Cell Function – General

What does the cell do = **cell physiology**:

1. **Membrane Transport**
2. **Secretion**
3. **Membrane Potential**
4. **Cell Communication**
5. **Cell Division**
   - DNA replication
   - mitosis
   - meiosis
6. **Metabolism**
   - synthesis and decomposition
   - ATP and energy use
   - enzymes
   - metabolic pathways
   - major energy pathways
   - protein synthesis

Membrane Physiology

cell life must be maintained within a narrow range of conditions (requirements for life)

water is required
(none of the "activities" associated with the term "living" can proceed without water
limited temperature,
pressure,
specific ions and chemicals

"external" environment changes much more drastically than internal environment

cell's survival depends on its ability to maintain this difference

1st line of defense in protecting the cell is cell membrane
(cell wall is porous and nonselective)

interface between living and nonliving

ALL living organisms possess a cell membrane

its structure similar in all kingdoms

<u>Membrane Function:</u>

is semipermeable (=selectively permeable)
→ some small molecules cross by passive diffusion
→ some substances require expenditure of energy
→ some require extra "helpers" to get across

movement through membrane:

passive - works with a gradient
occurs spontaneously
does not require extra ATP

active - works against gradient
requires ATP
doesn't usually occur outside living cells

PASSIVE MOVEMENTS

1. Diffusion

movement of a solute down a concentration gradient

main way small things cross membranes and move within cells and fluid compartments

based on intrinsic motion of molecules [Brownian Motion]

occurs for solids, liquids and gasses in a solvent

eg. O2, CO2, atoms, small molecules, lipid soluble molecules
- nonpolar, lipid soluble
- some small polar molecules

movement down a concentration gradient until dynamic equilibrium is reached

define: **solute** and **solvent**

speed of diffusion depends on
- a. gradient
- b. permeability (may or not be membrane)
- c. surface area (eg. microvilli)
- d. (temperature)

2. Facilitated Diffusion

movement of a solute across a membrane down a concentration gradient

resembles ordinary diffusion

move lipid insoluble things across membrane
- – they need help to cross
- - specific for certain solutes

accelerates diffusion through membrane

uses specific **carrier molecule** (=carrier protein)

may be through channels or pores created by
these proteins

does not require ATP (energy)

can be **leakage** or **gated** channels
→ important in muscle and nerve impulse conduction

eg. glucose in intestine and kidneys
eg. some ion leakage channels in muscle and nerve cells
eg. chemical and voltage gated channels in muscle and nerve cells

3. <u>Osmosis</u>

diffusion of water, across a membrane, down a water concentration gradient

osmotic pressure increases as water moves in and volume increases pushing out on membrane
(osmotic pressure develops in sol that originally contained the highest conc of soulte)

two solutions with same osmotic pressure =isosmotic;
no osmotic pressure actually develops

isosmotic = isotonic

hypertonic = sol has more solutes than another
(eg. human cell is hypertonic to distilled water)

hypotonic = sol has fewer solutes than another

isotonic = solutions have equal concentrations of solutes

4. <u>Filtration</u>

water and solutes pass through a membrane down a pressure gradient

hydrostatic pressure = blood pressure

unidirectional (no equilibrium is reached)

5. <u>Dialysis</u>

diffusion across membrane down pressure
gradient to separate by size

separates crystalloids (dia = 001 μm; glucose, ions, O2) from
colloids (dia = .001-.1 μm; proteins, enzymes)

ACTIVE MOVEMENT

1. Active Transport (=solute pumping)

movement of a solute across a membrane up a concentration gradient using ATP and a protein carrier

uses energy (ATP)

moves specific solutes against (up) concentration gradient
=physiological pump
eg. Na/K pump

helps maintain concentration gradients

able to move things in or out quickly

counteracts diffusion

requires energy (ATP) and protein carriers

very specific

there are several different kinds of active transport (see text)

2. Vesicular Transport (=bulk transport)

large particles and macromolecules are moved across membrane

requires ATP

several kinds of vesicular transport:

a. **Exocytosis**
   moves substances out of cell
   secretory cells, gland cells
   eg. how golgi bodies secrete things

b. **Endocytosis**
   moves substances into cell
   cell membrane forms vesicle around material and pinches off to form vacuole
   i. bulk endocytosis
      nonselective, most body cells
   ii. receptor mediated endocytosis

specific uptake of most macro molecules by specific body cells

very selective → must trigger receptor

eg. enzymes, insulin, hormones, cholesterol

1. **phagocytosis**
   "cell eating"
   esp macrophages
   fuses with lysosome for digestion
2. **pinocytosis**
   "cell drinking"

Secretion

“application” of membrane transport

many body cells function in secretion

either as individual cells or as components of glands

types of materials secreted:

- **sweat**
  - → temperature homeostasis
- **oils and fats**
  - → scents, lubrication, protection, waterproofing
- **mucus**
  - → protection, trap pathogens
- **collagen and various fibers**
  - → important components of connective tissues
- **digestive enzymes**
- **hormones**
- **neurotransmitters**

Membrane Potential

"application" of membrane transport

all cells are **polarized**

→ separation of charge

more positive charge on outside of cells

more negative charge on inside of cells

determined mainly by

differing concentrations of sodium, potassium, chlorine, and proteins

and differing membrane permeabilities to these ions

this separation of charge creates a voltage difference (=**potential**) across the membrane

eg. as in a battery

varies between -20mv to –200mv

exists across all cell membranes

= **resting potential**

Cell to Cell Communication

how cells interact and coordinate activities

A. Cell Adhesion Molecules

on almost every cell

holds cells together temporarily or permanently

functions:

-> anchors
-> movement of cells past one another
eg. embryonic development

B. Cell Membrane Junctions:

how cells are joined together

affects:

→strength of tissues
→how things move
through cells
between cells
across membranes

1. tight junctions

proteins of two different cell membranes fuse together
form impermeable junction encircling cell
eg: keep digestive enzymes in intestine from leaking into blood

2. desmosomes

rivet-like couplings of "linked proteins"
guy wires throughout sheet of cells
makes sheets strong
eg. skin, heart muscle, neck of uterus

3. gap junctions

allows direct passage of materials between cells

eg. intercalated discs in cardiac muscle cells
eg. neuroglia cells
→ "activates" cell to do something

C. Signaling / Membrane Receptors

molecular sites at which cells chemically recognize and bind extracellular substances

diverse group of proteins, glycoproteins and lipoproteins

serve as binding sites
- binding often causes metabolic changes
- also important in cell-to-cell identity

1. contact signaling

actual coming together and touching
- induces recognition

allows normal development and immunity

2. electrical signaling

channel proteins that respond to changes in membrane **voltage** by opening and closing ion gates (active transport)

change the relative concentrations of + & - ions across membrane
- → determines electrical activity of cell
- in neurons and muscle cells

3. Chemical Signaling (Ligands)

most membrane receptors
- → main way cells talk to each other

specific chemicals bind to receptors on or in cell to cause change in cell function

eg. most neurotransmitters, hormones

different cells respond in different ways to same chemical
- eg. ACh → stim skeletal muscle cells
- → inhibits heart muscle cells

some receptor proteins are enzymes

some open and close membrane channels

Cell Division

the cell is a bag of chemical reactions

these reactions are controlled by the DNA in the nucleus of the cell

the cell must also be able to transmit genetic "instructions" to new cells as it divides

therefore DNA must be able to perform 2 major functions:

1. control metabolism
2. pass the genetic code to next generation

it is only in the last 50 years that the means and mechanisms of this cellular control of metabolism have been worked out

genome = all the genetic material that a cell contains

all living cells contain chromosomes

most DNA is contained within these chromosomes

sometimes there is additional genetic material in cell

	genome
bacteria & archaebacteria	single circular chromosome & plasmids
most eucaryotes	chromosomes, mitochondria, chloroplasts
fungi	chromosomes & some have plasmids
viruses (not living)	small strands of DNA or RNA

Size of Genomes:

entity	# of Genes	length
virus	4-5	
E. coli	3000 (1 chromosome)	1mm (500x's cell length)
humans	~30,000 (46 chromosomes) 3-10 Billion N-bases 500x's letters of the Bible ~1 gigabyte of RAM/cell	3' (180,000x's cell length) (DNA model = ~12 miles)

most of the genetic material is in the chromosomes of the cell

on these chromosomes are the genetic instructions that control everything the cell does

each instruction = gene

each gene is a unit of inheritance

each gene has two major functions:

1. help to maintain and control cellular metabolism
2. ability to copy itself accurately and transfer copy to newly created cells

in eucaryotes this DNA is so long that it must be organized in some way to facilitate cell division

→ DNA is wound around special protein molecules
= histones

the DNA and histones make up the **chromatin** of the **chromosomes**

DNA Structure

only a few different kinds of atoms make up the DNA molecule: C H O N P

DNA is a long polymer of smaller units = **nucleotides**

each nucleotide is made of three even smaller pieces:

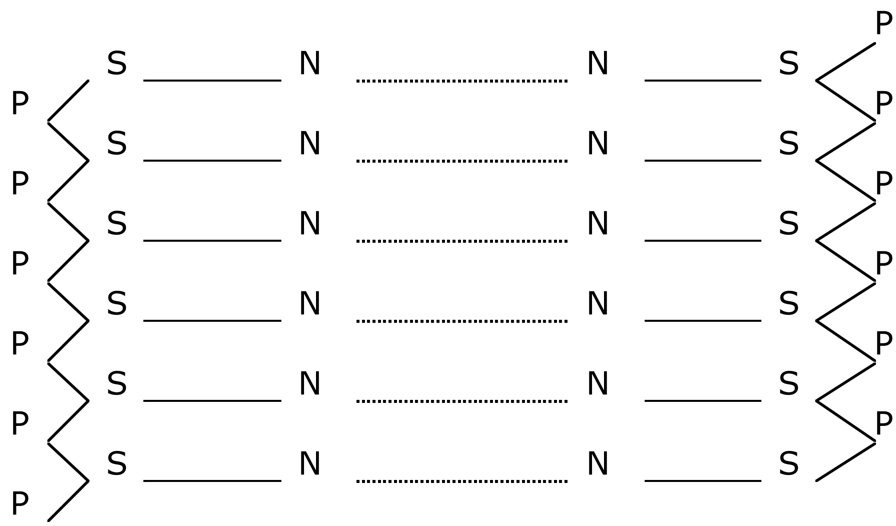
sugar
phosphate
Nitrogen base

each DNA molecule consists of a double strand of these nucleotides

these two strand spiral around each other to form a double helix

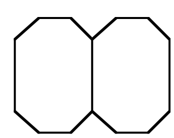
the S and P alternate to form the backbone of each strand

the N bases are connected by hydrogen bonds to join the 2 strands together

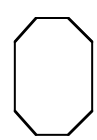


there are 4 different kinds of bases possible in the DNA molecule:

purines: adenine & guanine
A G



pyrimidines: thymine & cytosine
T C



the purine and pyrimidine bases of opposite strands are connected in **ladder-like** fashion by **hydrogen bonds**

the two strands are:

- **antiparallel**
- **complementary**
  - **A** only binds to **T**
  - **C** only binds to **G**

it is the specific binding requirements of the N-bases that allows replication
→ if you know 1 strand, you know the other

DNA Replication

1. DNA unzips
2. **DNA polymerase** collects the proper nucleotides from its surroundings and uses each strand as a **template** to build 2 new **complementary strands**

if you put DNA, nucleotides and DNA polymerase in a test tube
→ you get exact copies of the original DNA

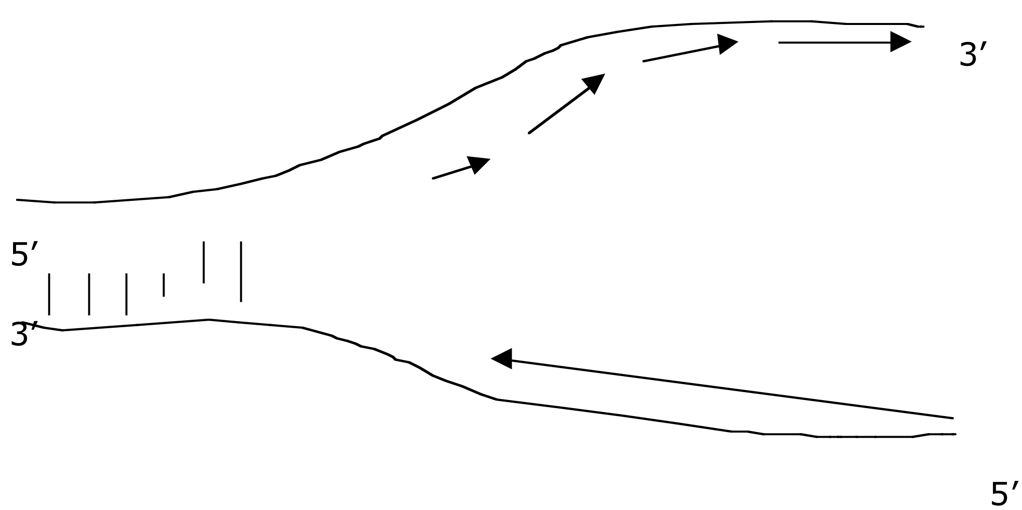
DNA Polymerase is a complex of several enzymes:
1. recognizes a specific b ase and identifies its complement
2. brings the complementary nucleotide to proper end of new strand
3. catalyzes reaction that connects it to the new strand

Characteristics of DNA Replication

DNA replication is **semiconservative:**
each new DNA molecule consists of one old strand and one new strand of nucleotides

replication doesn't need to begin at an "end" of the DNA molecule

DNA polymerase adds to the 3' end only:
5' → 3'
leading strand is continuous
lagging strand synthesis is discontinuous
→ Okazaki fragments



enzymes break the hydrogen bonds linking the two
strands at many places along the DNA molecule forming **replication forks**

the fragments of the lagging strand are then joined
by **DNA ligase**

replication progresses at a rapid pace:
eg. E. coli → 300-1000 nucleotides are replicated/sec at 37º
eg. eucaryotes → 200 nucleotides/sec

since the replication is occurring at many places at the
same time the entire process of replication occurs quickly
eg. cells in onion root tip → 20 minutes

occassionally errors are made
another group of enzymes “edits” and corrects those errors

Cell Cycle

we have identified and defined cell function at a point in time; now we will look at the cell through time

just as individuals go through a "life cycle" from birth, through reproduction and then to death

→ cells do the same = **cell cycle**

cell cycle is the life cycle of a cell

during most of a cell's "life" it performs its specialized functions and activities

= **"normal" metabolism**

= interphase

human cell cycle ~24 hours

→ each day ~50 Billion body cells die and are replaced

we've defined what some of those normal activities are above

at one or more points during its life it must **reproduce** to make copies of itself

→ for growth (>\# of cells)

all life begins as a single cell

in complex organisms that single cell grows and divides repeatedly to form a complex multicellular organism

eg. humans: ~100 trillion

→ repair or replace damaged cells

cells lining intestine must be replaced ~ every 3 days

red blood cells are replaced every 3 months

cell reproduction is one of the most fundamental of all living functions:

survival = reproduction

it is the driving force for evolution

each new cell must receive:

a complete set of instructions (chromosomes, genes, DNA)

and a basic assortment of cellular structures to continue this metabolism

the instructions are coded in the DNA located in the chromosomes in the nucleus of each cell

each set of instructions = a **gene**
(human cells contain ~30,000 different genes)

each **chromosome** contains many genes
(60,000/46 = ~1300 genes/chromosome)

“daughter cells” must get copies of all genes
ie. exact copies of the DNA in “parent” cell

in humans, each cell has a double set of chromosomes
46 or 23 pairs
→ 1 of each pair from mom; 1 from dad

two basic types of cell division:

Mitosis

– makes identical copies of cells
→ parent cell is genetically identical to the two daughter cells produced

= **clones**

almost every cell in your body is essentially a clone of the original **fertilize egg**

only difference is which genes are “switched on”
→ determines what it has specialized into

Meiosis

the formation of egg and sperm require a different kind of cell division in which the daughter cells contain only a single set (23) of chromosomes

only sex cells (eggs and sperm) are formed by Meiosis

Mitosis

Interphase

the nondividing stage of a cells life cycle = **interphase**

normal metabolism characteristic of the cell occurs here

as the cell approaches time to divide:
    it begins to duplicate all the organelles and
        materials the new cells will need to get started
    it also must duplicate the genetic instructions
        (chromosomes) that will be needed

the chromosomes are replicated during interphase
    → this process in not visible to us

after this the cell begins the division process that
    becomes visible (under a microscope and special stains) as a series of
    distinct stages or phases called **Mitosis**

mitosis in humans typically takes ~ 1 hour

Prophase
    nuclear membrane disappears
    nucleoli disappear
    chromosomes begin to appear
    centrioles split and begins to form **spindle**

Metaphase
    spindle is fully formed
    replicated chromosomes (2 **chromatids**) line up along the center
        of cell (equatorial plane)

Anaphase
    centromere splits and **chromatids** (each half of the replicated
        chromosome) separate and begins to migrate toward the opposite
        side of the cell (now = chromosomes)

Telophase
    the chromosomes reach opposite sides of cell
    begin to disappear (no longer visible)
    the nucleus reforms
    the spindle disappears
    cytokinesis = the cell splits (pinches) into two separate cells
        (not always, eg coenocytic striated muscle cells, no cytokinesis)

The end result of mitosis:

1 parent cell produces two daughter cells
each new daughter cell has the
same # and
same kinds of chromosomes
as the original parent cell

The time required to complete cell division (mitosis) varies from several minutes to several hours:

eg. fruit fly = 7 minutes
eg. human = 60 min (~1 hr)
eg. spiderwort plant = 340 min (~6 hrs)

also the various stages of mitosis are not all equal in duration:

eg. humans:

Prophase:	1 to few hours (usually longest)
Metaphase:	5 - 15 minutes
Anaphase:	2 - 15 minutes
Telophase:	10 - 30 minutes

Also, some cells divide repeatedly and regularly while others stop dividing after birth.

In humans:

a. during development, cell cycle is relatively short
all cells are dividing about every 30 minutes

b. some cells continue to **divide regularly** after development, throughout adult life

eg. epithelial cells, most connective tissue cells

eg. cells lining intestine reproduce every 3 days

c. some cells **divide only irregularly** or as needed in adult life

eg. liver cells only divide if repair is needed

d. some cells **stop dividing** shortly after birth
→ divide little if at all through all our adult lives

eg. muscle cells, nerve cells

Meiosis

type of cell division used only to produce sex cells
men = **spermatogenesis**
women = **oogenesis**

involves chromosome replication during interphase as in mitosis

but follows with two sets of cell divisions to produce a total of 4 cells

Enzymes

the sum of all chemical reactions taking place within a
cell = **metabolism**

metabolism involves chemical changes (reactions)

the two major kinds of metabolic reactions are:

synthesis	=	**anabolic reactions (anabolism)**
decomposition	=	**catabolic reactions (catabolism)**

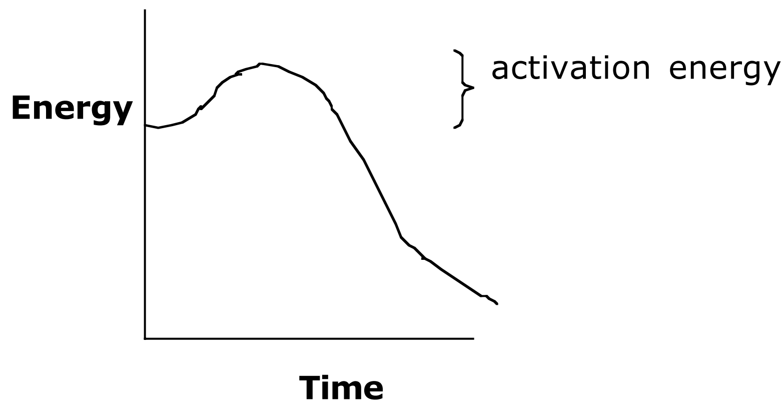
in a reaction,
the material(s) you begin with = **substrate(s)**
the material(s) you end up with = **product(s)**

for each reaction to occur the molecules must be near each other and oriented properly

to do this energy must usually be added

eg. in a chemistry lab chemicals are mixed in a beaker.
all matter contains energy (no energy = no matter)
some of this energy is energy of motion
each molecule is in constant motion and vibrates and moves around in the solution and constantly bumping into other atoms and molecules
if they collide with enough force and in the correct orientation they may undergo a chemical reaction
at room temperatures this movement is usually not enough to cause the molecules to slam into each other hard enough to produce a reaction
(usually need to add energy even for reactions that ultimately release energy)
heat energy is added = energy of activation (or increased pressure or concentration of solute)
this causes the molecules to vibrate and move much faster
with enough energy these collisions are strong enough to cause a chemical reaction to occur
the overall rate and speed of a chemical reaction depends on the relative numbers of molecules that have attained activation energy

the amount of extra energy needed to get a reaction
to occur = the **activation energy**



for 100's of years we knew that yeasts etc could perform chemical reactions, but that we could not do the same reactions without adding heat

➔ until 19th century concluded: living cells are aided by "vital forces"

in 19th century, Buchner found that yeast "juice" could do the same thing even if the cells were not living; he called the "active agents" **enzymes**

essentially all reactions that occur in cells require enzymes in order to occur

Characteristics of Enzymes:

1. all enzymes are **proteins**

2. enzymes are special proteins that **lower the activation energy** needed to get a reaction to occur

3. each reaction has a **specific** enzyme that catalyzes it
   usually each enzyme catalyzes only a single reaction
   specificity is due to 3-D shape (configuration) of protein
   each has a characteristic shape with a specific primary, secondary and tertiary structure
   which is due to hydrogen and sulfur bonds

4. enzymes (and all proteins) are **very sensitive to environmental conditions**
   since the shape of the enzyme is due mainly to weak hydrogen bonds,
   each enzyme operates under a narrow range of conditins
   optimum range of
      temperature
      pH
      salt/water concentration
      pressure
      etc

5. Usually only a small part of the enzyme protein is involved in a particular reaction
      = **active site**
   Lock and Key model

   enzymes act by holding onto one or more substrates to bring them together for a reaction.

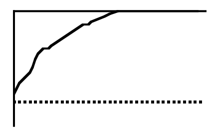
6. enzymes are **not used up** in reactions
   they can be used over and over again

   E + Substrate → ES Complex → E + Product

7. enzymes are very **efficient**:
   eg. a single enzyme molecule can cause 300-400 reactions/ second

eg. 1 molecule of catalase can metabolize
5 – 6 million substrate molecules/ minute

8. the **reaction rate** can be affected by:
    1. molecule size
        smaller→ faster
    2. temperature
        higher→ faster
            (but within a narrow range)
    3. substrate concentration
        higher→ faster
            (up to certain limit)



enzyme concentration
    higher→ faster
        (up to certain limit)

9. because they are used over and over and are very efficient, enzymes are needed in only **very low amounts**

10. some enzymes require

coenzymes
= essential organic compounds many are called vitamins that cannot be made by body
eg. NAD, FAD, NADP, etc

or

cofactors
= inorganic metal or ion required for proper configuration of active site
eg. Fe, Zn, Mg, etc

ATP & Energy Use

Energy used and released inside cell must be
controlled

It is generally produced from the catabolism of organic
molecules especially glucose

ATP is a special energy transfer molecule
→ its bonds easily store and release energy

exists mainly in two forms:
high energy ATP
lower energy ADP

=adenosine triphosphate: A~P~P~P

high energy bonds

between the phosphorus atoms are "high energy"
bonds

→ release 4-6 x's more energy than that released
when "ordinary" bonds are broken

ATP
⇅
ADP
⇅
AMP

ATP releases energy ↓

ATP stores energy ↑

one form of AMP = cyclic AMP often controls the activity of other enzymes in cell
→ is a regulator molecule

ATP is the immediate source of energy for cells
food breakdown
→ releases energy from food and stores it as
ATP until needed

Cell Metabolism

metabolism refers to all the chemical reactions that are occurring within a cell

there are two basic kinds of reactions:

1. **Anabolic Reactions**
2. **Catabolic Reactions**

1. Anabolic Reactions (Anabolism)

refer to all the synthesis reactions occurring in the cell

synthesis reactions make bonds, **require** or store **energy**

synthesis of organic polymers occurs by **dehydration synthesis**

2. Catabolic Reactions (Catabolism)

refer to all the decomposition reactions occurring in the cell

decomposition reactions generally break bonds to **release energy**

decomposition of organic polymers occurs through **Hydrolysis**

Metabolism = synthesis + decompositon

or

Metabolism = Anabolism + Catabolism

<u>Oxidation/Reduction</u>

All reactions concerned with energy release also involve the transfer of electrons

electrons can never occur freely

→they are transferred or passed directly from one molecule to another

= oxidation/reduction reactions

(=electron transfer reactions)

e^- donor → e^- acceptor
[oxidized] [reduced]

usually H^+ ions are transferred along with electrons as H atoms

the H^+ need carriers to move them around:
eg. NAD, NADP, FAD

Metabolic Pathways

Metabolism in most cells is a collection of groups of enzymes forming a metabolic pathway

many of the reactions occurring in cells occur in a sequential, stepwise fashion

= **metabolic pathways**

→**intermediate products**
→branching
→end product inhibition
→genetic errors

often an energy releasing step is **coupled** with a energy requiring step

Most chemical reactions and entire metabolic pathways that occur in cells are **reversible:**

same enzyme may catalyze reaction in either direction
reaction rate and direction depends partly on the concentrations of substrates and products
=Law of Mass Action

eg. $H_2CO_3 \underset{}{\overset{\text{carbonic anhydrase}}{\rightleftarrows}} H_2O + CO_2$

{rate & direction of reaction depends on substrate concentrations}

Compartmentalization of cells helps to organize enzyme activities and makes them more efficient
eg. aerobic respiration → mitochondria
eg. photosynthesis → chloroplasts
eg. lipid synthesis → endoplasmic reticulum

Protein Synthesis

all life involves a complex series of interacting
chemical reactions
→ metabolism

anabolic → photosynthesis
protein synthesis
dehydration synthesis

catabolic → hydrolysis
respiration

these reactions do not take place randomly

they must be controlled:
the cell maintains a balance of materials
can accelerate and decelerate the production of
various products it is using

almost all reactions occurring in a cell require a specific
enzyme to occur
these enzymes force the reaction to occur w/o
having to add large amounts of outside energy

all enzymes are proteins

therefore, if you control protein synthesis
you can regulate all metabolism

codes for individual proteins = genes

each gene is a consecutive sequence of several 1000
nucleotides

a typical cell is continually producing 100's of different
kinds of proteins, many of them are enzymes

as an enzyme is needed the gene(s) is(are) activated
and the required protein (enzyme) is made

somehow, the nucleotide sequence on the DNA molecule must direct the assembly of amino acids to make proteins

Two problems with protein synthesis:

1. DNA is in chromosome in nucleus and proteins are made at ribosome

   → how does info move from nucleus to ribosomes?

2. proteins consist of a series of 20 different kinds of amino acids
   nucleic acids are a series of only 4 kinds of nucleotides

   → how do 4 different nucleotides code for 20 different amino acids

protein synthesis is a 2 step process:
- transcription
- translation

involves a second kind of nucleic acid = RNA

both DNA and RNA are made of nucleotides but:

DNA	**RNA**
double helix	mostly single stranded
sugar=deoxyribose	sugar=ribose
ATCG	AUCG
	3 distinct kinds: mRNA; rRNA; tRNA

Transcription

mRNA copies the code on the DNA molecule

similar to replication but doesn't involve whole chromosome

a sequence of nucleotides on a DNA (=gene) acts as a template for synthesis of complementary mRNA strand

involves an enzyme: RNA polymerase

1. unwinds DNA at area of specific gene and unzips it
2. RNA polymerase binds at specific base sequence that it recognizes as a "start" signal
3. RNA polymerase moves along DNA strand (5'→3') only and assembles complementary mRNA
4. the mRNA separates from DNA as it forms
5. transcription continues until the RNA polymerase comes to a specific nucleotide sequence on the DNA molecule that it recognizes as a "stop" signal
6. mRNA molecule separates completely from DNA
7. DNA strands reattach and reform helix

mRNA now contains the complementary bases
(U for T) that were on the DNA molecule
= the code for a specific protein

Translation

mRNA moves out to ribosomes and directs the
construction of a specific protein using tRNA

what is the "code" contained on the mRNA molecule

Triplet Code

4 nucleotides must code for 20 different amino acids:
if 1 nucleotide codes for 1 amino acid
→ could only get 4 different AA's
if 2 nucleotides codes for 1 amino acid
→ could get no more than 16 different AA's
if 3 nucleotides code for 1 amino acids
→ can get 64 different combinations
more than enough for the 20 AA's
plus some extra for punctuation

DNA is the molecule of inheritance for all organisms

the code is nearly universal
→ all life is interrelated

translation is the process by which the genetic code on
the mRNA is converted to a specific sequence of amino acids at the ribosome

ribosomes = 2 subunits of rRNA and proteins
ribosomes organize and direct translation
1. mRNA binds to ribosome

2. the AUG codon on mRNA signals where to start translation
3. as mRNA passes through the ribosome each codon is read in turn
4. individual AA's are picked up by tRNA
   each tRNA has 3 reacting sites:
      anticodon – complementary to codon on mRNA
      specific sequence that recognizes a specific amino acid and picks it up → ~ 20 different tRNA's
   requires ATP to pick up AA's
5. tRNA's anticodon finds its codon match and temporarily binds
6. it sAA is now held next to the growing polypeptide chaqin and binds to it by peptide bond
7. ribosome then moves to next codon
8. once AA's are released tRNA's leave ribosome and pick up another of the same kind of AA molecule
9. terminatioin of protein synthesis occurs when ribosome reaches "stop" codon (UAA, UAG, or UGA)
10. the polypeptide chain separates from the mRNA and the ribosome

each strand of mRNA may be used to make several copies of the same protein

10-20 ribsomes bind to same mRNA = polyribosome
→ each independently makes a separate copy of the same protein

eventually mRNA is degraded into constituent nucleotide