molecules; needed substances are then actively reabsorbed: process for unwanted substances passing out of body through urine
- substances passing to urine are present in renal artery but not renal vein
- small difference due to metabolic activity of kidney itself: blood is deoxygenated, higher partial pressure of carbon dioxide, less glucose
- plasma proteins are not filtered and should be present in same concentration in both

The ultrastructure of the glomerulus

- blood in capillaries is at high pressure in many tissues, pressure forces some of plasma through capillary wall to form tissue fluid
- in glomerulus of the kidney, pressure in capillaries is particularly high and capillary wall is particularly permeable so volume of fluid forced out is high: glomerular filtrate
- most solutes filtered out freely, almost all proteins are retained: ultrafiltration (separation in size)
- permeability to larger molecules depends on shape and charge
- basement membrane separates capillaries; gaps in wall of capillary are called fenestrations
- podocytes function as barrier through which waste products are filtered
- three parts to ultrafiltration system: fenestrations, basement membrane, podocytes
- fenestrations: 100nm in diameter, allow fluid to escape but not blood cells
- basement membrane: covers and supports wall of capillaries, made of negatively charged glycoproteins: prevents plasma proteins being filtered due to size and negative charge
- podocytes: form inner wall of Bowman’s capsule, have extensions wrapping around capillaries of glomerulus and short side branches called foot processes; narrow gaps between foot processes prevent small molecules being filtered out of blood in glomerulus
- if particles pass through they are part of the glomerular filtrate

The role of the proximal convoluted tubule

- glomerular filtrate flows into the proximal convoluted tubule
- almost all of the filtrate must be reabsorbed into the blood: happens in the first part of the nephron: the proximal convoluted tubule: by its end all glucose and amino acids and 80% of water, sodium and other mineral ions have been absorbed

- sodium ions: moved by active transport from filtrate, pass to peritubular capillaries; pump proteins located in outer membrane of tubule cells
- chloride ions: attracted to space outside of tubule because charge gradient of sodium ions
- glucose: co-transported out of filtrate by co-transporter proteins in outer membrane of tubule cells, sodium ions move down concentration gradient from outside tubule into tubule cells which provides energy for glucose to move at the same time to fluid outside of tubule; same process is used to reabsorb amino acids
- water: pumping solutes away creates solute concentration gradient: reabsorbed by osmosis

The role of the loop of Henle

- overall effect is to create gradient of solute concentration in the medulla
- energy to create gradient is expended by wall cells in ascending limb: sodium ions are pumped out of filtrate to fluid between cells in medulla (interstitial fluid)
- ascending limb is impermeable to water: water is retained even though interstitial fluid is hypertonic (higher solute concentration) relative to filtrate
- normal body fluids have concentration 300 mOsm; sodium pumps can create gradient of up to 200 mOsm, interstitial concentration of 500 mOsm is achievable
- cell walls of descending limb are permeable to water, but impermeable to sodium ions; as filtrate flows down descending limb it is drawn out due to solute concentration of interstitial fluid: filtrate entering ascending has 500 mOsm: sodium ion pumps get this to 700 mOsm this again affects descending limb to 900 mOsm; this cycle can go up to 1’200 mOsm (humans)
- system for raising solute concentration is example of countercurrent multiplier system; countercurrent because fluid flows in opposite directions
- countercurrent system is also present in vasa recta preventing blood flowing through vessel from diluting solute concentration of medulla, still allowing to carry away water and sodium

Some animals have relatively long loops of Henle

- the longer the loop of Henle, the more water volume will be reclaimed: animals adapted to dry habitats will often have long loops
- in order to accommodate the long loops, the medulla has to be thicker

Function of ADH

- filtrate entering distal convoluted tubule from loop of Henle is hypotonic: more solutes passed out of filtrate in the medulla
- if solute concentration is too low, little water is reabsorbed in distal convoluted tubule and collecting duct (usually low permeability to water); large volume of urine is produced with low solute concentration: solute concentration of blood is increased
- if solute concentration is too high, hypothalamus detects it: causes pituitary gland to secrete antidiuretic hormone (ADH): hormone causes walls of distal convoluted tubule and collecting duct to become much more permeable to water: most water is reabsorbed; kidney produces small volume of concentrated urine: solute concentration of blood is reduced

Animals vary in terms of the type of nitrogenous waste they produce

- breaking down amino and nucleic acids creates nitrogenous waste in form of ammonia
- ammonia is highly basic and can alter pH balance, toxic because it is a highly reactive chemical
- marine/freshwater habitat animals can release ammonia directly: easily diluted in environment
- terrestrials expend energy to convert it into less toxic urea or uric acid
- marine mammals release urea due to evolutionary history
- converting ammonia to urea requires energy and conversion to uric acid even more
- advantage of uric acid that it isn’t water-soluble: does not require water to be released: birds don’t have to carry water for excretion
- uric acid is linked to adaptations for reproduction: within eggs uric acid (insoluble) crystallizes rather than building up toxic concentrations

11.4 Sexual reproduction

Similarities between oogenesis and spermatogenesis

- oogenesis: production of egg cells in ovaries, starts in ovaries of a female fetus: germ cells in fetal ovary divide by mitosis and distribute themselves through cortex of ovary

- when fetus is four or five months, cells grow and divide by meiosis (primary follicle), by seventh moth they are still in first meiotic division, single layer of cells (follicle cells) forms around them
- no further development takes place until after puberty
- no more primary follicles are produced, but at start of each menstrual cycle, some are stimulated to develop by FSH: mature follicle containing a secondary follicle
- spermatogenesis: production of sperm, happens in testes which are composed of mass of narrow tubes (seminiferous tubules) with small groups of cells (interstitial cells, Leydig cells) filling the gaps (interstices) between the tubules
- seminiferous tubules are also made of cells; outer layer is called germinal epithelium where process of sperm production begins
- most mature stages are found closest to the fluid-filled center of seminiferous tubule
- cells that have developed are spermatozoa (sperm)
- in wall of tubules are large nurse cells (Sertoli cells)

Differences in the outcome of spermatogenesis and oogenesis

- each mature sperm consists of a haploid nucleus, system for movement, system of enzymes and other proteins that enable it to enter the egg
- each complete meiotic division results in four spermatids; process of sperm differentiation eliminates most of the cytoplasm (egg must increase its cytoplasm)
- all requirements for beginning growth and development of embryo must be present in egg
- first division of meiosis produces one large and one very small cell (first polar body, degenerates); large cell goes to second division of meiosis, completing it after fertilization
- in second division again one large and one small cell are produced; small cell, second polar body, degenerates and dies
- result of division is egg that is much larger than the sperm cell
- process of egg formation happens once per menstrual cycle, usually one egg per cycle
- from puberty onwards, testes produce sperm continuously

Preventing polyspermy

- membranes of sperm have receptors that can detect chemicals released by egg (navigation)
- events happening once sperm arrive at egg, are designed to result in the union of a single sperm with egg and to prevent multiple sperm entering (polyspermy)
- the acrosome reaction: zona pellucida is coat of glycoproteins that surround the egg, acrosome is a large membrane bound sac of enzymes in head of sperm, sperm binds to zone pellucida and contents of acrosome are released, enzymes for it digest the zona pellucida
- penetration of the egg membrane: acrosome reaction exposes an are of membrane on tip of sperm that has proteins to bind to egg membrane, first sperm to get to zona pellucida binds and their membranes fuse together, sperm nucleus enters the egg cell (fertilization)
- the cortical reaction: sperm causes activation of egg, cortical granules (vesicles near eggs cell membrane) release their contents form egg by exocytosis once egg is activated, cortical vesicle enzymes digest binding proteins so no further sperm can bind and hardens zona pellucida

Internal and external fertilization

- aquatic animals often release gametes directly into water, fertilization outside of female's body
- external fertilization has risks as predation, pollution and susceptibility to environmental variation such as temperature and pH fluctuations
- terrestrial animals depend on internal fertilization (gametes would be at risk of drying out)
- internal fertilization ensures that sperm and ova are placed in close proximity and developing embryo can be protected inside female

Implantation of the blastocyst

- fertilized ovum divides by mitosis to form two diploid nuclei and cytoplasm divides equally
- two cells replicate DNA, carry out mitosis and divide again
- further cell divisions occur, but some divisions are unequal and there is migration of cells, giving the embryo the shape of a hollow ball (blastocyst)
- 7 days old blastocyst is made of 125 cells and has reached uterus, having been moved down by the oviduct by the cilia of cells in the oviduct wall
- zona pellucida which has protected the embryo breaks down

- blastocyst has used up its resources and needs an external supply: sinks into the endometrium or uterus lining (process is implantation)
- outer layer of blastocyst develops finger-like projections to penetrate uterus lining; exchanges materials with mother's blood
- after 8 weeks it is considered to be a fetus rather than embryo

Role of hCG in early pregnancy

- pregnancy depends on maintenance of the endometrium, which depends on continued production of progesterone and estrogen: hormones prevent degeneration of uterus lining
- early in pregnancy, embryo produces human chorionic gonadotropin (hCG): stimulates corpus luteum to continue secreting progesterone and estrogen: stimulate development of uterus wall

Materials exchange by the placenta

- three groups of mammals: placental, monotremes (lay eggs), marsupials (offspring in a pouch)
- placenta is needed because body surface are to volume ratio becomes smaller as fetus grows
- placenta is made of fetal tissue, which is in close contact with maternal tissues in uterus wall
- fetus develops membranes forming amniotic sac with amniotic fluid for support and protection
- basic functional unit of placenta is a finger-like piece of fetal tissue (placental villus), maternal blood flows in the inter-villous spaces around the villi (not confined to vessels)
- fetal blood circulates in blood capillaries also to surface of each villus
- cells separating maternal and fetal blood form the placental barrier; selectively permeable

Release of hormones by the placenta

- in ninth week, placenta starts to secrete estrogen and progesterone to sustain pregnancy; corpus luteum is no longer needed for this function
- danger of miscarriage if this switch-over fails

The role of hormones in parturition

- durning pregnancy, progesterone inhibits oxytocin secretion by pituitary glands and contractions of the muscular outer wall of the uterus (myometrium)
- at end of pregnancy, fetal hormones signal to placenta to stop secreting progesterone; oxytocin is secreted and stimulate contractions of muscle fibers in myometrium
- contractions are detected by stretch receptors, which signal pituitary gland to secrete more oxytocin: makes contractions more frequent and more vigorous; this causes more oxytocin to be secreted (positive feedback system)
- gradual increase in myometrial contractions, allows baby to be born with minimum intensity of contraction
- relaxation of muscle fibers in the cervix causes it to dilate; uterine contraction bursts amniotic sac and amniotic fluid passes out; further uterine contractions push baby out through cervix and vagina; umbilical cord is broken and baby takes its first breath