Lecture 1 (you are a machine)

work measured in same unit as energy, Joules (J)
one joule is the energy used when applying a force of one newton over one meter
Animal's work: use chemical energy to create molecular order
Molecular order: structure of molecules in your body, what makes you you
analogy: Theseus' paradox
what makes a machine a machine, is how the molecule arrangement, not the types of molecules
without energy, molecular structures disappear over time
animal bodies are constantly doing work to maintain renew and re synthesize their molecular structure
animals must get their energy from photosynthesizing lifeforms (exceptions are the hydrothermal vent communities)

Lecture 2 (we obey the laws of thermodynamics)

Energy can be kinetic or potential
Radiant Energy
- emitted by all things in the universe

Chemical Energy
- energy stored in bonds between atoms
- what we use to do work
- what keeps us with high molecular order

Electrical Energy
- flows of charged particles through space

Mechanical Energy
- Energy that moves stuff

Heat
- energy of random motion of particles
- not the same as temperature

First law of thermodynamics says that energy can not be created or destroyed, it can only to transformed from one form to another
- Animals transform chemical energy in food into other types of energy
- inefficient energy transformations, they will always produce heat
- heat produced can be used to maintain body temperature
- warm blooded-homeotherms
    - to maintain temperature
    - more expensive
- cold blooded- poikilotherms

The further an animal is up on the food chain, the less of the sun's energy they get
- eating further down the food chain is more efficient in getting sun energy
    - ex. how whales eat plankton

molecular order is a result of the stored potential of chemical energy
In the absence of external energy inputs to restore balance, the molecules will break down
Macrostates

- volume
- pressure

Microstates

- position of all atoms

Example, macrostates would be number of people on the dance floor, and microstates specific people
Entropy is the measure of the state of all the possible microstates
highest state of entropy when equal amounts are on and off
less even=lower entropy
the entropy of the ball measures how many positions and speeds its atoms could have
entropy is the measure of the MICROscopic level
Entropy is molecular disorder
How many microstates could DNA be?

- not many, or you'd be messed up

life requires low entropy

- arrangement of atoms is what allows you to stay alive
- high entropy in your body would not be you

Second law of thermodynamics says that unless external energy is provided, the entropy of a system will always increase
Second law of thermodynamics explains why animals need food

- An animal's body will use the energy acquired from food to keep the entropy in its own body low

An animals work is to use chemical energy to decrease entropy

Lecture 3 (it's all about protein)

molecular structures: how the atoms in the molecules in your body are arranged

- determined by both covalent and noncovalent bonds

Biosynthesis: transforming chemical energy in food into other forms of chemical energy by breaking and forming molecular bonds

- results: new molecular structures and heat

proteins are large molecules ,composed of amino acid sequences
proteins are the workhorses of the body

- they determine the forms of work animals can do

The proteins an animal's cells express determine what sorts of chemical energy it can absorb and transform

- example: chitinase

The structure of proteins endows it with certain functions
different species manufacture different protein structures, giving each species its own special powers

proteins have 4 levels of structure

- Primary structures (strung together by covalent bonds)
- Secondary Structures (Hydrogen bonds)
  - Alpha and Beta sheets
- Tertiary Structure (3d shape of alpha helix and beta sheets)
- Quaternary Structures
  - each component is called a subunit

If entropy had its way, our proteins would lose their structure
Our body is constantly recycling and re synthesizing proteins
Evolution and development are all about changing the protein structures that your body synthesizes because DNA encodes amino acid sequences
we can piece together evolutionary trees by looking at protein isoform amino acid sequences
proteins our bodies synthesize change over development

- ex: lactase

Animals exhibit phenotypic plasticity

- phenotypic plasticity: an animal's ability to change it's phenotype to adapt to a changing environment

our memories are a result of protein synthesis
transcription factors are proteins that can bind to DNA to regulate its transcription into mRNA
DNA methylation is gene modification that can be inherited
Epigenetics: inheritable changes to gene expression that occur outside of the DNA sequence

- motherly affection causing mice brains to develop more fully and how famine affects the changes that will be heritable

Lecture 4 (Magic of Enzymes)

Enzymes act as catalysts, helping to initiate chemical reactions that would have trouble occurring otherwise

- usually end in -ase

Biosynthesis: Enzymes determine what non protein molecular structures an animal synthesizes
molecules that are transformed by the reactions catalyzed by enzyme are substrates
molecules produced by reactions with enzymes are products
enzymes bond non covalently to substrates
enzyme+substrate=enzyme-substrate complex=enzyme-product complex=enzyme+product

- ^can go backwards or forwards. although one movement backwards requires more energy, but still happens

Enzymes speed things up, they do not make them happen
A+B=C+D $\frac{[A][B]}{[C][D]}$ =constant
molecular structure of enzymes give specific binding sites for their substrates

- Like a lock and key

What determines whether a chemical reaction occurs?

- molecules move from states of high energy to low energy

- systems move from low entropy to high entropy (especially high temperatures)
- Gives us Free Energy
    - Energy-Temperature x Entropy

Chemical reactions move toward lower free energy
When enzymes bind to their substrates, they lower activation energy
Enzymes change their shape when they bind/unbind to substrates and products
Enzymes bond non-covalently and reversibly to the site
Enzymes obey the mass action law and the michaelis menten equation
Michaelis Menten Equation measures speed of the reaction with the enzyme

$$V= \frac{Vmax[S]}{Km+[S]}$$

- V is measured in moles per second
- [S] is substrate concentration
- low [S]= low V
- Km changes the affinity of the substrate
- Km is substrate concentration at half of Vmax

enzymes can have multiple binding sites, producing cooperativity
hilco coefficient less than zero=negative cooperativity
when we have it, the graph is s shaped (sigmoid function)
When enzymes exhibits cooperativity and one of the molecules that binds to the enzyme is not a substrate, it’s called a allosteric modulation

- still binds, causing it to alter shape, affecting when it can bind with

Enzyme activity is regulated by allosteric modulators and phosphorylation

- enzymes can regulate each other, leading to chain reactions

Attaching a phosphate group can alter an enzyme's ability to catalyze
one enzyme can phosphorylate another, which can produce
enzymes can have different forms, specific forms being called isozymes
because of increasing entropy, animals must use energy to recycle and re synthesize their molecular structures, enzymes being critical in the processes

Lecture 5 (Life’s borders: Membranes and epithelia)

Cell membranes are made of lipid bilayers, with embedded carbohydrates and proteins.
Lipids are insoluble in water because of their nonpolar structure
Lipids have three functions in the body

- cellular borders
- Energy Storage
- Signalling

Phospholipids are amphipathic, having both polar and nonpolar structures
Tails are non polar, but the head is polar
This makes one part hydrophobic while the other is hydrophilic

- heads are hydrophilic, and tails are hydrophobic

when phospholipids are in water, they form bilayers. The hydrophobic layers (tails) stick to each other, while the heads go up for the water, (Layers are fluid, moving like water)
The presence of double bonds in the tail's hydrocarbons gives them kinks
If there is no double bonds, the lipid is Saturated. If there are double bonds then it is a non saturated
Saturated fats are more fluid
Temperature affects fluidity
5 types of functional proteins in cell membranes

- Channels
- Transporters
- Enzymes
- Receptors
- Structural proteins

Receptors allow cells to communicate with other cells

- a way for extracellular signals to affect intracellular functions

Receptors have specific sites for specific molecules (Ligands) to bind non covalently
Also alters shape of the site
Ligand gated channel: special sites for ligands in the extracellular portion, when ligands bind at the sites, the channel is open
Enzyme linked receptor: receptor when ligand binds, the same part of the enzyme in the intracellular portion activates, producing the second messenger cyclic GMP
G protein linked receptor: when a ligand binds, the receptor changes its shape, altering G protein, which causes enzyme to activate, producing the second messenger cyclic GMP
Intracellular receptor: can alter transcription of DNA if ligand gets through cell membrane and nuclear envelope
Drugs do what they do because they bind to receptors
Drugs are often allosteric modulators of receptors
Receptors are one of the ways the environment can alter our cells functions, including gene expression
Epithelia are collections of cells that form macroscopic borders in the body
Animals have different epithelia depending on the molecules they need to transport in and out of their body
Epithelia are collections of cells that form junctions to create borders
Transcellular:across epithelium (through cells)
Paracellular: though the tight junction (through spaces between cells)
Epithelia can stop molecules from being absorbed by the body
Desmosomes are tiny localized spots where the contact between two cells are strengthened

Lecture 6 (Electrochemical Gradients)

Equilibrium is the state that all physical systems move towards (in the absence of external energy)
Equilibrium is achieved by molecules going down potential energy gradients

Without external energy, equilibrium won't be left
Gradient is a change in the magnitude of any value from one point to another
(ex moving from one hill from another hill (top of the hills being the gradients))

- moving down the hill requires no energy, but going up the hill requires energy

Objects always move down energy gradients without external energy
Two energy gradients are chemical potential and electrical potential
Chemical potential is determined by concentration of molecules in an specific area
High concentration=High chemical potential
Simple diffusion is molecules "going down" the chemical potential gradient
Even number of possible states gives us the highest amount of entropy
the rate of the diffusion (J) is the net number of molecules passing from region of high conc (C1) to low conc (C2)

- J=D $\frac{C1-C2}{X}$

D is a diffusion coefficient (Depends on what the molecules are going through), X is the distance between C1 and C2
Cells do not have chemical equilibrium with their extracellular fluids
They use energy to maintain chemical gradients that would otherwise disappear due to diffusion
when equal potentials is achieved, equilibrium is achieved
Most animals bodily fluids are not in equilibrium with the environment
Some species adopt a strategy of equilibrium with the environment, which saves energy

- Fish keep their concentration of salts in their body different from the water

Molecules with electrical charges move down electrical potential gradients
differences in electrical potential between two reasons is measured in volts
1V=1 $\frac{J}{C}$
C is coulomb of electric charge
J is a joule of energy (different joule from above)
Lipid membranes are capacitors, meaning they store electrical charge across the two lipid sheets
When oppositely charged particles are stored on the cell membrane, voltage is created
this is because moving across the separated charges cause molecules to gain or lose electrical potential energy
chemical and electrical gradients combine to determine the passive flow of molecules across the cell membrane

- this is the electrochemical gradient

Chemical and electrical gradients can work together or against each other, the electrical chemical gradient is the net effect

- If both gradients head in the same direction, diffusion will be faster. If they oppose each other, then diffusion will be slower
- Without energy, molecules go down the electrochemical gradient

movement of water across the membranes, we're talking about osmosis

because water is the solvent of life it doesn't make sense to talk about its concentration therefore we talk about osmotic pressure, but they share similar principles
most molecules cannot pass through the lipid bilayer because cell membranes are selectively permeable

- specialized proteins called channels and transporters in the membrane can determine what passes thorough

channels are protein with structures that open holes in the membrane for specific molecules to pass through by diffusion
channels open and close to regulate movement of molecules across the membrane
Transporters are proteins the shuffle molecules across the membrane, they bind and change shape so the molecules are on the other side
if energy is used molecules can be transported up by the electrochemical gradient
Ex, Sodium potassium ATpase pump (primary active transport)
Because transporters bind to their targets like enzymes, they must follow the Michaelis Menten equation

- $V = \frac{Vmax[M]}{Km+[M]}$
- V is the number of molecules transported per second, Vmax is the maximum rate, and [M] is the concentration of the transported molecules, Km is the michaelis constant where the substrate concentration at which reaction rate is equal to half of Vmax

passive transport is down the electrical chemical gradient
Active transport is up the electrochemical gradient (requires energy)

- primary active transport: uses ATP energy to help change the shape of the transporter directly, enabling movement up the gradient (breaks phosphate bond)
- Secondary Active transport: uses electrical chemical gradient to push molecules up the gradient
- Cells use active transport to send molecules up the electrochemical gradients, preventing entropy from increasing

passive and active transport work together to determine gradients

Lecture 7 (Nutrition, Feeding, and Digestion)

Animals can synthesize a lot (carbs, lipids, nucleic acids proteins), but cannot synthesize essential nutrients

- Essential nutrients: nutrients required for life, but cannot be synthesized in the body

All amino acids are made of nitrogen, carbon, hydrogen, and oxygen

- They contain an amine (H2N) and carboxylic acid (COOH) group

Animals can synthesize certain amino acids, and must obtain the missing ones from food. The ones that cannot be synthesized are called essential amino acids
one major problem with amino acids is that we have no way to store them (compared with lipids)
extra amino acids are just used for energy

- break them down to extract energy (deamination: which removes the amine group)

most lipids contain fatty acids (chains of hydrocarbons)
Often referred to the number of carbons on the chain, the number of saturated bonds, and the position of the saturated bond

- 18.2w6
    - 18: how many carbons 2:amount of unsaturated bonds 6: first bond on the 6th carbon link

many animals don't have enzymes to synthesize fatty acids with double bonds in certain positions (e.g in the third link)

- Hence they are called essential fatty acids

Carbohydrates can be composed of one or many monosaccharides
When used for storage or structure, they are referred to as polysaccharides
Animals can synthesize many carbohydrates, thus there are no essential carbohydrates
Vitamins are molecules needed in small amounts that cannot be synthesized
Many minerals are also essential nutrients (Sodium, Iron, Zinc)
Engaging in biosynthesis requires

- sources of oxygen, carbon, hydrogen
- nitrogen for amino acids
- essential nutrients
- chemical energy

Animals have evolved special feeding apparatuses to allow them to hunt a certain species of plants or animals

- Suspension feeding (filter feeding) can be a very efficient way of feeding in aquatic environments

Two strategies for breaking down food

- fermentation via symbiotic enzymes
- digestion

Symbiosis is another critical strategy for obtaining the necessary nutrients

- symbiotes help animals break down and synthesize molecules that they cannot

vertebrates don't synthesize enzymes that can break down cellulose
Ruminants have a symbiotic relationship with microbes (rumen) that can break cellulose down
digestion uses enzymes to catalyze the breakdown of molecules

- lactose and lactase

Most digestion occurs in digestive tracts and chambers (in vertebrates and arthropods)

- can be acidic, have muscles to break down food

molluscs rotate a strand of mucous, dragging the captured food into the stomach

- food is absorbed into cells before being broken down

Enzymes allow animals to break down molecules in food into molecules that can be absorbed
Hydrophobic molecules can be absorbed straight through the cell wall by being emulsified by bile salts
Hydrophilic molecules must be transported into cells, and depending on the electrochemical gradients, it can either be active or passive

- glucose absorption requires a facilitated transport, requiring energy.

Lecture 8 (Metabolism)

Metabolism refers to the enzyme driven chemical reactions converting chemical energy into molecular structure, mechanical work and heat
energy converted into heat and work cannot be reused

- chemical energy that have been converted heat and energy is called consumed energy

Metabolic rate is the rate of energy consumption

- measured in J/s aka watts
    - Use the Joules used, not the energy changed into potential energy
- animals measure energy in watts
- humans have a metabolic rate of 80-100 watts, same as a light bulb

food consumption is an indirect measure of metabolic rate
Not all processes require oxygen, hence oxygen intake is not a good measure
Heat production is the only measure because all work gives off heat
Metabolic rate depends on what you are doing
Basal metabolic rate

- homeotherms
- at comfortable temperature, no need to produce heat for warmth

Standard metabolic rate

- poikilotherms
- metabolic rate at standard metabolic conditions

Metabolic rates depends on body size
Metabolic rates scales allometrically with body size (Y=aXb)
To do work, animals must first transform energy in their food into energy in ATP

- ATP is the primary fuel source for all biological relations

metabolic reactions creating atp can either be aerobic (require O2) or anaerobic (no O2)
Oxidation is when a molecule loses an electron
Reduction is when a molecule gains an electron
Aerobic pathways
Glycolysis

- convert glucose (glycogen) to pyruvic acid molecules
- uses ATP, to create more ATP. Also reduces CNAD molecules into NADH2

The Krebs cycle

- From Pyruvic acid
- produces Co2
- ATP molecules (from GTP)
- reduces NAD and FAD

Cells cannot use all the NAD and FAD as electron dumping ground
Cell is in redox balance if it can get rid of all the electrons as fast as it can add them
Inside mitochondria, enzymes take electrons from $NADH_2$ and $FADH_2$ (oxidizing them) and combine them with O2 and hydrogen protons to create water, which is used as an electron dump

- Aerobic metabolism use oxygen as an electron dump, making water

While electron move, they give up energy to move proteins into the intermembrane space
this creates an electrochemical gradient between the intermembrane space and the core
Cells can also just let protons pass back through the membrane without generating ATP, if the goal is to produce heat
The potential energy for this proton electrochemical gradient is then used by ATP synthase (an enzyme) to generate more ATP

- This is oxidative phosphorylation

anaerobic glycolysis: attach it to lactic acid

- When there isn't any oxygen to accept electrons
- produce molecules that build up

Water and CO_2 is easy to get rid of, but lactic acid still has energy on it plus is hard to remove
anaerobic glycolysis cannot be sustained,must have oxygen
Our bodies switch mechanisms depending on the length of the exercise

- anaerobic for short bursts, while aerobic is for sustained activities

Pros of Aerobic: con produce a lot of ATP (oxidative phosphorylation), can be sustained as food is available
Cons of Aerobic: limited by O_2 availability, O_2 availability is slow to increase
Pros of anaerobic: limited in rate of ATP production by food availability, can accelerate rapidly
Cons of Anaerobic: self limited due to electron buildup, requires period of O_2 dependent recuperation
Pejus range: In poikilotherms, when the body performance of an animal deteriorates as body temperatures rise or lower

Lecture 9 (The energetics of aerobic activity)

Different forms of ATP production has its pros and cons

	Aerobic	Anaerobic
pros	-can produce a lot of ATP (thanks to oxidative phosphorylation) -Can be sustained as long as food is available	-only limited by food availability -can accelerate rapidly
cons	-Is limited by O_2 availability -O_2 availability is slow to increase	-self limiting due to electron buildup -requires periods of O_2 dependent recuperation

Daily life must be largely fueled by aerobic metabolism
average daily metabolic rate: the average number of Joules of energy used each day to live

- largely determined by aerobic activity

Transportation plays a large role in determining ADMR

- Amount of power needed for transport depends on speed and power
- Power required for transportation depends on the mode of transportation

Running exhibits a linear relationship with speed and power, while flying exhibits a nonlinear relationship with speed and power

Cost of transport is the energy cost of transport over a given distance

- energy/m
- different modes of transport have different costs

In most animals, any kind of sustained activity must be performed with ATP generated by aerobic metabolism

THerefore an animal's maximal rate of aerobic energy production (maximal aerobic production) determines what levels of activity it can sustain over longs periods

Maximal aerobic power is usually referred to the maximal rate of oxygen consumption or the maximum rate of aerobic power consumption

- V_{O2max}
- Different animals and individuals have different V_{O2max} values, which determine how strenuous an activity feels
- If an activity uses 75% of the V_{O2max} value, then we can only do it for about 1-2 hours

Maximal aerobic power is determined by our genes and experiences and evolution

Maximal aerobic power is typically quite a bit higher than basal or standard metabolic rates (so we wouldn't be exhausted by just living)

Animals will change their ADMR depending on what they're doing

Sometimes an animals life changes so that its admr is much higher than its usual resting metabolic rate

- such as when pregnant

Some animals must be able to engage in aerobic activity over long periods

- long distance migrations

Lecture 10 (Temperature is Critical)

Homeotherms: animals that use metabolic rate to regulate body temperature

Poikilotherms: animals that don't

- Most regulate body temperature with their behaviour (like going out to the sun)

	No endothermy	Yes endothermy
	poikilotherms or ectotherms	Endotherms
No Thermoregulation	non thermoregulating poikilotherms and ectotherms	non thermoregulating endotherms

Yes Thermoregulation	thermoregulating poikilotherms and ectotherms Behavioural thermoregulation	thermoregulating endotherms homeotherms

Heat is transferred between animals and the environment through conduction, convection, evaporation, and thermal radiation

Law of conduction

- Hconduction=k $\frac{Tb-Ta}{d}$
    - where k is thermal conductivity, Tb is the body core, Ta is the environment, and d is the distance from Tb to Ta

Law of convection

- Hconvection=hc(Ts-Ta) hc$\propto\frac{\sqrt{V}}{\sqrt{D}}$
    - where hc is the coefficient of convection, Ts is the body surface, V is the wind speed, and D is the cylinder diameter
    - If ts is larger than ta, then the animal will lose heat, but if ts is lower than ta, it will gain heat

These laws affect the ability for animals to regulate heat transfer to the environment

Evaporation is an effective means of heat transfer. Heating water from 0-100C requires 400J of heat, but liquid water to gas requires 2400J of heat

Hradiative=$\varepsilon\sigma T_s^4$

Where ε is the emissivity (effectiveness of a material's surface to emit energy as thermal radiation), σ is the Stefan Boltzmann constant and Ts is surface temperature

Body temperature has important consequences for cellular physiology and survival

- because it directly affects proteins/enzyme function

Chemical reactions are temperature dependent, molecules with the necessary energy to get over activation energy increase exponentially as temperature increases

Enzyme substrate binding is temperature sensitive: as temperature increases, enzymes lose shapes, and they also lose their substrate affinity

- different enzymes have different temperature affinity relations

Temperature and survival are intimately linked

Some poikilotherms prevent freezing, but producing an antifreeze agent to prevent their plasma from freezing

Some tolerate it by, exuding intercellular water to increase the concentration within the cell. This lowers the freezing point, saving the animal from freezing

Homeotherms use energy to keep body temperatures stable.

- Lower critical temperature is the lowest temperature tolerated by an organism and higher critical temperature is the highest temperature tolerated by an organism

Homeotherms use evaporative means to cool off. (ex. panting, sweating, gular fluttering)

Homeotherms generate heat metabolically to keep warm, either through shivering or nonshivering thermogenesis. (using uncoupling proteins in mitochondria)

- brown adipose tissue (where it takes place) has special uncoupling proteins, which when moving down the mitochondrial gradient from synthesizing ATP, allows the energy to be released as heat

Insulation provides another way to regulate temperature

If we only consider dry heat transfer (conduction, convection, or radiative) we can use the equation to calculate an animal's metabolic rate at low temperatures

- M= $\frac{1}{I}$ (Tb-Ta)
    - where I is insulation, Tb is body temperature and Ta is the environmental temperature

By changing insulation, animals can alter both the slope and intercept for their metabolic rate relations to temperature

When temperatures get really low, heterotherms can turn to heterothermy to avoid the high energy costs of maintaining body temperature. (Escape the demands of thermoregulation)

- when an animal exhibits different thermal regulations from time to time and place to place
    - regional heterothermy: when an animal exhibits different temperatures at different body regions at the same time
    - Temporal Heterothermy: when an animal exhibits a type of thermoregulation at one time, and another at another time (ex hibernation)

Lecture 11 (Gas Exchange)

Pressure is measured in Pascals (Pa) which measures the amount of force (in Newtons) in a square meter (N/m2)

When there are multiple types of gases, we use partial pressures

- Partial pressure of gas Y is calculated as Py=FyP
    - where Py is the pressure of gas y and FyP is the fraction of gas y of the total pressure

Partial pressure is just like chemical potential for gasses

- like anything with potential energy, gases will spontaneously (without external energy) move from high concentration (or partial pressure) to low concentration (or partial pressure)

When gas y is in a solution, the concentration, Cy, can be determined by Henry's law

- Cy=APy
    - where A is the absorption coefficient
    - the Concentration of gas Y is determined by A
    - A is affected by the gas (ex. CO_2 has a coefficient 70 times higher than N_2), the temperature (heat decreases A), and Salinity (salts in the water decrease A)

Because partial pressure is just a measure of chemical potential (for gases), diffusion of gases is just like the diffusion of anything else

- J=$\frac{K(P1-P2)}{X}$
    - J being the rate of gas diffusion and X being the distance, and K being the diffusion coefficient of the substance

Partial pressure and concentration are different things

- partial pressure of a gas rules over the concentration

K is larger in air than in water

- dry sand allows oxygen to diffuse into the nest, but when the nest was temporarily saturated with water, the eggs suffocated
- another example of how diseases that saturate the lungs are so deadly

The low K value in water means animals larger than a mm can't rely on diffusion to need their cell's O2 needs

- lower K value of water causes a slower diffusion compared to that of air

So we need to use convection to force the flow of fluids, (which requires energy)

- note: gas is a fluid

Diffusion is slower across large surfaces, thus we use convection
We use convection to move the air into the alveoli, where diffusion moves the air into the blood capillaries. Then we use convection to move the blood to the muscles, where diffusion moves the O2 into the muscle mitochondria
Small animals can rely on diffusion much more than large animals
Large water breathing animals also use a mixture of convection and diffusion, but use more energy to get the same amount of O2 (2% of the resting metabolic rate of air breathers, vs the 10% needed for water breathers)
The only potential energy available to get O2 into the mitochondria is the partial pressure difference between the extracellular and intracellular in the body
Therefore, the primary purpose of the respiratory and a part of the circulatory system is to maintain a high partial pressure of the O2 around your cells in your body
At each stage of transport across the body, the partial pressure of O2 drops

- this is the oxygen cascade, which must be regulated for sufficient transport

Lecture 12 (Breathing)

Lungs and gills facilitate gas exchange between the environment and the blood

- they provide large surface areas and thin epithelia to promote diffusion

Four mechanisms to promote exchange between the environment and blood

- tidal gas exchange
- cocurrent gas exchange
- countercurrent gas exchange
    - most efficient method of gas exchange
- crosscurrent gas exchange

Most fish push water from the buccal cavity into the opercular cavity (where the gills are)

Some fish use a countercurrent method of gas exchange, where the blood travels opposite to the current of water going into their gills
Fish use two methods to bring water with either a two pump system or ram ventilation
Mammalian lungs have a complex branching system in order to maximize surface area for gas exchange
We pull air into our lungs using our muscles, creating a tidal gas exchange system
Most of the system is just a pathway for air (trachea, bronchioles), the actual gas exchange occurs in the alveoli and the respiratory bronchioles

- trachea provide air passage for diffusion
- last bit of travel in the lungs is done by diffusion
- the air moves down by convection, and gets into the blood by diffusion

Pulmonary Surfactant is a mixture of lipids and proteins that helps regulate the surface tension of the alveoli

- premature babies do not have enough pulmonary surfactant and thus need help to keep the alveoli inflated

We do not inflate/deflate our lungs fully, allowing us to increase O_2 intake when exercising
Increased ventilation keeps our oxygen cascade constant

- Ventilation volume and rate changes maintain the oxygen cascade

The brainstem has chemosensors in it that senses CO_2 and H^+ levels. It uses these sensors to receive signals of oxygen levels and adjusts tidal volume and breathing rate accordingly to our oxygen needs
Bird lungs are different, they use two large sacks as a bellows system. Inflating these sacks causes air to rush in through the parabronchi and deflate the sacks to cause the air to rush out

- Parabronchi have holes that lead to air capillaries where gas exchange occurs
- Avian Gas Exchange is carried out in a crosscurrent method

Insect breathing requires more on diffusion

Lecture 13 (O_2 and CO_2 transport)

Respiratory pigments are proteins that can reversibly and non covalently bind to O_2 and CO_2
This helps facilitate transport because when a gas molecule is bound to another gas molecule, it does not contribute to the partial pressure
A tetramer is formed in hemoglobin and once a oxygen molecule has bound to one site, the tetramer shape is altered, altering the affinity for O_2 at the other heme sites
Other animals use hemocyanin, another common respiratory pigment molecule. It uses copper to bind with O_2 and floats freely in the blood
The iron in hemoglobin makes it red, and the copper in the hemocyanin makes it blue. Hence why they are called respiratory pigments
Respiratory pigments work like enzymes, reversibly binding to specific molecules non-covalently and exhibit cooperativity, allosteric modulation, etc etc Pigment activity can also be described using Michaelis Menten style equations. The main difference being that pigments do not catalyse chemical reactions with their substrates, they just bind and release.

O2 equilibrium curves plot the O2 concentration of the blood compared to the partial pressure
The concentration, cooperativity and affinity of respiratory pigments affects how gasses are loaded and unloaded at different places
Respiratory pigments flow through blood, picking up O2 and dropping it off. This increases during exercise
Like enzymes, we talk about the affinity of a respiratory pigment for O2, and can measure it using the P50, the half max partial pressure of O2

- $S = \frac{SmaxPO2h}{P50h+PO2h}$ (S=saturation)

As P50 goes up, oxygen affinity also increases
Cooperativity affects the shape of the equilibrium curve, and how pigments load and unload O2
CO2 partial pressures are intimately linked with pH
Most of the Co2 in the blood is "in the form of" HCO3, some can bind with hemoglobin
Increased CO2 in the blood makes the blood more acidic (lower pH)

- since CO2 is a weak acid, and HCO3 is called carbonic acid (obvious enough there)

We can regulate the pH in our blood by exhaling CO2
If CO2 is kept constant, we can buffer H+ to maintain pH

- HX<->H^+ +X^- (Hx and X are a buffer pair)
- Imidazole groups on the hemoglobin act to buffer H+

Bohr effect refers to the pH dependency of a respiratory pigments affinity for O2

- (Ex. At what pH will hemoglobin have the highest affinity with O2)
- This allows hemoglobin to "sense" the metabolic demand of the animal and adjust

Haldane effect: The CO2 equilibrium curves depends on blood oxygenation

- Deoxygenation promotes CO2 uptake in the blood, and oxygenation promotes CO2 unloading

pH, O2, and CO2 all interact through Bohr and Haldane effects in red blood cells to regulate each other

Lecture 14 (Circulatory Systems)

The heart's main job is to provide the necessary mechanical energy for the blood to move through the body via convection, allowing it to diffuse into muscles
Steps in the heart

- Oxygenated blood enters left atrium via pulmonary vein
- Blood goes through atrioventricular valve to the left ventricle
- Left ventricle pumps blood through aortic valve into the systemic aorta, then flowing through entire systemic circuit
- Now partially deoxygenated, blood flows through venae cavae into right atrium
- Blood then flows through right atrioventricular valve into the right ventricle
- Right ventricle pumps the deoxygenated blood through the pulmonary valve to the pulmonary trunk, flowing to the lungs in the pulmonary circuit

Muscle contractions are a result of changes in muscle cell electrochemical gradient

- this generates an electrical signal detectable by EKG's
    - On these graphs, P=Atrial depolarization, R=Ventricular depolarization, T=ventricular repolarization

When blood never leaves the system and only loops through, it is a closed system

- Vertebrates and some invertebrates have this

When blood leaves the system to directly infuses tissues, it is an open system.

- Many invertebrates have this

Total fluid energy moves blood through the circulatory system

- Total fluid energy= potential energy produced by the heart+kinetic energy+potential energy of position in earth's gravitational field
- Blood literally falls into the legs

When lying down or pumping blood against gravity, most blood movement has to come from difference in pressures caused by the heart

Poiseuille Equation

- $F = \pi r^4 \frac{Pin - Pout}{8\,\eta l}$
    - l=length of vessel/vein, r=radius of vessel/tube, Pinn=pressure at entrance Pout=pressure at exit

Blood flow slows dramatically at terminal arteries, where it loses most of its pressure

The arterioles are lined with smooth muscle cells that can constrict and reduce arteriole radius, slowing blood flow (Vasoconstriction)

Vasodilation is when the muscles relax

Capillaries have a thin epithelial cell layer and are the sites for gas, water, and nutrients exchange between the blood and body cells all over the body

Maintaining the proper blood pressure is another important function of the heart

Blood pressure and radius help determine the rate of blood flow

- The body can alter either of these to increase/decrease blood flow to a region of the body

Lecture 15 (Water and Salt Regulation)

Three distinct yet related aspects of water and salt that animals regulate

(Each concept can be applied to the whole body compared to the external environment, or intracellular fluid compared to extracellular fluids)

- Osmotic Pressure
- Ion Concentration
- Water Volume

Osmotic pressure is the amount of hydrostatic force to counteract water movement by osmosis

- (ex How hard you have to push to stop water from moving up in a metal tube)

Higher osmotic pressure leads to a higher ion concentration

Organic solute molecules (amino acids) are able to separately regulate both ion concentration or osmotic pressure

Volume is also regulated by ion concentration, and can also be regulated independently using non ion solutes
All animals must also regulate osmotic pressure in respect to their blood
The idealized method of osmotic regulation is used by regulators. They keep osmotic pressure at a constant regardless of external osmotic pressures and blood osmotic pressure changes (isosmotic line)
The idealized method of osmotic conformity is used by conformers, which match their osmotic pressures to the isosmotic line

- Isosmotic line: The line depicting the situation in which the osmotic pressure of blood is the same as the osmotic pressure of the external environment

Terrestrial animals lose a lot of water through evaporation
Rate of evaporation is determined by the saturation deficit

- Saturation deficit: Difference of partial pressure of water in the air compared to the water
- $J = K\frac{WVPs - WVPa}{X}$
    - WVPs is the partial pressure of the solution while WVPa is the partial pressure of the air

Breathing is a big source of animal water loss, since the mouth and nasal passages are moist, and the lungs promote diffusion
Nasal passages help prevent evaporative water loss through using counter current cooling
Urination is another source of water loss, being used to rid the body of cellular waste molecules (ex nitrogen from protein breakdown)
The U/P ratio is the ratio of the osmotic pressure of urine to that of the blood (Dynamically regulated)

- U/P=1 (Isosmotic urine)
    - formation of urine does not change the ratio of solutes to water in blood plasma. Does not alter blood plasma osmotic pressure
- U/P<1 (hyposmotic urine)
    - ratio of solutes to water in plasma is shifted upwards, Osmotic pressure of plasma is raised
- U/P>1 (Hyperosmotic urine)
    - ratio of solutes to water in plasma is shifted downwards, osmotic pressure of plasma is lowered

Some animals can get their water just through eating
Water produced by metabolism (MWP)vs Water lost via evaporation (EWL) can be expressed as a ratio MWP/EWL

- If an animal's MWP/EWL ratio is above one, it does not need to drink much or anything at all
- Temperature dependent

Regulation in Freshwater Fish

- generally get salt and water from food, do not drink water
- gills actively take up Na+ and Cl-

- water uptake dictated by osmosis and salt loss dictated by diffusion
- large amounts of very hyposmotic urine and salt and water loss through feces
- hyperosmotic to ambient water

Regulation in Saltwater Fish
- salts and water ingested through food and water . (source of net water gain)
- salt gain by diffusion and water loss by osmosis in gills
- active extrusion of Cl-, and either active or passive outflux of Na+
- salt and water in feces
- small amounts of water in urine, nearly isosmotic to plasma, rich in Mg2+ and SO42-
- hyposmotic to ambient water

Fighting the equilibrium through osmosis requires a lot of energy
In saltwater fish, primary and secondary active transport combine via paracellular and transcellular pathways to remove NaCl from the blood
Animals living by the sea must get rid of large amounts of salt, and this allows them to drink seawater
Terrestrial animals must overcome the challenges of avoiding evaporative water loss and the urine concentrating (U/P) capabilities of the kidneys
- Species have evolved different ways to cope with the two challenges depending on whether they live in damp or xeric(dry) environment
- animals in dry environments must avoid evaporative and urinary water loss

Lecture 16 (Kidney function and Nitrogen Excretion)

We pee to get rid of bodily waste molecules. But we must be wary of ionic, osmotic, and volume changes associated with the water loss
Kidneys in vertebrates produce and regulate urine
- Production of the primary urine
- Modification of the primary urine to produce the definitive urine

Primary urine is essentially blood with the large molecules removed
Primary urine is produced in the bowman's capsule and glomerulus by ultrafiltration, active secretion, and reabsorption
- Ultrafiltration occurs because of blood pressure

The rate of primary urine production is known as the glomerular filtration rate (GFR)
GFR is much higher than definitive urine production, adults produce about 120mL/min
- most of the water is reabsorbed, so the kidneys continually cycle our blood

Active secretion is another process which contributes to the formation of primary urine in the nephrons
Urine formation is different in different animals
Reptiles, amphibians, freshwater fish
- After forming primary urine, they reabsorb many of the salts while limiting reabsorption of water, leaving a U/P≥ 1
  - Urine with a low U/P ratio is good to get rid of excess water from the body

Nephrons are usually all folded up within the kidney and can reach 1 cm in length

Most vertebrate species cannot produce definitive urine that is more concentrated than blood, but they can produce diluted urine
Salts and water are reabsorbed in the proximal tubule, but in distal tubules, water can be shut out to lower the osmotic pressure of the urine
Aquaporins are dynamically added or removed from the epithelium of the distal tubule in response to antidiuretic hormone in the blood to regulate the U/P ratio

- Antidiuretic hormone: Prevents production of dilute urine

Mammals and some birds are able to produce urine with a U/P>1 ratio

- Good for dry environments to preserve water

The loop of henle lies between the distal and proximal tubules

- Loop of H. produces urine with high osmotic pressure/high concentration by using the single effect and countercurrent multiplication

The single effect: ascending limb of the loop actively transfers out Na and Cl ions, where they will diffuse into the descending limb. Water from the descending limb is osmotically removed goes into the interstitial fluid
Countercurrent multiplication: The descending limb deals with water, while the ascending limb deals with ions (Na+ Cl-, K+) . Water is passively reabsorbed since energy is being expended to reabsorb ions in the ascending limb.
Species can be ammonotelic, ureotelic, uricotelic depending molecule they use to rid the body of nitrogen.

- ammonotelic: ammonia, ureotelic: urea, uricotelic: uric acid

Ammonia does not cost a lot of energy, but is highly toxic unless voided and thus only passable for aquatic species which can allow it to diffuse across their gills
Urea requires energy to be made, but is much less toxic and can be stored in higher amounts until voided through urine

- what mammals use

Uric acid, guanine, and other purines are not every toxic and can be expelled through poop, but cost a lot of energy to make

- what non-mammalian terrestrial animals use

Strategies use different amounts of energy, and differ in water saving and toxicity

Lecture 17 (Neurons)

The nervous system is made of billions of tiny tree like cells that function like microcomputers .

- aka neural doctrine

Neurons are packed tight in the brain and can be connected through synapses to thousands of others
Neurons electrically integrate chemical signals from presynaptic neurons in the soma and dendrites, they send the integrated information down the axon with action potentials, which cause the release of electrochemical signals (neurotransmitters) into other postsynaptic neurons
Molecules with an electrical charge will go down electrical potential gradients

- Differences in electrical potential are measured in volts
  - $1V = 1\frac{J}{Q}$ Q=coulomb of electric charge, J=joule of energy

Cell membranes act as capacitor resistor circuits
- Lipid membranes are capacitors, meaning they store electrical charge across the two lipid sheets
- Ion channels are resistors

Voltage is created when opposite charges are placed on the cell membrane. This is due to moving across separated charges cause molecules to gain/lose electrical potential energy
Capacitance measured in Farads. F=Q/V
- Capacitance: ability for a body to store an electrical charge

Ion channels in membranes act as resistors (Ω [ohms] are used to measure resistance)
- When the channels open, resistance goes down and ions that pass through will go down the electrical potential gradient and go toward equilibrium

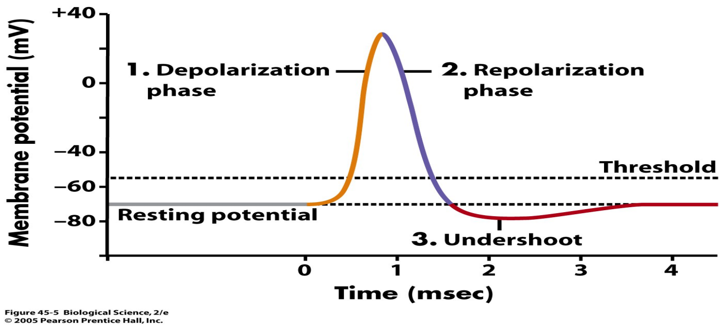
We use Ohm's law to calculate the amount of current flowing across a circuit
- $I = \frac{\Delta V}{R}$

The voltage across the capacitor changes as a current flows through the circuit
A current can flow through a neuron without any change to resistance
This lets electrical signals travel down dendrites toward the axon and soma
The distance travelled and speed the current travels (current flow) is determined by membrane length and the time constant: λ λ *and* τ
The voltage of any part of a neuron depends on what kind of currents are travelling across the membrane and down the dendrites
Reversal Potential: Selective permeability to certain ions with a chemical gradient causes them to move, creating a voltage that counteracts the movement of more chemicals down the chemical gradients
To calculate the reversal potential for an ion, use the Nernst equation
- $Ex = \frac{RT}{zF} log(\frac{[xo]}{[xi]})$
  - Ex=reversal potential for ion x, R=gas constant, T=temperature, F=Faraday's constant (charges per mole of ions), z=valence of ion x (positive or negative), [xo]=concentration of ion x outside of the cell, [xi]=concentration of ion x inside the cell

The different ionic currents of the different chemicals neurons are permeable to combine to determine the cell's voltage
Resting phase: when all the chemicals in the cell counteract each other
To calculate the voltage of the membrane, use the Goldman equation
- $Vm = \frac{RT}{zF} log(\frac{PK[Ko]+PNa[Nao]+PCl[Clo]}{PK[Ki]+PNa[Nai]+PCl[Cli]}$
  - PK, PNa, and PCl=relative permeabilities of said chemical
  - Thus, the changing permeability for different ions changes the stable voltage for cell changes
  - Resting potential of most cells is -65mV (the resting potential of K+)

Axons of neurons are equipped with high densities of voltage gated ion channels

- help axons “actively” propagate voltage changes over long distances (action potentials)



- Graph depicting action potentials, once it shoots above 0 mV, that part of the graph is the overshoot.
- Note: For exam, look at slides 27-28 on lecture 17 to see how membrane channels are involved with action potential graph. Important for the exam

Hodgkin Cycle: An initial depolarization changes the voltage from resting potential to the threshold, The change in voltage leads to the opening of the voltage controlled Na+ channels, increasing PNa and Na+ flow, which causes a further depolarization of the membrane

- As the membrane depolarizes, it continues activating unactivated Na+ channels and cause the action potential to propagate down the dendrite
- Voltage gated ion channels lead to action potentials

Axons are insulated by myelin sheaths, created by Schwann cells

- Leads to an increase in axon membrane resistance (R_m, and creates a longer length constant for better propagation
- $\lambda = K\sqrt{\frac{Rm}{Ri}}$

Our thoughts and actions are dictated by the action potential in the axons in our brains

Lecture 18 (Synapses) (A lot of important details are rooted in the pictures use in the lecture, check with the pictures for exam)

Neurons send action potentials down their axons, when it arrives at the synapse, it causes a change in the voltage of the postsynaptic cell
Synapses can either be chemical or electrical, most are chemical.
Electrical synapses are formed by two connexon proteins linking the membranes of two cells

- think of connexon proteins as “connection proteins”
- Very fast

Chemical synapses have an extra step in transmission of voltage changes

- At the arrival of an action potential, neurotransmitters are released into the synaptic cleft and bind to receptors on the postsynaptic membrane
- There are many types of receptors. One is ligand gated (ionotropic) or G protein coupled receptors (metabotropic). Both lead to changes in postsynaptic voltage

- Summary: way to have different effects on postsynaptic cell voltage

Chemical synapses affect postsynaptic neurons by releasing neurotransmitters which bind to receptors

Different types of neurotransmitters bind to different receptors

Different receptors open up ion channels that can cause either a positive/negative current flow in the cell (Postsynaptic potentials)

- If positive current is created: Excitatory
- If negative current is created: inhibitory

Neurons can also synapse into the muscles, which his how the nervous system controls movement

Neurotransmitters are released in packages called vesicles

First the target is targeted by the dendrite, where the package then travels to the end, where it docks and uses into the border, priming and being released in the fusion stage. The empty packet goes through endocytosis and returns

Most psychoactive drugs operate by altering synaptic transmission

- different drugs affect different receptors and transmitters

When multiple synaptic inputs come in at about the same time, a large postsynaptic current results. Called a temporal summation

When multiple synaptic inputs come in at different times, a large postsynaptic current results. Called a spatial summation

Summation of synaptic inputs plus action potential threshold is a calculation

- $\Sigma Excitatory(t) - \Sigma Inhibitory(t) > threshold$

Synaptic transmission is plastic (malleable)

- Facilitation and Anti Facilitation
- their release of transmitter or postsynaptic receptors change from different electrical activity
- can learn to react differently to a constant stimulus
- ex. the change in response time for sea slugs to withdraw their gills when stimulated
- This learning results from changes in the synapses in the neural circuit governing gill withdrawal response
- promotes learning and memory making

Mammalian memories are stored in the synapses in the hippocampus

- Long term potentiation: High frequency electrical stimulation of hippocampal pathways led to permanent increases in synaptic length
- Genetic implants can hijack LTP and create false memories

Lecture 19 (Organization of the Nervous system)

Circuits of neurons control and coordinate movement

In most animals, there is a degree of centralization, where circuits of neurons are spatially together forming the central nervous system and the sensory and motor neurons outside the CNS making up the peripheral nervous system

- CNS is divided into the forebrain, midbrain, and the hindbrain

The CNS and the PNS make up the nervous system
Grey matter consists of somas, dendrites, and non-myelinated axons
White matter: bundles of myelinated axons that are able to project to distant targets
Bundles of axons in __ are called __

- CNS-tracts/commissures
- PNS-nerves

In invertebrates (ex arthropods), their CNS is organized into groups of ganglia

- Think of them as little brains all over the body instead of one big brain

Vertebrates use a central column to control reflexes and to relay information from the body to the brain
The somatic nervous system handles signals to and from skeletal muscles (voluntary movement)
The autonomic nervous system handles to and from smooth muscles and organs
The action potentials from the sympathetic and parasympathetic nervous systems have opposing effects on the body

- Sympathetic nervous system reacts to stress. (increased heart rate, releases sugar from liver, flight or fight)
- Parasympathetic system reacts to no-stress (calming, slower heart rate and breathing)

There is some localization in the brain, specific regions deal with specific actions and computations
Brain plasticity is when certain parts of the brain can pick up functions of other parts

- If there was massive damage in one area of the brain at a young age, the brain can accommodate and "assign" the function to another region

The brain devotes more cells to more complex/important functions
Complex computations are distributed over millions of neurons in the brain
There is no assigned side for being creative and one for being good at logic
Brain's is also divided in time.

- Circadian rhythms are the daily rhythms of brain activity

Circadian rhythms are not perfectly 24 hour cycles, they need cues (darkness) to maintain the 24h cycles
The suprachiasmatic nuclei are in charge of maintaining this endogenous clock

- endogenous: originating in an animal's cells/ tissues
- up and down regulation of SCN cells result in endogenous clock

Lecture 20 (Endocrine system)

Hormones are chemical signals that control physiological functions and are transmitted through blood
Neurons send signals through the synaptic cleft into other neurons
Non Neural endocrine cells and neurosecretory hormones are released into adjacent capillaries and travel through larger blood vessels to make it to the receptors on the target cell
Local autocrine and paracrine signals release signals to nearby cells and to receptors on the same cell

Hormone releasing cells are usually clumped into organs called endocrine glands
Hormones bind to the receptors on the cell membranes, which can initiate biochemical changes

- ex. insertion of proteins in the membrane, synthesis or breakdown of certain proteins, or gene expression changes

Three major types of hormones

- steroids
- peptides/proteins
- amines

Steroids are lipids, making them hydrophobic

- derived from cholesterol
- able to pass through cell membrane, working for reception and secretion

Peptides/proteins are sequences of amino acids, making them hydrophilic

- derived from amino acid sequences
- peptide hormones bind to membrane bound receptors
- ex. glucagon and insulin are examples peptide hormones working together to regulate blood sugar levels

Insulin is stored and secreted in vesicles
Insulin is detected by membrane bound receptors, which triggers insertion of GLUT4 transporters to move glucose in cells, reducing blood sugar levels
In diabetes, the release of insulin is interrupted in type I and is unable to reach the membrane bound receptors in type II
Amine hormones are modified amino acids, and can be either hydrophobic or hydrophilic
Some amine hormones are used as neurotransmitters in the brain (ex. dopamine)
In vertebrates, the pituitary gland and hypothalamus control endocrine system functions

- hypothalamus signals pituitary gland to release hormones to control the endocrine system

Neurosecretory cells in the hypothalamus release nonapeptide hormones into the circulatory system of the posterior pituitary gland
Neurosecretory cells also control the hormonal release of the endocrine glands in the anterior pituitary gland.
Hormones released from the anterior pituitary gland can also control other endocrine glands

- ex. water and salt regulation

Osmoregulators in the neurons in the hypothalamus detect high osmotic pressure in the blood and release antidiuretic hormones in the posterior pituitary by neurosecretory cells
The released hormones (ex. arginine vasopressin), bind to receptors in nephron epithelium cells, which trigger the insertion of aquaporin proteins into the apical membranes, all to allow water to diffuse out
Hormones can also preserve Na+ in the blood and increase blood volume during times of low blood pressure

Lecture 21 (Motor control)

Spinal reflexes are simple movements controlled by small spinal cord circuits
- complement and correct voluntary movements

Spinal reflexes are fast actions to prevent injuries
- ex. pulling your hand away from a hot stove

Flexion reflex is what enables involuntary muscle movement, which is driven by neural circuits in the spinal cord
- this illustrates reciprocity

Simple tasks like sitting in a chair require coordinated mechanical energy from muscles, but the spinal reflexes can handle this instead of conscious control

α motor neurons are attached to extrafusal muscle fibers

γ motor neurons are attached to intrafusal muscle fibers

1a afferent neuron activity rises when the muscle is lengthened and is lowered when the muscle is contracted and shortened

Stretch reflex arc is mediated by a circuit linking spindle activity to extensor and flexor muscle control

The stretch reflex will help you compensate for unexpected weights

Stretch reflex receives commands from the brain and can fix any errors from the brain on how much strength is required for the task

Pattern generators control involuntary muscle movement patterns

Many important patterns are oscillatory, meaning they repeat over and over
- ex. fish tail during swimming
- locusts need oscillatory wing muscle muscle activation patterns in order to fly
    - measured in cycles/s (hertz)

Locusts use a pattern generator circuit in the CNS in order to produce the oscillatory wing movements.
    - usage of a central pattern generator and not a peripheral pattern generator

Peripheral pattern generators help control the frequency of oscillations

Many types of pattern generators
- Cellular oscillators are neurons that generate temporally patterned activity by itself, without synaptic independence from other cells (a specific neuron makes the pattern)
- Network oscillators are networks of neurons interacting that the network output is temporarily patterned (neurons work together to produce the pattern)
    - crustaceans chew food using a CPG consisting of a cellular and network oscillator

In vertebrates, walking and swimming are controlled by the CPG (in the spinal cord)

Coupled oscillators can produce more complex actions
- salamander walking

3 major centers for coordinating voluntary movements for vertebrates
- basal ganglia
    - selects between competing movement commands and inhibits certain movements
    - Parkinson's affects the basal ganglia and the inhibition on involuntary movements

- cerebellum
    - coordinating movements and making adjustments for error
    - affected by alcohol to make the drunk movements
- motor cortex
    - calculates how to control muscles for arbitrary voluntary movements

All three circuits work together to translate the goals of the association cortex into the optimal movements to meet the goals

Lecture 22 (muscles)

Muscles are anything that can produce contractile energy (mechanical energy)

- striated muscle
    - skeletal muscles and cardiac muscles
- Smooth muscles
    - organ and gut muscles

Muscle fibres /cells are multinucleate cells bundled up by tendons and connected to bones

- They have multiple nuclei because they all formed into one single cell over development

Striated skeletal muscle cells are long multinucleate cells/fibres in bundles
Muscle cell membranes (sarcolemma) have invaginations called T-tubules, which help conduct voltage charges

- T-tubules are close to sarcoplasmic reticulum (similar to the ER in other cells)

SR envelopes myofibrils, which are collections of parallel protein filaments responsible for muscle contractions

- each myofibril is divided into several sarcomere regions

The interaction between myosin and actin is what allows chemical energy to be transformed into mechanical energy
Myosin filaments pull along actin filaments, which causes muscles to contract

- this process utilizes ATP as an energy source
- analogy: think of myosin as rowers, which row together to produce a very strong force

Filaments of tropomyosin block the binding sites for myosin heads and actin. Thus, they can only bind and contract the muscle when Ca^{2+}

- Muscle contraction is therefore Ca^{2+} dependent

Motor neurons control the amount of Ca^{2+} in muscle cells
Ca^{2+} is actively transported to the SR in muscle cells, lowering the concentration for the rest of the cell.
Depolarization causes a change in DHPRs (DHPR enables Ca^{2+} to flow through RyRs, out the SR and into myofibrils leading to contraction)
SR transporters then stop the contraction by sucking up the Ca^{2+}
Muscles do not have to shorten when contracted thanks to tendons and other elastic components

- meaning muscles can stay the same during contractions and lengthening to maintain an spring like load of energy

Different muscle contractions produce different length changes in muscle cells
Muscle tension (force/cross sectional area) is dependent on the length of the muscle (medium length produces most tension)

Lecture 23 (Sensation and Perception)

Sensory transduction is the process of transforming any form of energy into electrical signals for the nervous system
Sense organs are filled with sensory receptor molecules to do the conversions
Each sensory organ is specialized to transduce one form of energy, although they can transduce multiple types
Principle of Labelled Lines: The receptor cells in the brain which are activated by a type of energy dictates how it is perceived.
Certain parts of the brain are in charge of particular senses, but is multimodal
Molecular receptors are responsible for transduction using either ionotropic or metabotropic pathways
3 major classes of energy transduction

- Mechanoreception
  - transduce mechanical energy using force sensitive proteins
- Chemoreception
  - chemical energy using ligand activated proteins
- Photoreception
  - transduce light using photopigments

Insect legs have bristles that connect to dendrites to mechanoreceptor neurons

- they fire at a greater rate depending on bristle distance

Mechanoreceptor dendrites depolarize in response to cellular membrane stretch

- because a transient receptor potential channels open up and allows positive ions to flow into the cell

The ears transduce the mechanical vibrations of the air into sounds, and transduce mechanical energy from gravity and body movement into vestibular signals

- Mechanoreception conducted by hair cells in the ear

Hair cells transduce the air vibrations in the utriculus and sacculus linear movement, and in the
semicircular canals rotational movement
The tongues and nose transduce chemical energy, but have different receptors to detect different molecular structures
Chemoreceptors on the tongue are grouped into buds
Tastes are mediated by both ionotropic and metabotropic mechanisms
Olfactory receptor cells in the nose transduce the chemical energy in the air
Olfactory receptor cells use G-protein coupled receptors that are bound to specific molecules

- humans have over 900 olfactory receptor genes and mice have 1500

Eyes transduce radiant (electromagnetic) energy

- done by using light sensitive chromophores and photopigments

Vertebrate rhodopsin is a photopigment with protein rhodopsin, which is bound to retinol (vitamin A)
When retinol changes shape in response to light so does rhodopsin,leading to a G-protein coupled pathway activation
Light actually closes Na+channels in vertebrate photoreceptors, and depolarize and release neurotransmitter in the dark
The eye focuses light on the retina, where most of our photoreceptor cells are
Images formed on the retina stimulate the photoreceptors in a pattern
Retina contains neural circuits that process the image before sending it to the brain
Retinal ganglion cells use signals from multiple photoreceptors for contrasts in light patterns

- used to detect on-centre, or off-centre patterns
    - Properties are created by straight through or lateral pathways in the retina
- Patterns get integrated to detect oriented edges, then eventually faces, objects

SImilar principles are present further up the primary visual cortex, but the responses are a result of integration of multiple retinal ganglion signals