2 Molecular biology

2.1 Molecules to metabolism

Synthesis of urea

- urea is a nitrogen-containing compound and component of urine: it is a means of excreting nitrogen form amino acids
- cycle of reactions catalyzed by enzymes produce it in the liver
- urea can be synthesized artificially, chemical reactions are different but product is same

2.2 Water

Comparing water and methane

- methane is a waste product of anaerobic respiration
- water molecules are polar and can form hydrogen bonds whereas methane molecules are nonpolar and do not form hydrogen bonds: physical properties are different
- water has a higher specific heat capacity, higher latent heat of vaporization, higher melting point, higher boiling point; methane is liquid over range of 22 °C, water is liquid over 100 °C

Cooling the body with sweat

- sweat is secreted by glands in skin: heat needed for evaporation of water in sweat is taken form tissues of skin, reducing their temperature: blood is cooled
- sweat secretion is controlled by hypothalamus of brain: has receptors monitoring blood temperature and receives sensory inputs form temperature receptors on skin
- if body is under target temperature no sweat is produced
- when adrenalin is secreted, sweat is produced because intense activity is anticipated
- transpiration is evaporative loss of water from plant leaves

Transport in blood plasma

- blood transports variety of substances with several methods to avoid problems
- sodium chloride: ionic compound that is freely soluble in water, dissolves into sodium ions (Na^+) and chloride ions (Cl^-)
- amino acids: have negative and positive charges, solubility depends on R-group, some are hydrophilic while others are hydrophobic but all are soluble enough
- glucose: freely soluble in water and carried dissolved in blood plasma
- oxygen: nonpolar molecule, diffuses in water due to small size but water is saturated at low concentrations, amount that blood plasma can transport is too small to provide for aerobic respiration, problem solved with hemoglobin in red blood cells
- fats molecules: entirely nonpolar, insoluble in water, carried in lipoprotein complex (groups of molecules with single layer of phospholipid on outside and fats inside: heads face outwards and tails face inwards; proteins in phospholipid monolayer, hence lipoprotein)
- cholesterol: hydrophobic apart from small region at one end, transported with fats in lipoprotein complexes, hydrophilic region facing outwards with phospholipid heads

2.3 Carbohydrates and lipids

Polysaccharides

- starch, glycogen, cellulose are made by linking different glucose types
- glucose can have -OH group on carbon atom 1 pointing down (α-glucose) or up (β-glucose)
- cellulose is made by linking β-glucose molecules: condensation reactions link carbon atom 1 to carbon atom 4: glucose subunits in chain are oriented alternately up and downwards: cellulose is a straight chain, unbranched; can form bundles with hydrogen bonds forming cellulose microfibrils: great tensile strength in plant cell walls
- starch is made by linking α-glucose molecules: condensation reaction links carbon atom 1 to carbon atom 4: glucose molecules are orientated in same way: starch molecule is curved: two forms of starch are amylose and amylopectin
- amylose is unbranched and forms helix; amylopectin is branched and has globular shape

- starch is only made by plant cells: both types are hydrophilic but too large to be soluble in water: useful in cells where large amounts of glucose need to be stored: if stored as glucose too much water would enter by osmosis, so starch is means of storing energy
- glycogen is similar to amylopectin but has more branching: more compact; many by animals and fungi: acts as sore of energy in form of glucose
- starch and glycogen have no fixed size and number of glucose molecules

Energy storage
- lipids and carbohydrates as energy storage in humans; lipids for long-term storage: stored in specialized groups of cells (adipose tissue) located immediately beneath skin
- amount of energy released in cell respiration per gram of lipids is double amount released form gram of carbohydrates; lipids even form pure droplets in cells without associated water while glycogen is associated with water: lipids are six times more efficient in amount of energy stored per gram of body mass
- lipids are poor conductors of heat: used as insulators
- fat is liquid at body temperature: can act as shock absorber
- glycogen used for short-term storage as it can be broken down to glucose rapidly and transported easily in blood (fats cannot be mobilized as easily)
- glucose can be used in aerobic and anaerobic cell respiration while fats only in aerobic

Health risks of fats
- main concern of fat affecting coronary heart disease (CHD): coronary arteries become partially blocked by fatty deposits leading to clot formation and heart attacks
- positive correlation between saturated fatty acid intake and rates of CHD: correlation is not cause; could be low amount of dietary fibre casting CHD
- some populations do not fit correlation (Maasai in Kenya): high consumption of saturated fats but CHD is unknown
- genetic factors and other aspects form diet can explain CHD rates
- positive correlation between amounts of trans-fat consumed and rates of CHD: fatty deposits found in diseased arteries with high amount of trans-fats: more evidence for causal links

Analysis of data on health risks of lipids
- evaluation: assessment of implications and limitations
- visual display: how large is average difference? how widely spread is data? size of error bars? results of statistical tests?
- assessing methods: sample size? sample evenly distributed in sex, age, health? measurement?

2.4 Proteins
Denaturation of proteins
- three-dimensional conformation of proteins stabilized by bonds/interactions between R groups
- denaturation: broken bonds result in change of conformation
- denatured protein does not return to former structure: denaturation is permanent; soluble proteins often become insoluble (hydrophobic R groups in centre getting exposed)
- heat causes vibrations within molecule and can break intermolecular bonds: denaturation; proteins vary in heat tolerance (Thermus aquaticus works best at 80°C)
- pH extremes change charges on R groups breaking ionic bonds or causing new ones: denature

Examples of proteins
- rubisco (ribulose bisphosphate carboxylase): active city catalyses reaction fixing carbon dioxide from atmosphere; present in high concentrations in leaves
- insulin: hormone signaling absorption of glucose, reducing blood sugar; binds reversibly to receptor in cell membrane; secreted by beta-cells in pancreas; transported by blood
- immunoglobulin: antibodies, bind to antigens on pathogens; binding sites are hyper-variable; basis of specific immunity to disease
- rhodopsin: pigments absorbing light; membrane protein of rod cells of retina; when retinal molecule absorbs single photon of light it changes shape: small amounts detected
- collagen: rope-like proteins made of three polypeptides wound together; immense strength
- spider silk: polypeptides form parallel arrays; is extensible and resistant to breaking

2.5 Enzymes

Lactose-free milk

- lactose (glucose + galactose) is naturally present in milk and converted by enzyme lactase
- companies culture yeast and extract lactase from it to sell
- lactose-intolerant people cannot drink a lot of milk unless lactose-reduced
- galactose and glucose are sweeter than lactose so less sugar needs to be added
- lactose tends to crystallize during production of ice cream: glucose and galactose are more soluble and remain dissolved giving smoother texture of ice cream
- bacteria ferment glucose and galactose faster so production is faster

2.6 Structure of DNA and RNA

Crick and Watson's models of DNA

- testing possible structures by model-making
- first: triple helix with bases on outside and magnesium holding stands together with ionic bonds to phosphate groups: helical structure fitted X-ray diffraction pattern from Rosalind F.
- Rosalind Franklin points out that there would not be enough magnesium available and model does not take into account of Chargaff's finding that amount of adenine equals thymine and cytosine equals guanine
- investigation of base pairs show that both have equal length so would fit between two outer sugar-phosphate backbones
- flash of insight for making parts fit together they had to run in opposite directions: antiparallel
- new structure immediately suggested mechanism for copying DNA and leads to realization that genetic code must consist of triplets of bases

2.7 DNA replication, transcription and translation

PCR - the polymerase chain reaction

- technique used to make many copies of a selected DNA sequence
- small quantity is needed and cycle of steps repeatedly doubles the quantity
- two strands in DNA hold by hydrogen bonds which are weak but in high numbers hold the DNA successfully together; if DNA is heated enough they eventually break and strands separate
- if DNA is cooled again the strands pair up again: re-annealing
- PCR machine separates DNA strands by heating to 95 °C for 15 seconds, then cools to 54 °C for 25 seconds: large excess of short sections of single-stranded DNA (primers) is present: primers bind rapidly to target sequence and prevent re-annealing of parent strands
- next stage is synthesis of double-stranded DNA using primers as templates, done with Taq DNA polymerase (from bacterium Thermus aquaticus)
- Taq polymerase has optimum at 72 °C so mixture is heated for 80 seconds
- after that the cycle is repeated, amplifying number by more than billion in 30 cycles (<1h)

Production of human insulin in bacteria

- diabetes due to destruction of cells secreting insulin in pancreas
- porcine (pig) and bovine (cattle) insulin was used to treat diabetes but allergies might develop
- 1982: human insulin is commercially available: produced using genetically modified E. coli bacteria; later using yeast cells and safflower plants
- each species was genetically modified by transferring gene for making insulin to it
- important that all organisms use same genetic code as humans, making transfer possible

2.8 Cell respiration

Yeast and its uses

- yeast: unicellular fungus, lives where sugar is available, respires aerobically and anaerobically
- yeast is added to bread to create bubbles of gas to give it lighter texture; dough is kept warm to encourage yeast to respire; oxygen soon used up so it respires anaerobically
- ethanol is also produced by anaerobic cell respiration but evaporates during baking
- bioethanol: ethanol produced by living organisms, used as renewable energy source; produced form sugar cane and corn using yeast: converts sugars into ethanol in large fermenters; starch and cellulose must be broken down into sugars, achieved by enzymes

Anaerobic respiration in humans

- lungs and blood system supply oxygen to most organs rapidly enough for aerobic respiration
- sometimes we resort to anaerobic cell respiration in muscles because it can supply ATP very rapidly for short period of time: used when we need to maximize power of muscle contraction
- today mostly used during training or sport
- anaerobic cell respiration involves production of lactate; there is a limit to concentration that body tolerates: reason for short timescale over which power of muscle contractions can be maximized (we can only sprint up to 400 meters)
- after anaerobic respiration, lactate has to be broken down involving use of oxygen
- oxygen debt: demand for oxygen that builds up during period of anaerobic respiration