7.014 Introductory Biology with Ecology

Spring 2010 Notes

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Cells

om → Molecule → Cell → Organism → Population → Community → Ecosystem → Biosphere

- Cell: fundamental unit of life.
  - metabolism - chemical reactions necessary for life
  - regulated growth
  - reproduces.
- Population: interacting / breeding organisms
- Community: combinations of interacting populations
- Ecosystem: + environment

Prokaryotic   Eukaryotic

membrane.

Prokaryotic:
- No nucleus
- Ex. bacteria, archaea.

Eukaryotic:
- nucleus.
- membrane-bound organelles.

Modern biology:

Function

Biochemistry: Proteins ↔ Function

Genetics: Function ↔ Genes

Proteins ⟷ Genes: Molecular biology (recombinant DNA).

Molecular composition of cell

80% H_2O

20%
- Proteins 50%
- Nucleic acids (DNA, RNA) 15%
- Carbohydrates 15%
- Lipids 10%.

__Autotrophs__ - can make everything themselves from CO_2, NH_3, PO_4^-, etc.

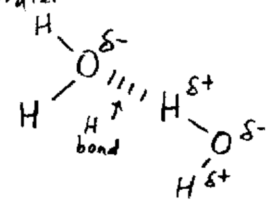
__Heterotrophs__ - need to eat s.t. made by other organism.

(1-1) Forces

1. Ionic bonds: +/− charges attract.
2. Covalent bond: Share electrons
   - Can be shared equally (C-C, H-H, C-H) or unequally (polar covalent).
   - More electronegative atom is "greedier" for electrons.
3. Hydrogen bond: Attraction between polar molecules with hydrogen.

   O−H ⋯ O
   O−H ⋯ N
   N−H ⋯ O
   N−H ⋯ N

   ex. Water



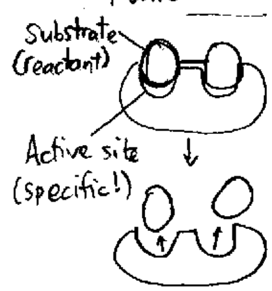
4. Van der Waals forces: Nonpolar bonds with transient polarity induce transient polarity in nearby nonpolar bond. Always present
5. Hydrophobic effects: In water, nonpolar regions stick together to exclude water.

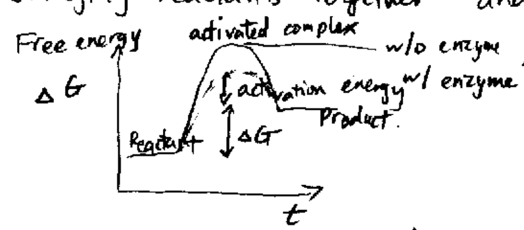
Stronger

(1-2) Biomolecules

1. Proteins - made up of amino acids

Function: • Enzymes catalyze reactions (w/o being used up) by reducing activation energy (energy needed to bring together/orient reactants, form high-energy intermediate). Enzymes help form the activated complex by bringing reactants together and orienting them





ΔG positive = requires energy

$\Delta G < 0 \Leftrightarrow K_{eq} > 1$
⇔ spontaneous
⇔ exergonic

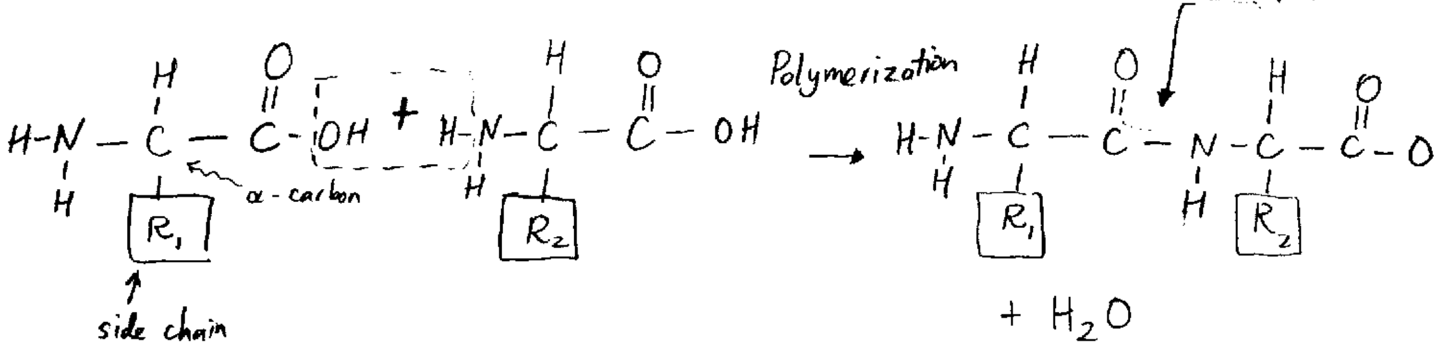
Note: Enzyme increases rate of both forward/reverse reactions

- Specificity & recognition (receptors) — antibodies

- Transport - ex. channels in cell membrane
- Structure - ex. hair, fingernails, ...

Monomer: Amino acid.

Bond: peptide bond.

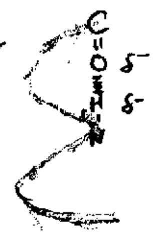


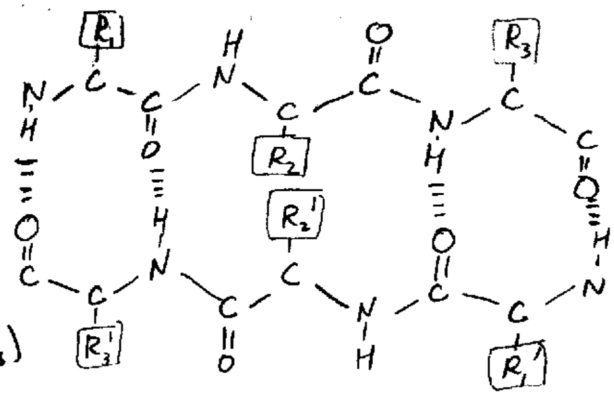
Pn structure

- Amino acids $\overset{\text{determine}}{\leadsto}$ bonding $\overset{\text{determine}}{\leadsto}$ folding, shape $\overset{\text{important}}{\leadsto}$ to function.
- Denatured at high temperature / wrong pH...

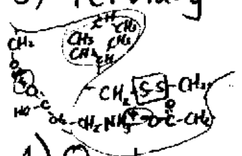
1) Primary - linear sequence of amino acids, held together by covalent (peptide) bonds

2) Secondary - local H-bonding

- α-helix 
- β-sheet



3) Tertiary - Polypeptide (polymer of amino acids)



All 5 forces.

Disulfide bonds (covalent) link cysteine side chains $\{CH_2 - \underset{(H)}{S} - S - CH_2\}$

4) Quaternary - Interaction between polypeptide chains (to form protein)

Enzymes interact with substrates through the 5 forces. Shape (& size) is important

Replacing an amino acid at the binding site with one that causes a different bond, or one of differing shape, may disrupt binding.

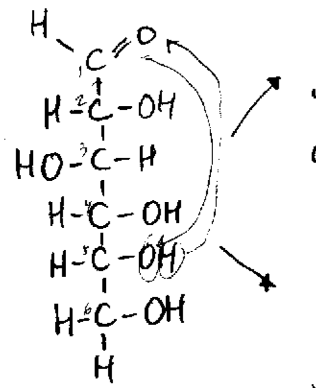
3 classes: Charged (Acidic − / Basic +), polar, nonpolar

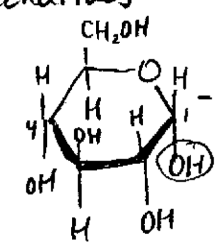
② Carbohydrates $(CH_2O)_n$

⟨ $(n-1)$ C's have −OH (hydroxyl)
⟨ 1 C has C=O (end = aldehyde / aldose, middle = ketone / ketose)

Function:
- Provide energy (glucose).
- Plants store energy as starch, animals store as glycogen.
- Cellulose makes up cell walls in plants (structural function)

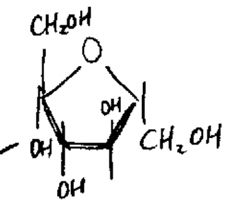
Monomer: Monosaccharides

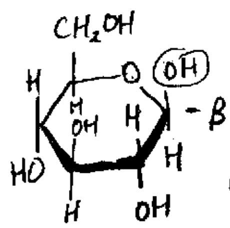




- α-glucose

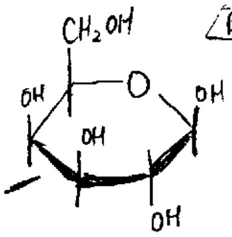
fructose





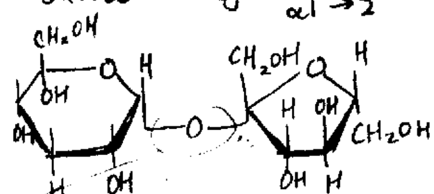
- β-glucose

β-galactose



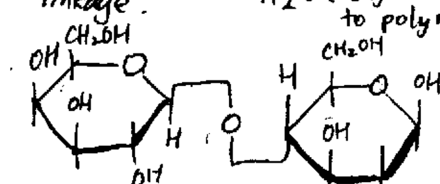
Disaccharides

Sucrose (glucose → fructose) α1 → 2



Bond: Glycosidic linkage.

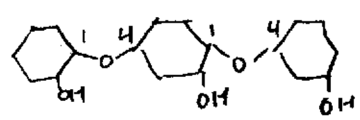
OH H → H_2O (dehydration to polymerize)



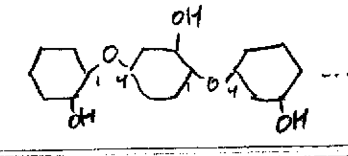
β-Lactose (β-galactose → β-glucose) β1 → 4

Polysaccharides.

- Starch / glycogen α1→4, helical, coiled.



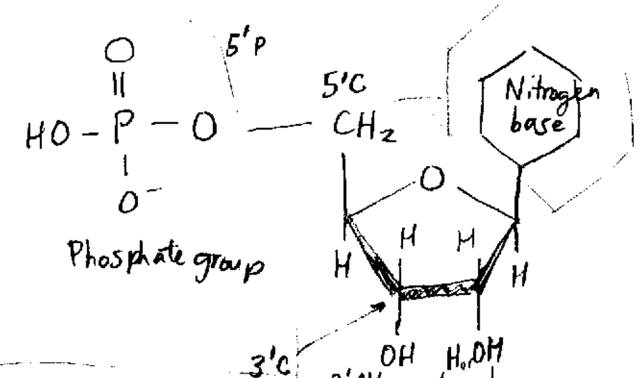
- Cellulose β1→4 linear, H bonds between chains



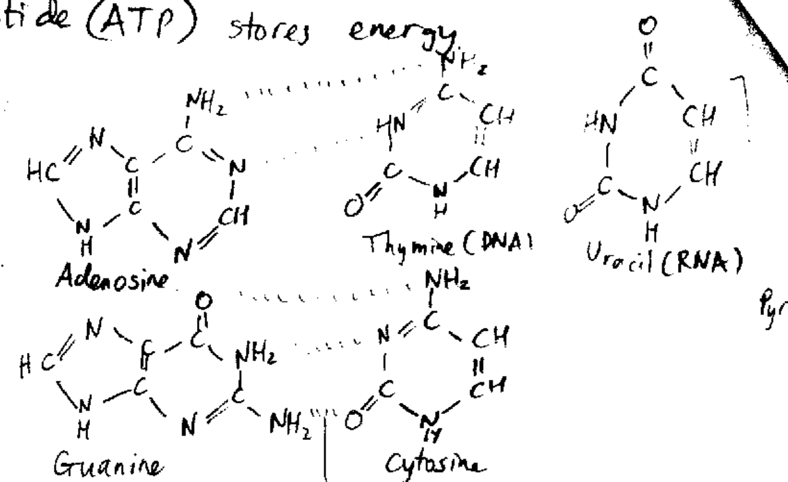
③ Nucleic acid

Function: • DNA acts as genetic material and codes for proteins.
• Triphosphate form of nucleotide (ATP) stores energy

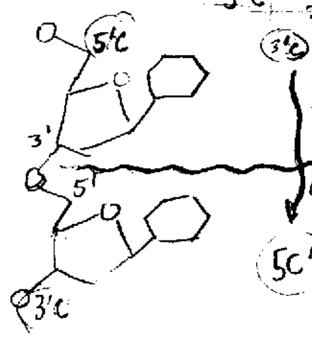
Monomer: Nucleotide.



Ribose (RNA - Ribonucleic acid)
Deoxyribose (DNA - Deoxyribonucleic acid)



More hydrogen bonding between C, G



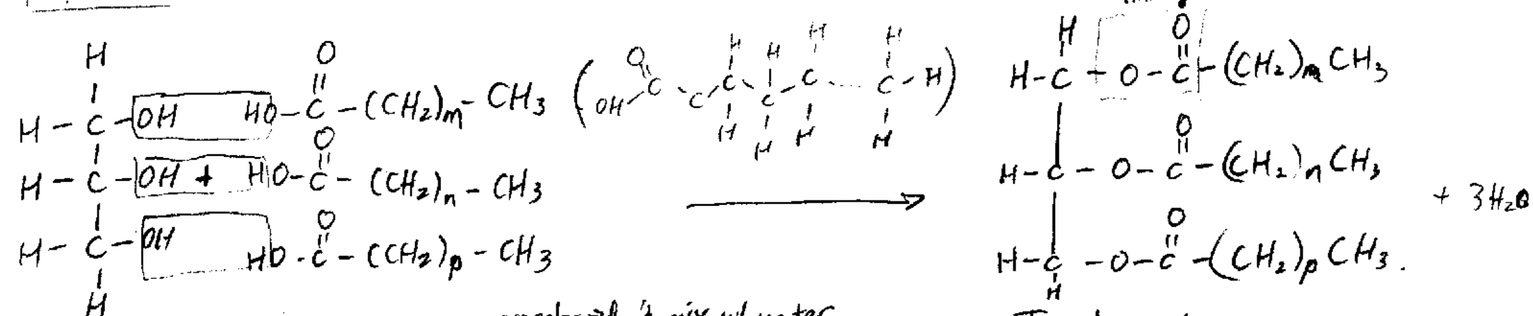
complementary sequence antiparallel.

Bond: Phosphodiester bond.

④ Lipids

Function: • Fats store energy
• Phospholipids make up cell membranes.
• Steroids function as hormones.

Molecules:



glycerol + fatty acid. nonpolar ⇒ don't mix w/ water

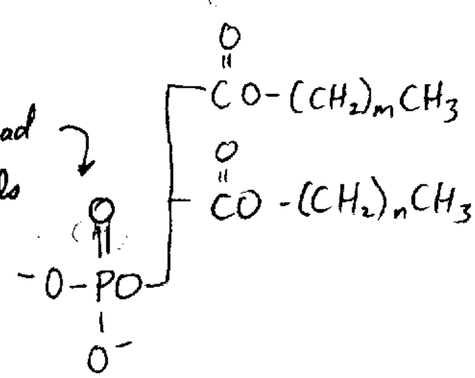
Triglycerol.

Saturated - No double bonds between C

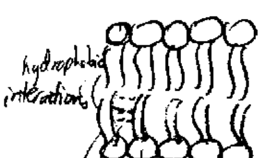
Unsaturated - Some double bonds - causes kinks - more fluid at same temperature. less packed,

Phospholipid

Hydrophilic head
Polar P-O bonds ⇒ attracted to water.



Hydrophobic tail
Nonpolar C-H bonds cluster together to exclude water

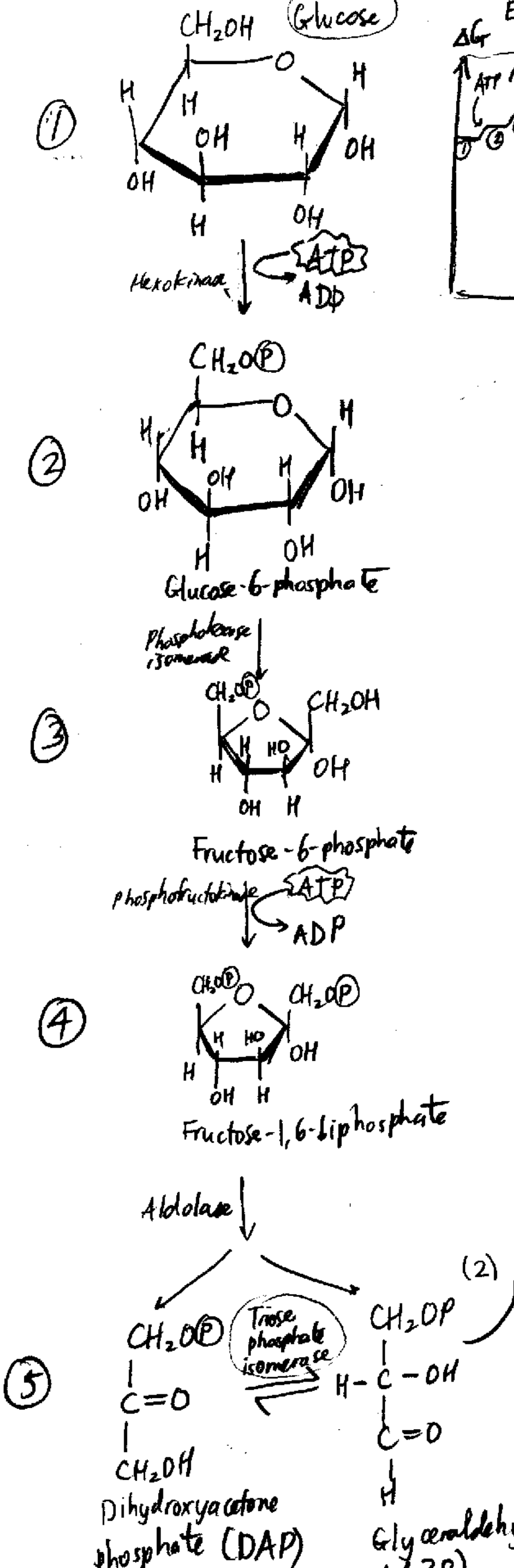


Phospholipid bilayer in cell membrane

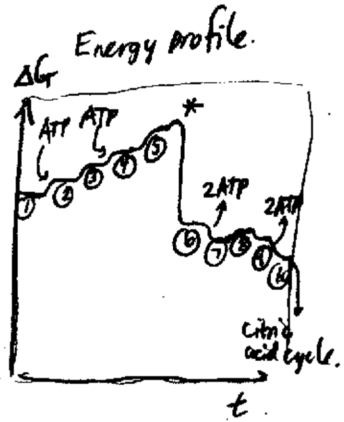
hydrophilic head
hydrophobic tail
van der Waals interactions

Glycolysis

Energy investing reactions



Energy profile

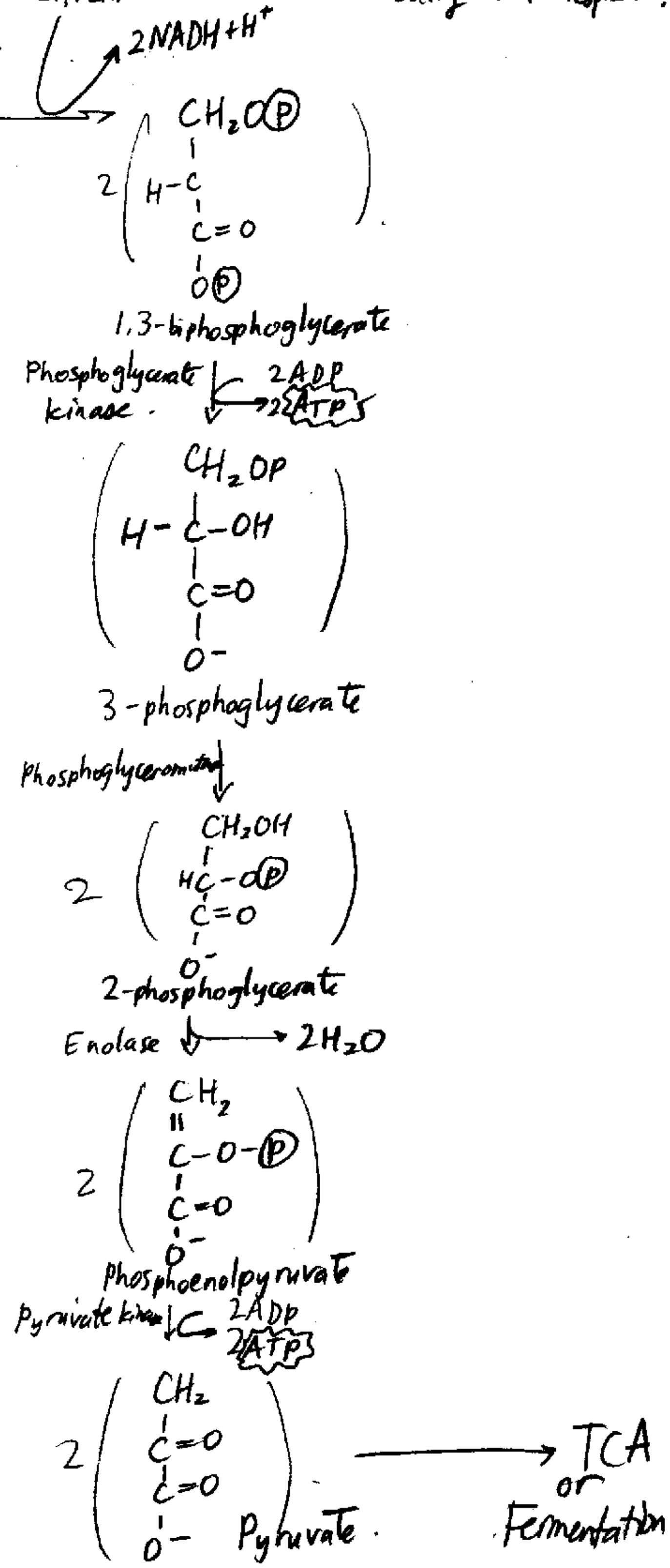


G3P is immediately used in next step, pushing reaction forward.

Energy harvesting reactions

- Cells that lack isomerase can complete glycolysis using G3P, but this generates only 2 ATP, i.e. no net gain of ATP from glycolysis. (Only $\frac{1}{2}$ as much G3P is made, the rest stays as DAP)

For the cell to get energy, it must carry out respiration.



Cellular Respiration

Glycolysis $C_6H_{12}O_6 + 2NAD^+ + 2ADP \xrightarrow{10\ \text{steps}} 2\,CH_3C(O)-C(O)-OH + \boxed{2ATP} + 2NADH$

glucose — pyruvate

Anaerobic (no O_2)

Fermentation — • reduce pyruvate

$2NADH \rightarrow 2NAD^+$

$2CH_3CH(OH)-C(O)-OH$ (lactic acid) OR $2CO_2 + 2CH_3CH_2OH$ (ethanol)

* Regenerate NAD+ needed for glycolysis
* No ADP made
* Total: 2 ATP

Aerobic (O_2)

NAD^+, CoA → $NADH$, CO_2, H^+

Acetyl CoA

Tricarboxylic Acid Cycle (TCA) a.k.a. {Citric acid cycle, Krebs cycle}

$2CO_2$

$3NAD^+$ → $3\boxed{NADH}$ $+3H^+$

ADP + P_i → ATP

FADH₂ ← FAD

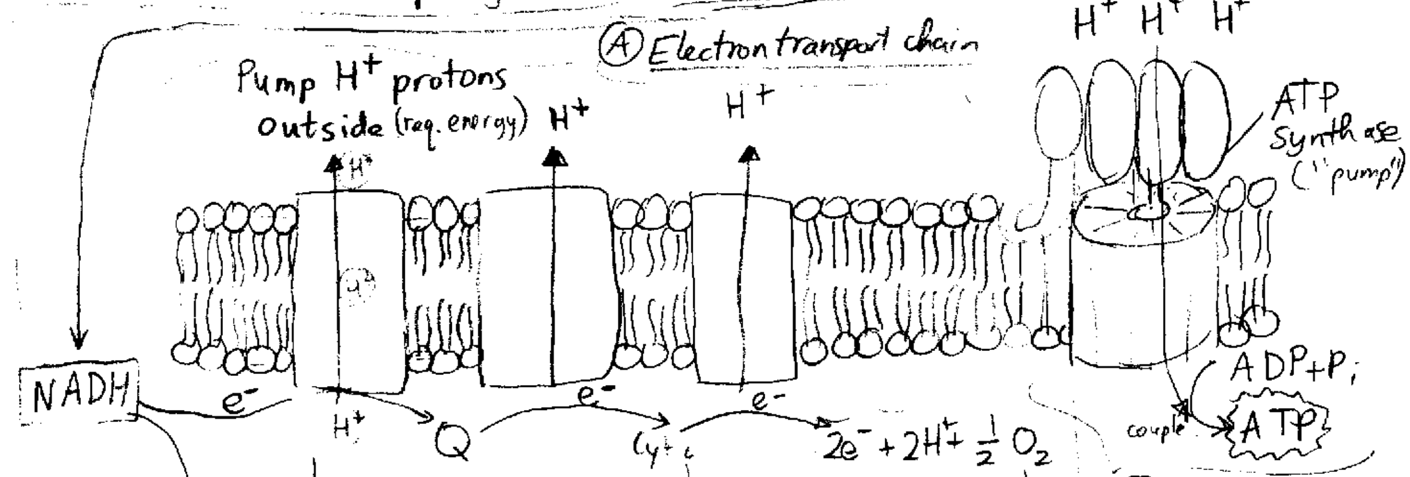
per molecule of pyruvate (2 per glucose)

$+2$ ATP/glucose

Net:
$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

Oxidative Phosphorylation

(A) Electron transport chain



NADH → NAD+ for glycolysis

Couple with electron transport

$\rightarrow H_2O$

terminal electron acceptor

sequence of increasingly electronegative proteins

(B) Chemiosmosis

Combination of proton concentration gradient & electric potential drives synthesis of ATP.

* Mitochondria (eukaryote), cell membrane (prokaryote)
* NADH → NAD+
  +(32 to 34) ATP
* Total: 36–38 ATP (more efficient)

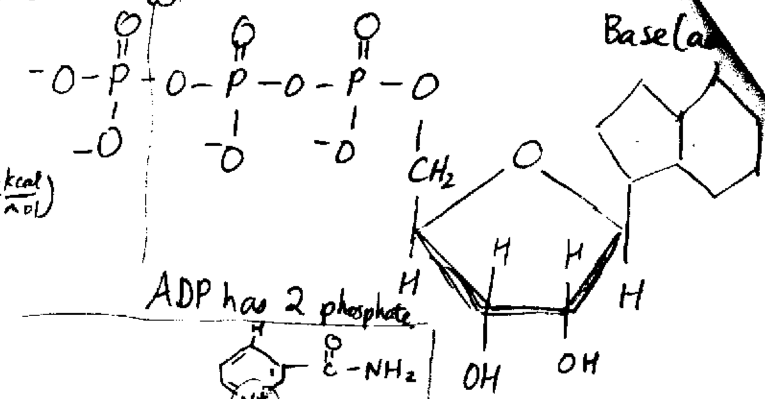
▷ Feedback inhibition: Enzymes can bind ATP or ADP.
- If cell has lots of energy (ATP), more likely to bind ATP; less ATP is made & reaction slows.
- If little energy, most likely to bind ADP; fast.

▷ Anoxygenic cellular respiration uses a substitute for O_2 as terminal electron acceptor. Since O_2 is the most electronegative electron acceptor, more electrons are pulled through and more ATP is produced in oxygenic respiration.

Cellular Respiration - provides energy for cell.

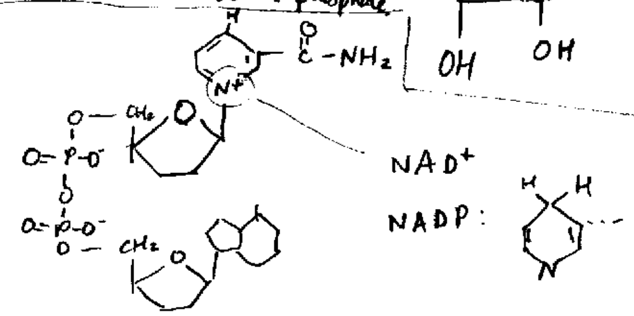
ATP - Adenosine triphosphate

- Short-term energy storage.
- $ATP \longrightarrow ADP + P_i$ provides energy ($\approx 12 \frac{kcal}{mol}$) coupled with reactions consuming energy.
- Energy generating reactions make ATP.



NADP Nicotinamide adenine dinucleotide

- $NADH \longrightarrow \underset{oxidized}{NAD^+}$ provides energy ($\approx 50 \frac{kcal}{mol}$)



Redox Review

Reduction: lose electron - more bonds to H

Oxidation: gain electron - more bonds to O

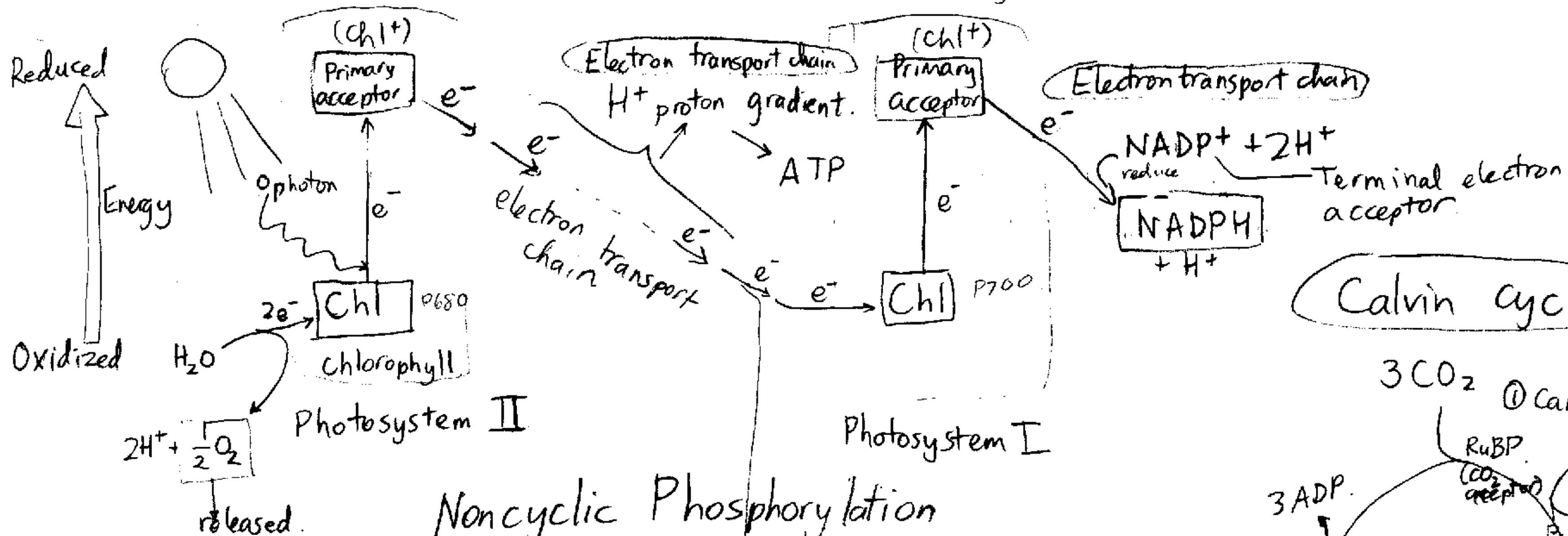
- More reduced = more potential energy for biological work
- Higher reduction potential (E_0) = more likely to occur in forward direction.

  Electrons tend to move from reduced compound to oxidized compound with higher E_0
- $\Delta G^{o\prime}$ and $\Delta E_0'$ have opposite signs ($\Delta G^o = -nF \Delta E_0'$)
  - Positive $\Delta E_0'$ = spontaneous
  - Negative $\Delta E_0'$ = nonspontaneous.

Ex. O_2 canot be present where nitrogen fixation occurs, because else O_2 will be reduced preferentially over N_2.

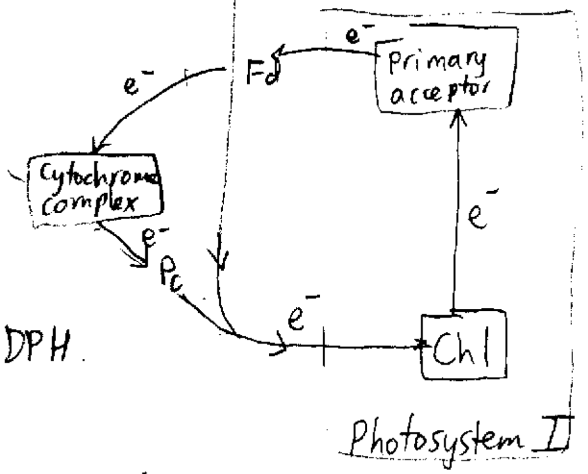
2-2

Photosynthesis:
Energy from sunlight

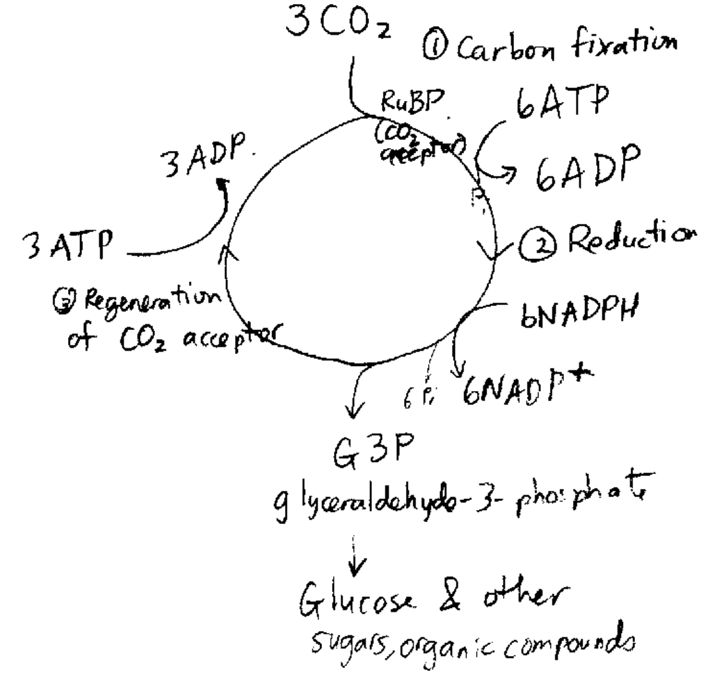


Light Reactions → Noncyclic Phosphorylation
Light Reactions → Cyclic Phosphorylation

- *No NADPH
- *No O_2 released
- *Used since Calvin cycle requires more ATP than NADPH.



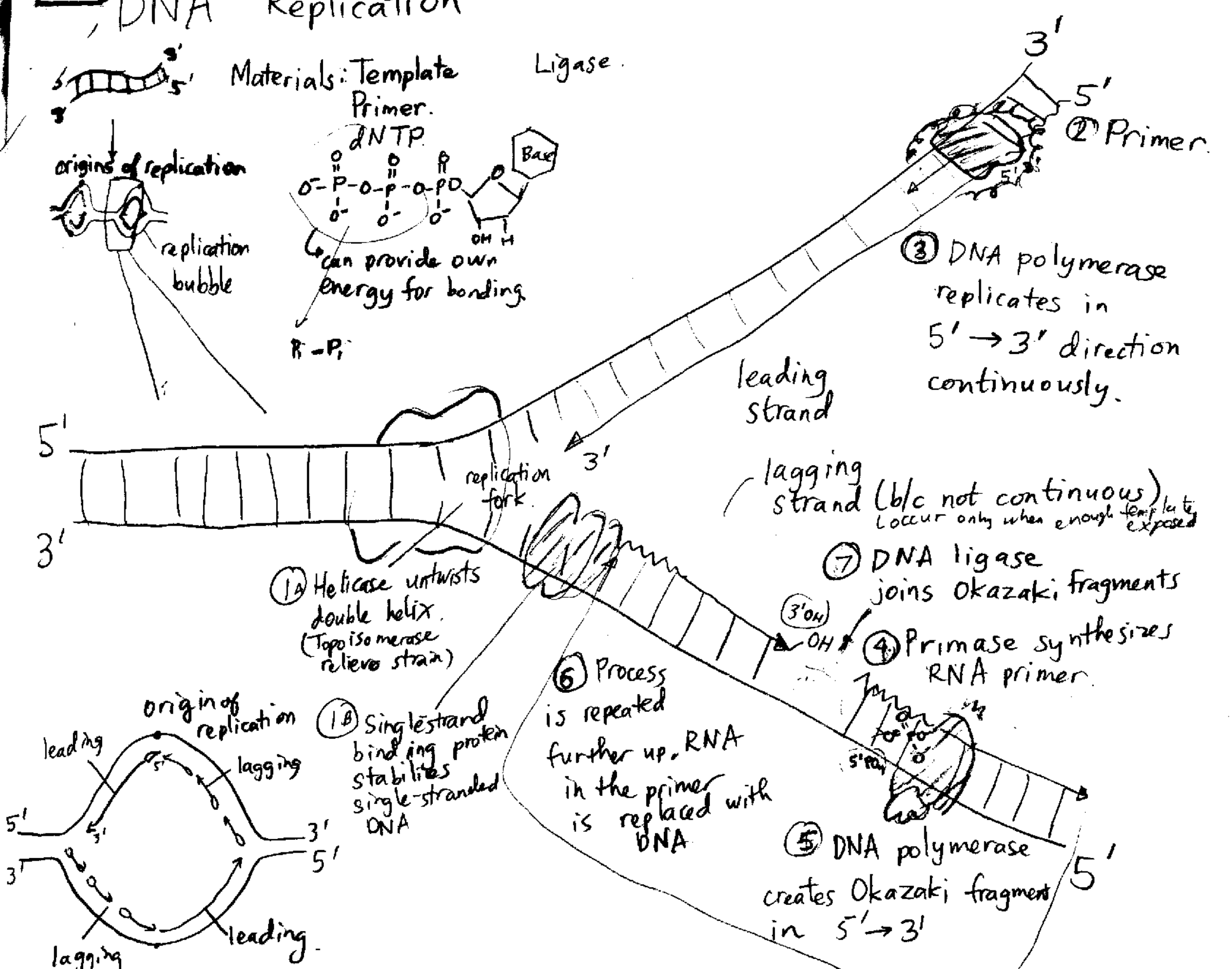
Calvin cycle



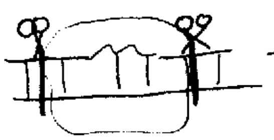
*Note cellular respiration uses $NAD^+/NADH$; photosynthesis uses $NADP^+/NADPH$
phosphate on 3-OH of adenosine

DNA Replication

Materials: Template
Primer.
dNTP
Ligase.



⑧ Exonuclease moves in the 3' → 5' direction to proofread:



→ DNA polymerase repairs, DNA ligase joins.

Ensuring fidelity (errors $\approx 10^{-10}$ of time)

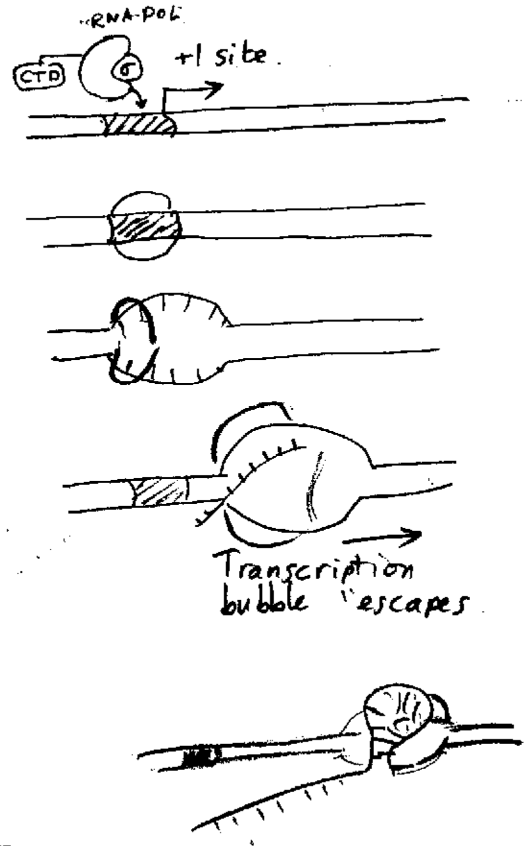
- DNA polymerase structure can easily tell between correct/incorrect base pairs (base pair conformation) + test for shape of base pair with hydrogen bonding (10^{-5})
- Exonuclease proofreads (10^{-2})
- Post-replication mismatch repair (10^{-3})

Defects in repair enzymes increase likelihood of cancer.

(3-2) Transcription.

DNA
↓ transcription (RNA polymerase)
mRNA
↓ translation (ribosome)
Protein

Central Dogma
How DNA codes for protein.



1. Initiation
   (A) RNA polymerase recognizes promoter
   (B) Forms closed complex
   (C) Breaks H-bonds to make single stranded, creating initial transcription complex

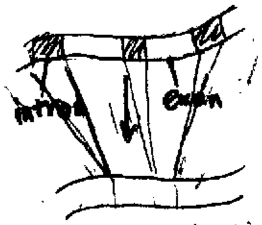
2. Elongation
   RNA polymerase
   - does not need primer.
   - proofreads
   - opens DNA on own.
   - (A) RNA Pol synthesizes 5' → 3' using ATP, GTP, UTP, CTP.

3. Termination
   Bacteria.
   - ρ - dependent termination
   - ρ - independent termination

   Termination sequence UUUU--- sequence forms stem loop, jams up mRNA.

(3-3) Translation

- Eukaryotes have 1
- Prokaryotes have multiple.

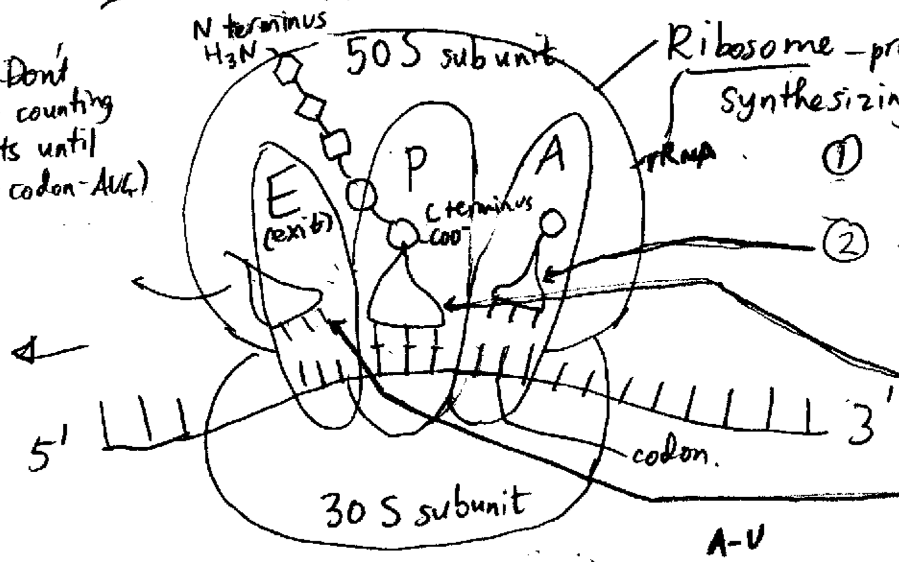


pre-mRNA

In eukaryotes, RNA splicing removes introns – noncoding sequences.
exons = coding sequences

mRNA.

(Note: Don't start counting triplets until start codon-AUG)



Ribosome – protein synthesizing factory

5' → 3'

1. Base pair read in triplets (codons)
   AUG is start codon.
2. tRNA (transfer RNA) with complementary triplet (anticodon) carries amino acid, binds. (look up a.a. in codon table) (universal)
3. tRNA adds amino acid to chain.
4. tRNA exits.
5. Continue until stop codon reached.

A-U
C-G

Experiments on DNA.

Transforming genes into Bacteria (Griffith).

S. pneumoniae bacteria has 2 strains.

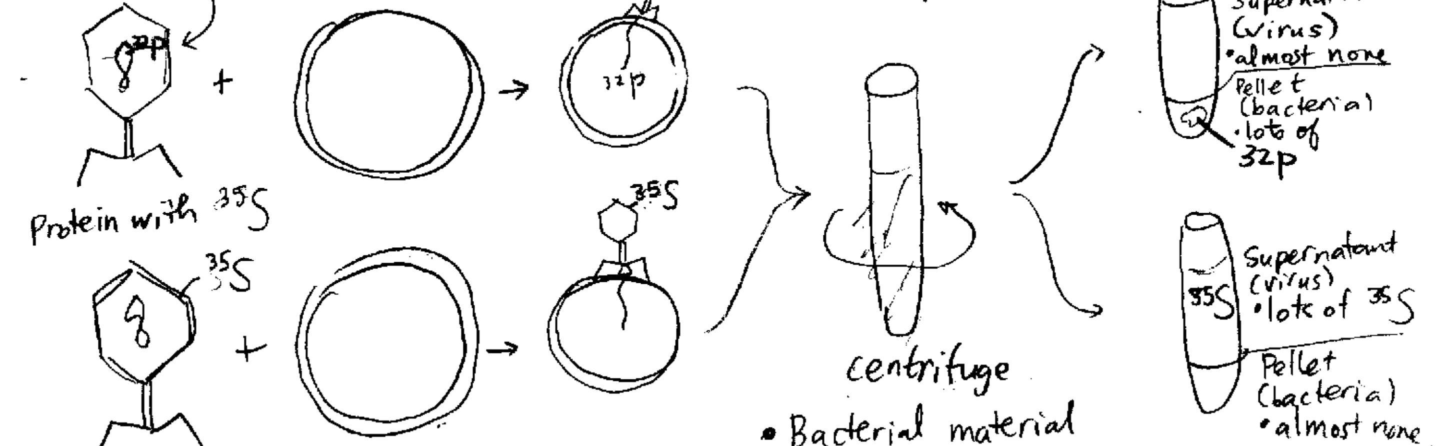
- Smooth colony: Makes protection capsule, harmful
- Rough colony: Doesn't make capsule, harmless.

Inject ... into mouse	Mouse ...
Living S cells	dies
Living R cells	alive
Heat-killed S cells	alive
! Heat-killed S cells & living R cells	dies

<u>Conclusion</u>: R cells acquired genetic material (heritable material) from S cells and were transformed into pathogenic (harmful) bacteria.

Is DNA or protein genetic material? (Hershey - Chase)

Bacteriophage - virus that infects bacteria, injects its genetic material, and hijacks the cell to assemble viruses.



- Bacterial material heavier, sinks to bottom (pellet)
- Virus material lighter, floats at top (supernatant)

<u>Conclusion</u>: Phage injected DNA into cell, so DNA, not protein, is genetic material.

⊳ How does DNA replicate? (Meselson-Stahl)

- Conservative model.

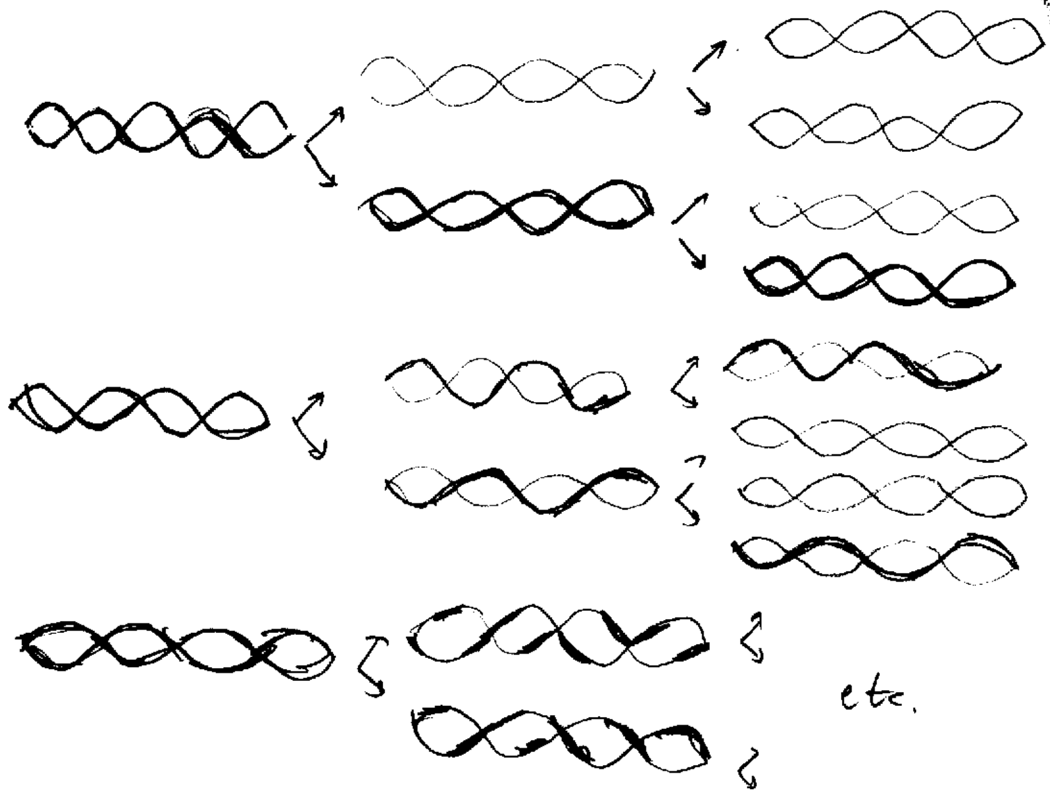
  Parental strands reassociate

- Semiconservative model.

  Parental strands separate, each acts as template

- Dispersive model

  Each strand is a mixture of old/new DNA.



Bacteria grown in ^{15}N → Transfer to ^{14}N

- Heavy DNA

20 min → After 1st replication

20 min → After 2nd replication

After 1st replication, After 2nd replication → Centrifuge.

	1st replication	2nd
Conservative	~~light~~ ~~heavy~~	~~light.~~ ~~heavy~~
Semiconservative	mixed.	light mixed ← correct
Dispersive	←mixed →	