Today’s lecture

- Temperature of earth: (continuation of last time)
- What is Life?
- The 4 types of macromolecules
  Nucleic Acids, Proteins, Carbohydrates, Lipids
- ΔG and stability of molecules
- Central Dogma of Molecular Biology
- DNA

Is there water-based life on other planets?

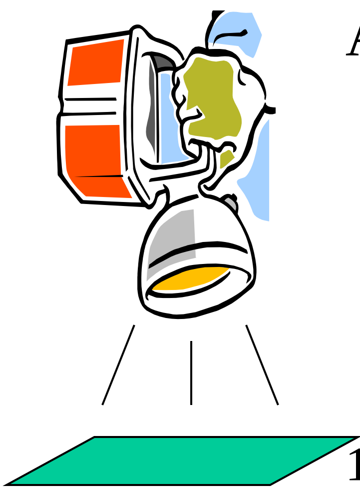
Example of physical limits to life.

Idea: For water-based life, $0^{o} < T_{ave} < 100^{o}C$

Can we calculate T_{ave} of planets in our solar system?

<u>Earth</u>

What determines (surface) temp?



Answer: Heat (photons) from sun

How much light?

$I_e = 1.35\ kW/m^2$

1 meter

How many (flood)lights?

1 meter

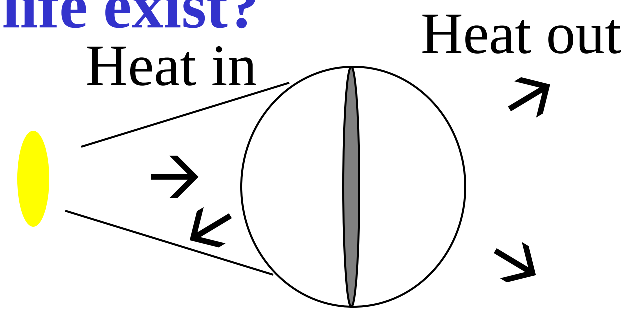
\# Floodlight ~ <u>30</u> (1 meter away)

(Incandescent light 3% efficient)

Why determines earth temperature?

Why can life exist?

Temp of earth constant
Heat in = Heat out



Heat In (Absorbed) = Heat Out

$= (1-\alpha) I_e \pi R_e^2$

$= \alpha\sigma T^4 \times$ (surface area)

σ = const ($=5.7 \times 10^{-8}$ W/m^{20}k^4)

T = absolute Temp.

α= reflectivity of object

$\alpha_{earth} \approx 0.3$

(Stefan-Boltzmann Law)
Kittel, Thermal Physics pg 91-96

$(1-\alpha) I_e \pi R_e^2 =$
$(\alpha\sigma T^4)\,(4\pi R_e^2)$

[Note: R_e^2 cancel]

$$\frac{(1-\alpha)I_e}{4\sigma} = T^4 \left[\frac{(1-0.3)1350\,W/m^2}{(4)(5.7\times 10^{-8}\,w/m^2k^4)}\right]^{1/4} = \langle T_e \rangle$$

$= 253^\circ$ K = -15 $^\circ$C

Too cold! Actual $\langle T_e \rangle = 288^\circ$ K = 15 $^\circ$C

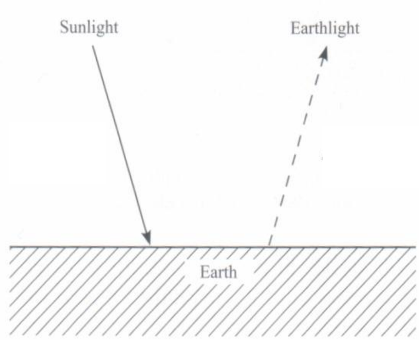
If Earth had no atmosphere the global average surface temperature would be -15˚C. With an atmosphere, temp is actually would be ≈15˚C.

Conclusions of calculations

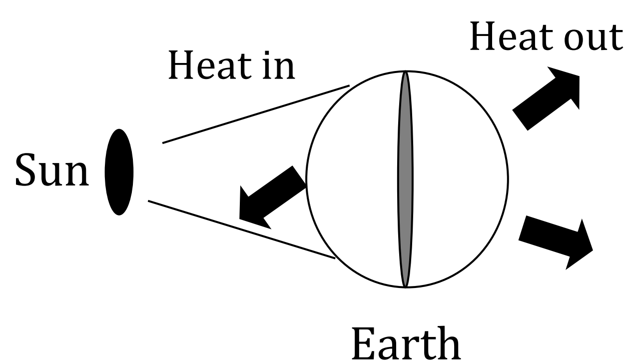
Temp of earth primarily determined by sun's photons, not earth's mantle.

Calculation off because of

Greenhouse effect: earth has an atmosphere.



An energy diagram for Earth with no atmosphere, just a bare rock in space.



You calculate what temperature should be!

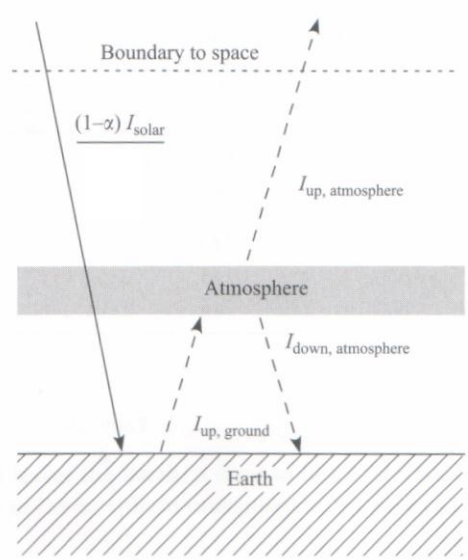


Fig. 3.4 An energy diagram for a planet with a single pane of glass for an atmosphere. glass is transparent to incoming visible light, but a blackbody to IR light.

Physics and Biology

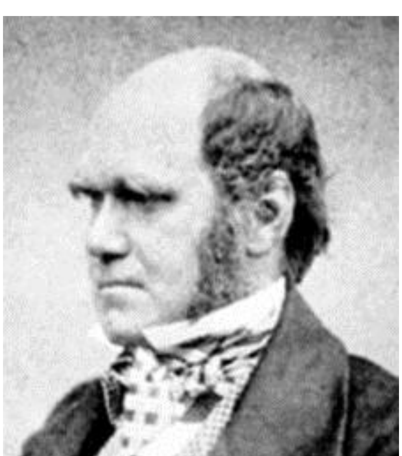
Physics says which of possible tricks evolution might use (are possible)

Physics places constraints
Tell what's possible and not possible

Biology must follow laws of physics

But within the laws of physics, many bio worlds are possible.

(e.g. we have DNA made up of 4 bases,
but why these 4 bases– have shown there are alternative bases)
Which world actually exists?
Many possible...
Often many ways of doing this
Our life form is just one.



Therefore, do:
Biology Experiments

Our existence predicated on
Central Dogma of Biology

What is life?

"I know it when I see it."
-- Justice Potter Steward
in a 1964 Supreme Court case on pornography

A person is clearly alive; so to is a mouse, or a mosquito. And a stone or piece of sand or a smudge of flour clearly isn't.

Qualities we associate with living include things that move, eats, and reproduces.

Move

Trees– don't move; neither is a person who has become immobilized….maybe don't include this?

Eat

Trees don't "eat"…but they do drink and breathe…replace by more general term…take in "food"…?

Reproduces

- Some people are sterile, but clearly alive.
- Bacteria is alive, but a virus? Bacteria use DNA, but some viruses use RNA.

Replace by general term…"nucleic acid" or "genetic".

Is it alive?

Reproduction con’t

Viruses can’t replicate by itself— to do this, it must take over a bacteria cell and use bacterial components— is enough for (many) scientists to claim that it is “dead”, or at least not alive.

On the other hand, many whales can’t reproduce by themselves– need a third whale to breath while they fornicate.

A more difficult situation is the mule, the result of a (male) donkey and a (female) horse. (A female donkey and a male horse almost can never interbreed.) A mule is always sterile, although is clearly alive.

At the molecular level, the definition of life becomes somewhat simpler.

All living organisms consist and make complex, heterogeneous macromolecules. They do this by ingesting the necessary substituents and make them from simple compounds. It has a way of reproducing itself, although any one member of the species need not be able to reproduce.

4 Large [Macro]Molecules

(from small molecules)

Biological polymers (Large molecule made from many smaller building block)

- DNA & RNA → Nucleotides
- Proteins → Amino Acids
- Carbohydrates → Sugars
- Fats (also called Lipids) →Fatty acids

Each is used to:

a. Make macromolecules/structural
b. Energy Source
c. Information– Storage/signaling

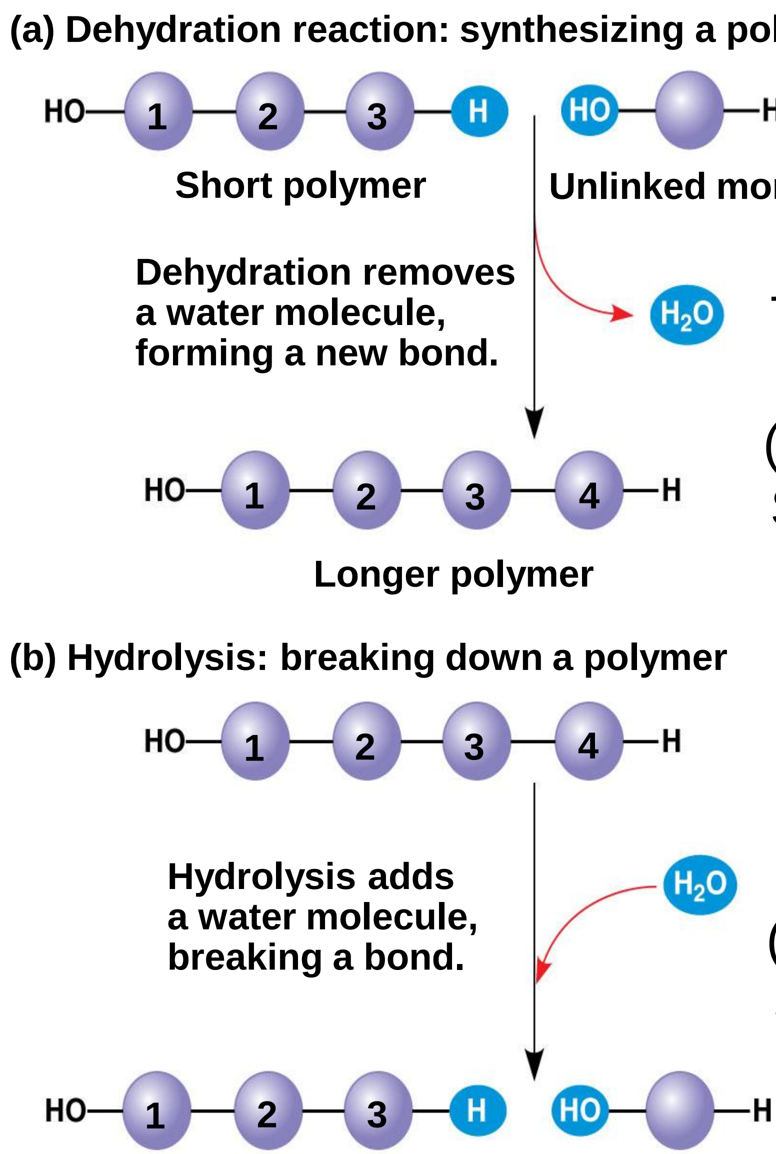
DNA & RNA ; ATP; Genetic Information

Proteins; break down yields energy; nerve impulses.

:

Forming/breaking down a polymer

Figure 5.2



Takes (free) Energy (E_{final}> $E_{initial}$; S_{final}< $S_{initial}$)

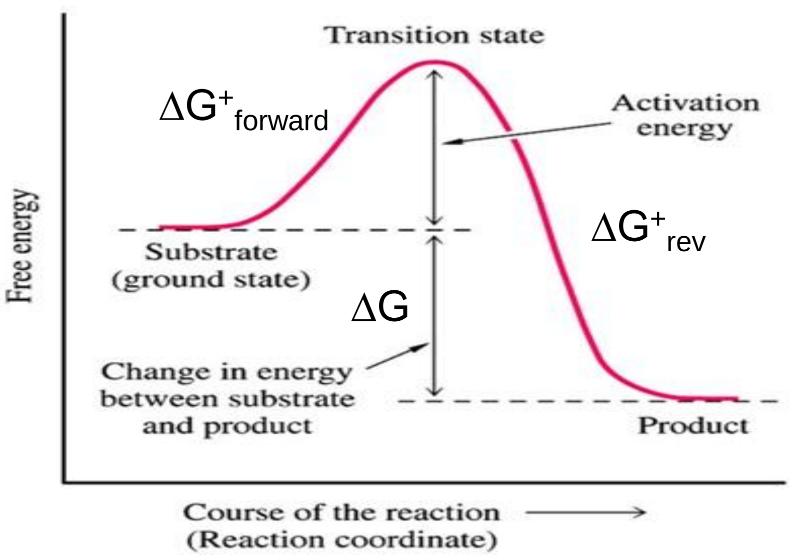
Gives (free) Energy (E_{final} < $E_{initial}$; S_{final} > $S_{initial}$)

Both systems are stable cause they have activation energy to convert!

Stability and thermal activation

Both systems are stable because they have activation energy to convert!

All chemical reactions involve changes in energy. Some reactions release energy (exothermic) and others absorb it (endothermic).



$K_{eq} = [B]/[A]$

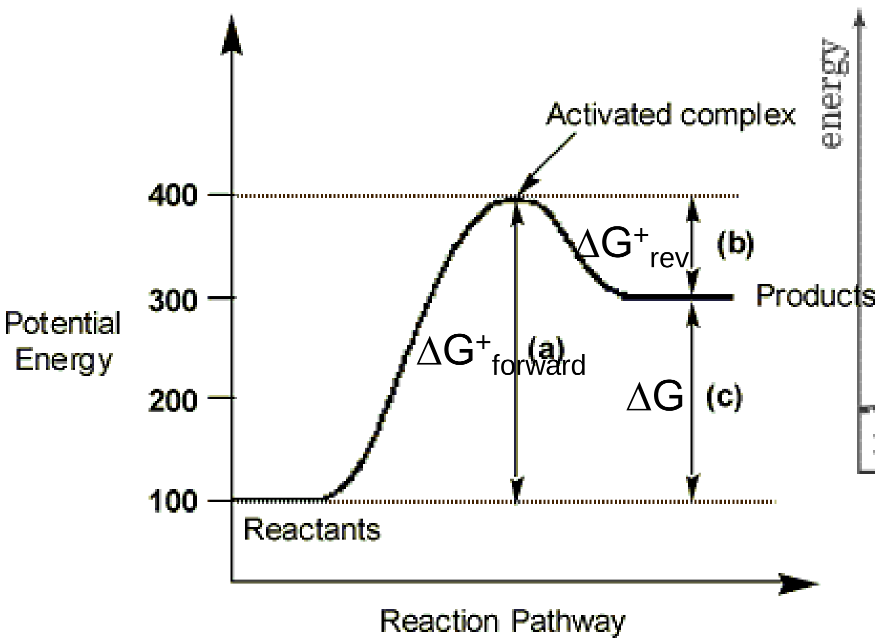
[Says nothing about $\Delta G^{+}_{rev/forward}$]

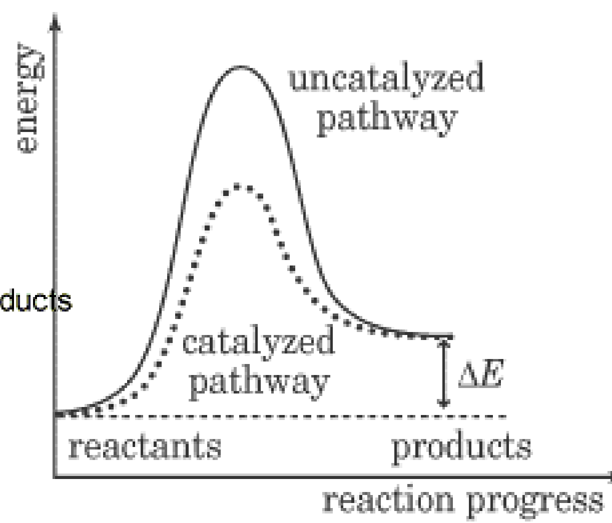
$K_{eq} = f(\Delta G)$?

$K_{eq} = \exp(-\Delta G/kT)$

$\Delta G = -kT \ln (K_{eq})$

Enzymes (Catalyst)





If Activation Energy < kT, then rxn goes forward. If not, need to couple it to external energy source (ATP).

Boltzman factor + Partition function

(review of basic Stat. Mech. – see Kittel, Thermal Physics

E_1 Temp, T

E_0

If T = 0 ºK, what proportion of particles will be in E_1, E_o?

Answer: $E_o = 1$ $E_1 = 0$

If T > 0 ºK, what proportion of particles will be in E_1, E_o?

$$P(E_i) = (\text{const.})\, e^{-E_i/kT}$$

$$\frac{P(E_1)}{P(E_0)} = \underbrace{e^{-(E_1 - E_0)kT}}_{\text{Boltzman factor}}$$

$$\sum P(E_i) = 1$$

$$\text{const.} = \frac{1}{\sum_{j=0}^{N} e^{-E_j/kT}} = 1/Z$$

J= represents j^{th} state

$$Z = \text{partition function} = \sum_{j=0}^{N} e^{-E_j/kT}$$

$$P(E_i) = \frac{1}{z} e^{-E_i|kT}$$

Partition Function for 2-state system

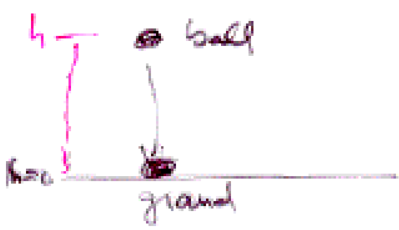
$$-|1\rangle \; E_1$$
$$-|o\rangle \; E_o$$

$$P(E_1) = \frac{e^{-E_1/kT}}{e^{-E_o/kT} + e^{-E_1/kT}}$$

Simple case: Ball in gravitational field.

Thermal fluctuations, finite probability of being at height, h.

E = ??



$$E = mgh$$
$$E_o \; h = 0$$
$$E_1 \; h = (mg)(h \text{ meter})$$

$$\frac{P(h)}{P(O)} = e^{-mgh/kT}$$

As ball gets smaller, probability gets smaller / larger ?

"Ball" the size of O_2? Why can you breathe standing up?

What is 1/e height for O_2?

For O_2, 1/e height is ~10 km ~height of Mt. Everest.
(10 kM is "death zone")
Probability of dying if you go over 20,000 ft is 10%
for every trip!!

Equilibrium, ΔE, ΔG

A ←→ B

Probability of being in B = $Z^{-1}\exp(-E_B/kT)$

Probability of being in A = $Z^{-1}(\exp{-E_A}/kT)$

K_{eq} = B/A = $\exp(-E_B/kT + E_A/kT)$

= $\exp -([E_A + E_A]/kT) = \exp -(\Delta E/kT)$

$\Delta E = -\ln K_{eq}$

In fact, this does not take into account the degeneracy of either state.

Use ΔG instead of ΔE—takes into account degeneracy of states.

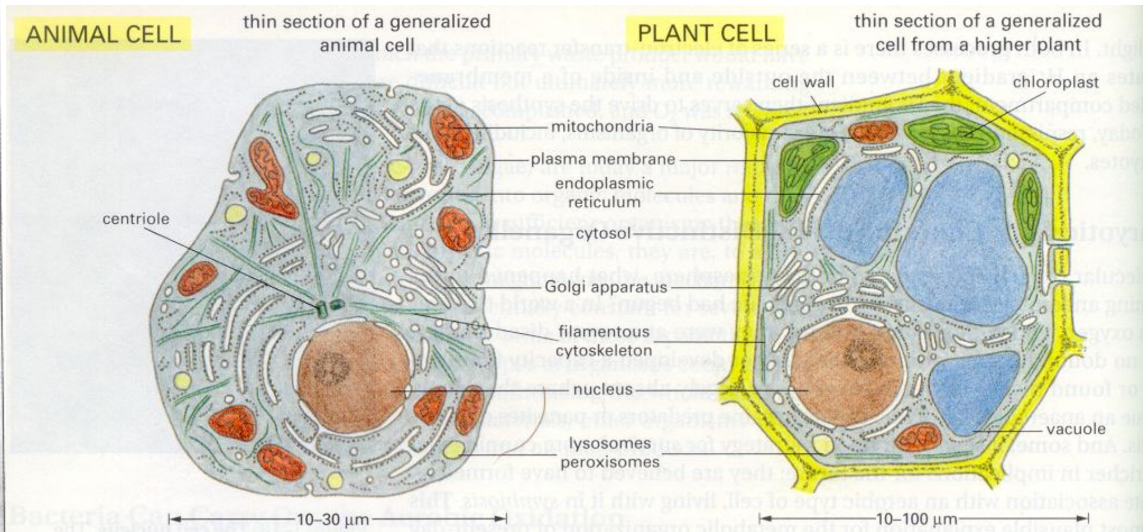
# of states = W

Entropy S = ln W

Most Biopolymers in Body are in Cells

Bacteria
Prokaryotes
(No nucleus)

Eukaryotic cell (us)
(Has nucleus)



←1 μm→

←10-30 μm→

←10-100 μm→

(Nucleus 3-10 μm)

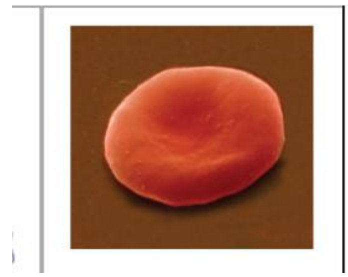
≈ 10^{14} (100 billion!) cells in body…
…more stars than in Milky Way Galaxy.

Yet there are ≈ 200 different types of cells in body. (Heart cell not equal to a brain cell…)

Nucleus contains DNA
Blueprint of cell

Every cell (which has nucleus) has identical DNA

[A few types, like red blood cells, are made with a nucleus but gets de-nucleated.]



Each cell type must express only a part of information in DNA.

How much DNA?   1 meter

In 46 pieces: chromosomes (in humans)

So a meter of DNA must be packed in 3-10 μm!

What does this tell about bendability of DNA?

Highly flexible. (Yet very robust in storing genetic information over a lifetime)

How this is measured? Use magnetic tweezers

DNA→ RNA→ Proteins

Central Dogma of Molecular Biology

DNA: linear series of 4 nucleotides (bases): A,T,G,C

↓ Transcription [DNA & RNA similar]

RNA: linear series of 4 nucleotides (bases): A,U,G,C

↓ Translation [RNA & Proteins different]

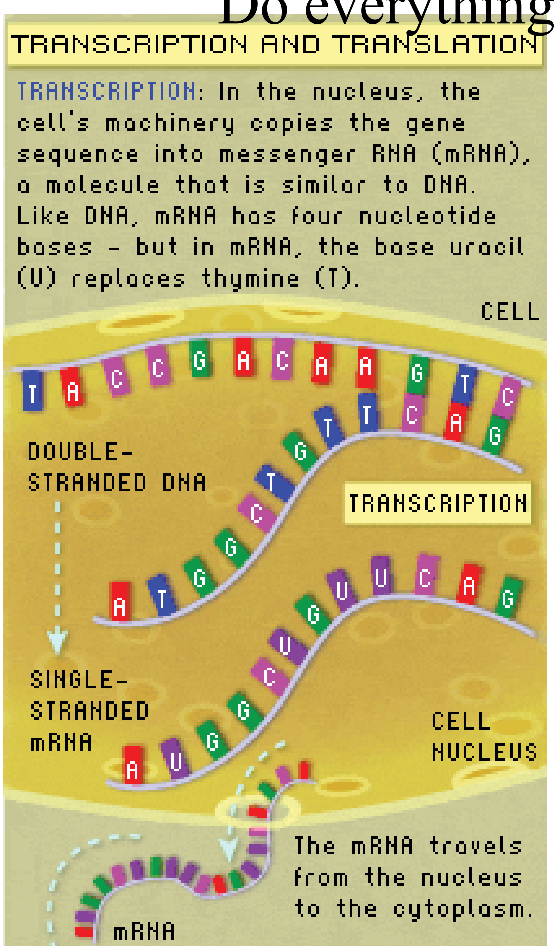
Proteins: linear series of 20 amino acids: Met-Ala-Val-…

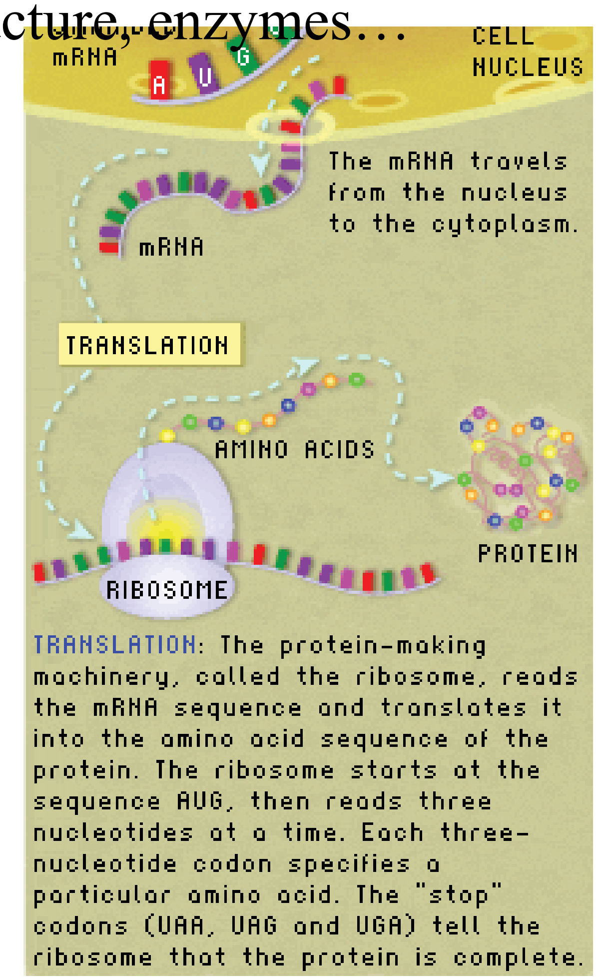
each coded by 3 bases → amino acid

AUG→ Methionine; GCU → Alanine; GUU→ Valine

Proteins are 3-D strings of linear amino acids

Do everything: structure, enzymes…





http://learn.genetics.utah.edu/units/basics/transcribe/

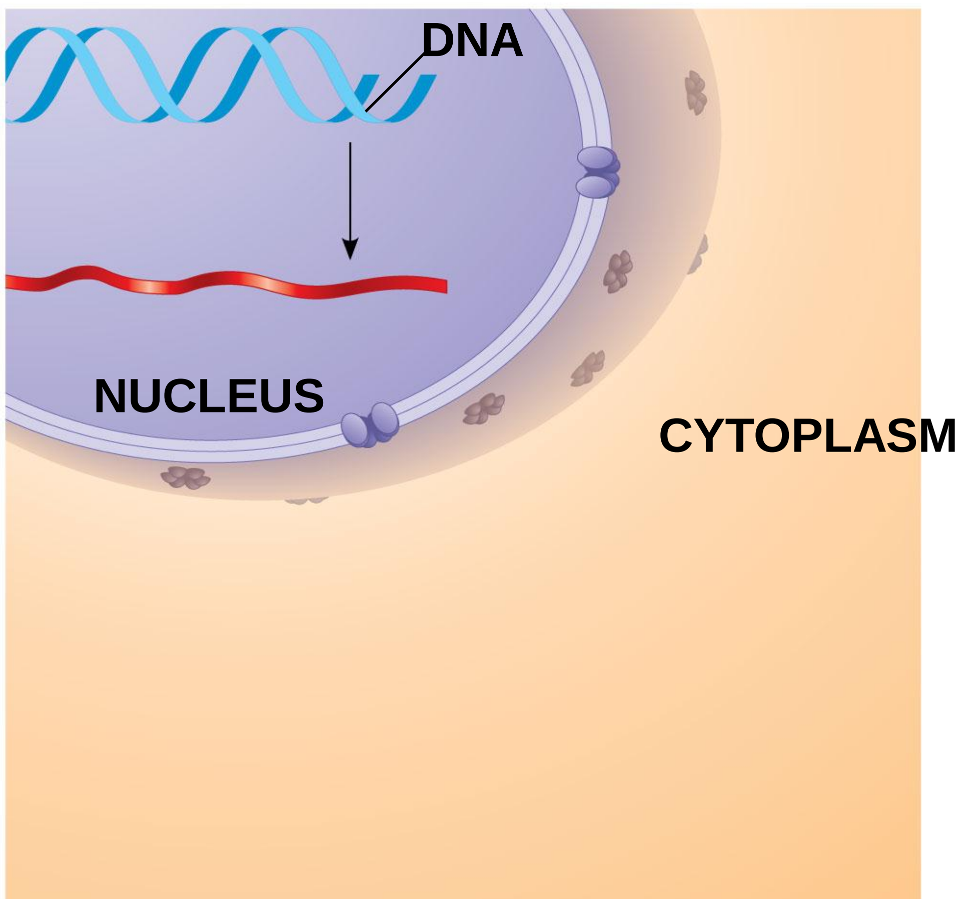

DNA
NUCLEUS
CYTOPLASM

Figure 5.25-1

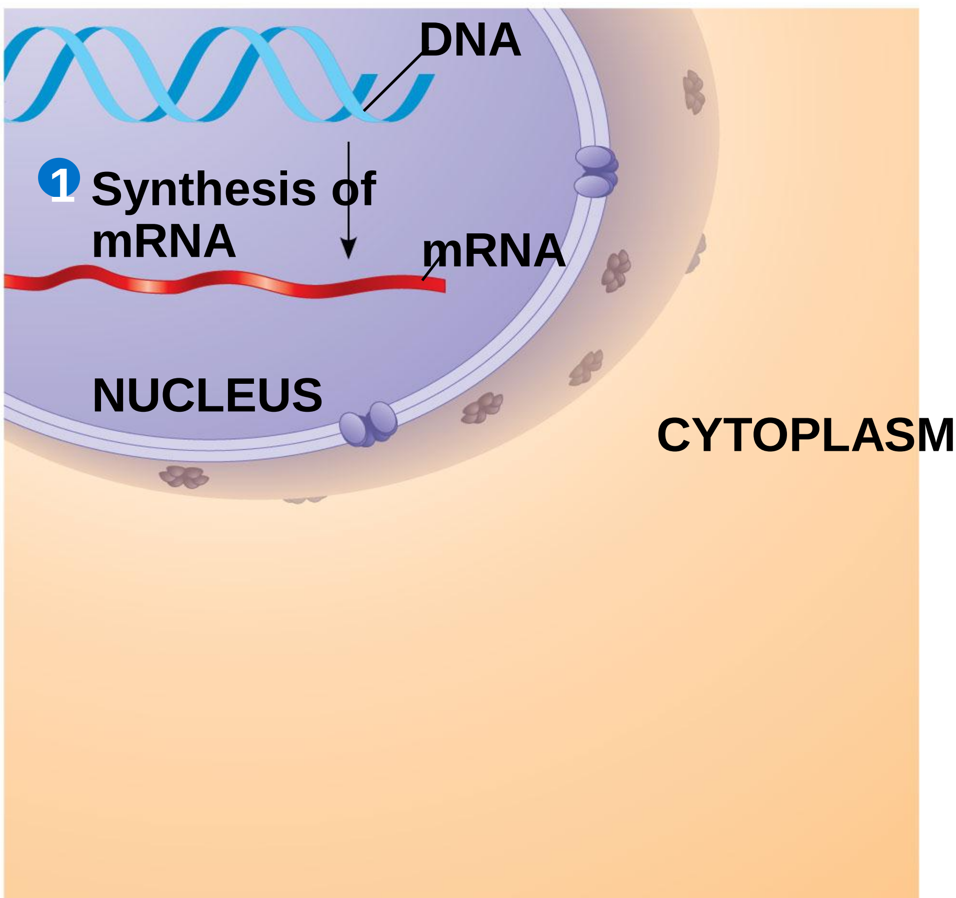


Figure 5.25-2

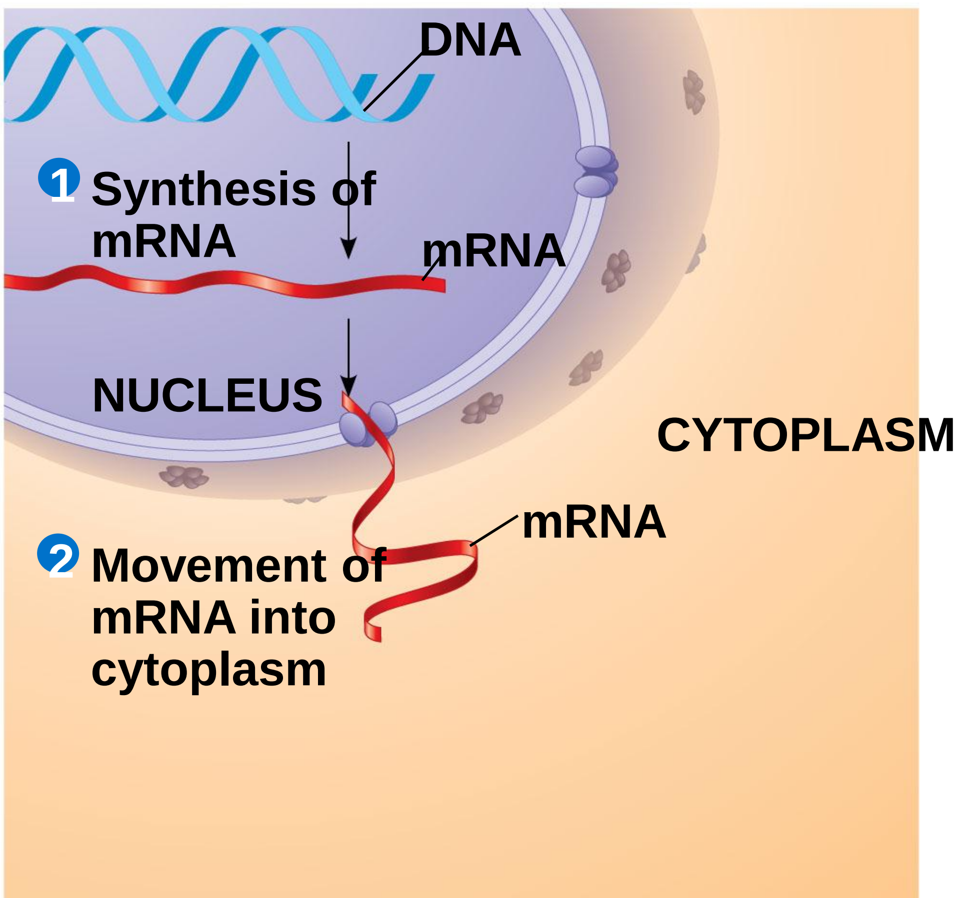
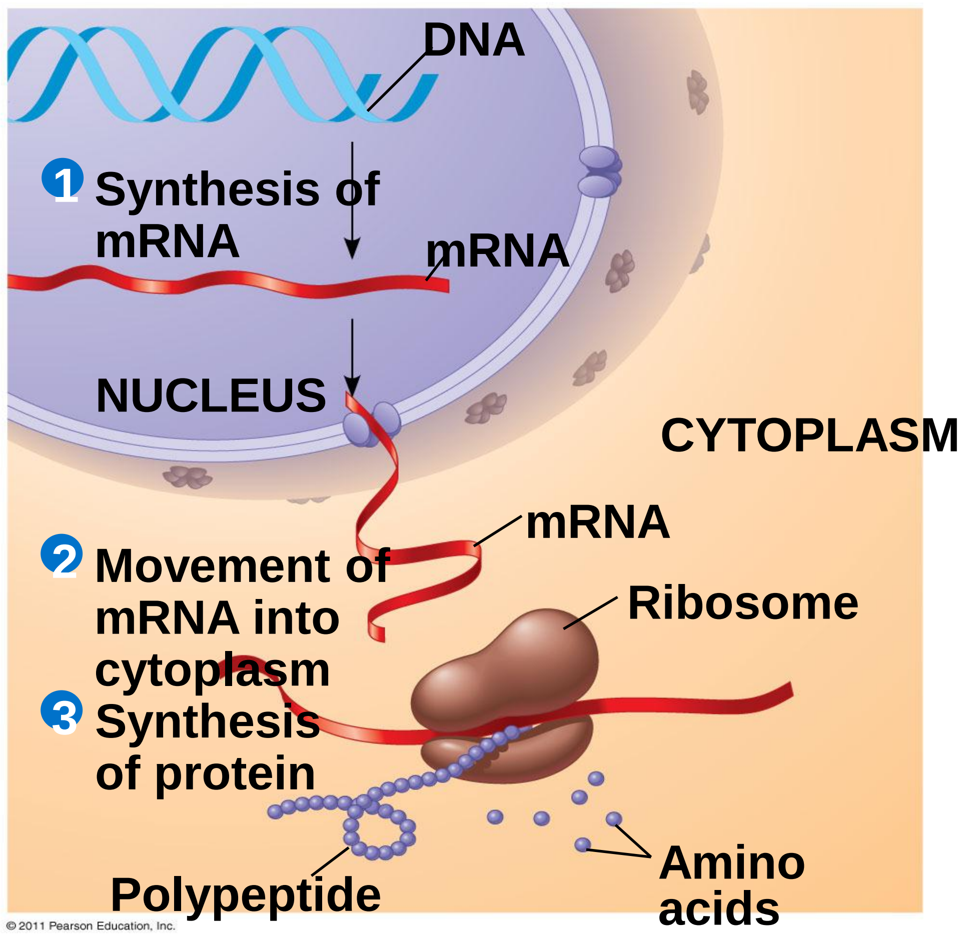
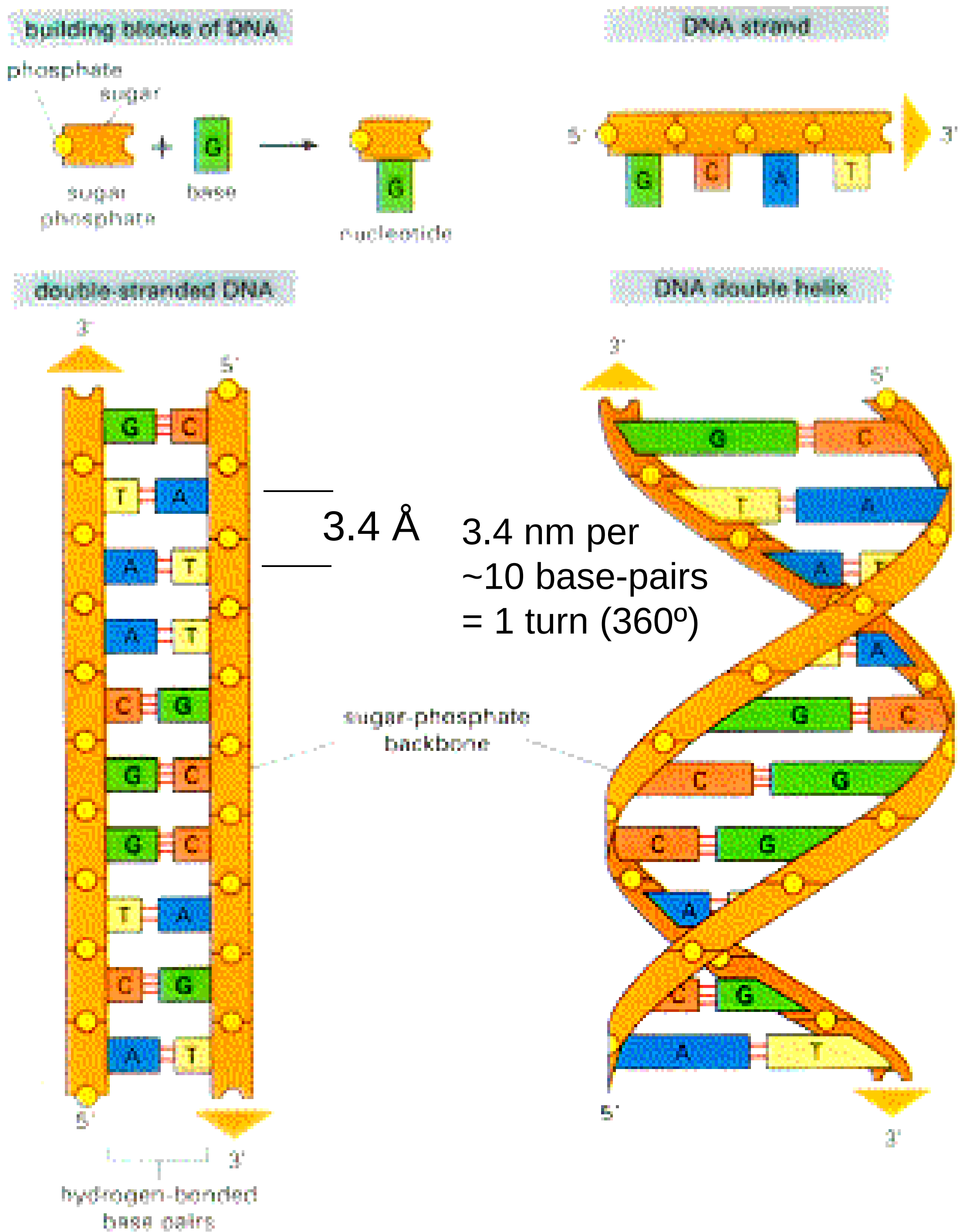

DNA
1 Synthesis of mRNA
mRNA
NUCLEUS
CYTOPLASM
mRNA
2 Movement of mRNA into cytoplasm

Figure 5.25-3



DNA
1 Synthesis of mRNA
mRNA
NUCLEUS
CYTOPLASM
mRNA
2 Movement of mRNA into cytoplasm
Ribosome
3 Synthesis of protein
Polypeptide
Amino acids
© 2011 Pearson Education, Inc.

DNA is a double helix of anti-parallel strands



Must come apart for bases to be read.

Minimal knowledge about Nucleotides

- 4 nucleotides: A,T,G,C
- A=T ≈ 2kT two hydrogen bonds

  G≡C ≈ 4kT three hydrogen bonds
- Many weak bonds…very strong overall structure. DNA is stable. How do you access the info in DNA? (Will calculate)

DNA is a linear polymer of nucleotides. Backbone is held together by covalent sugar-phosphate bonds.

DNA Backbone is negatively charge.
(One charge per nucleotide)

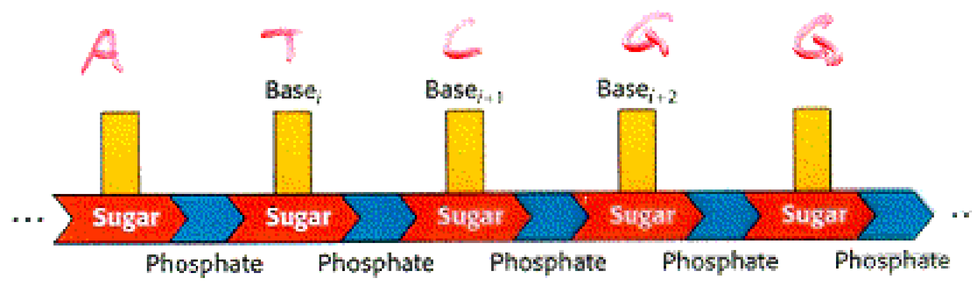
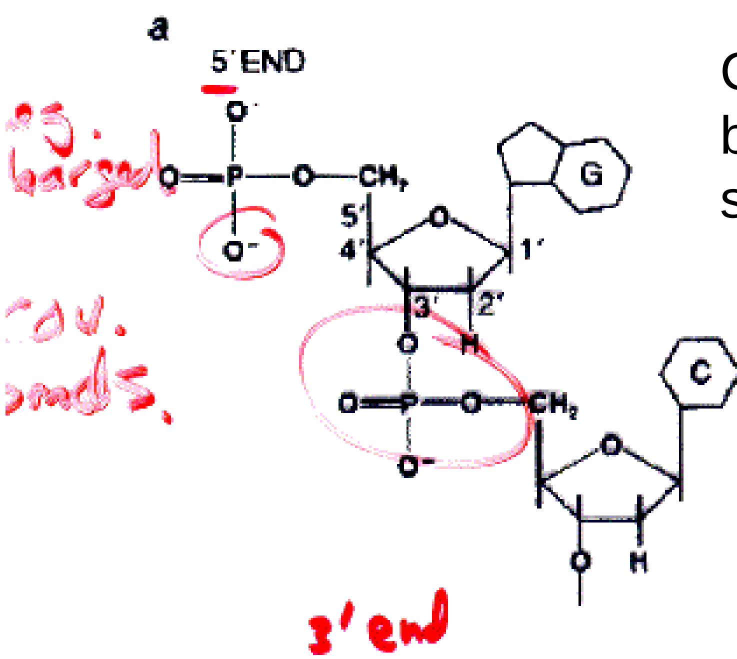


FIGURE 5.1 Polymeric structure of nucleic acids.



Covalent bonds holding bases together —very strong

The storage of information is in the linear arrangement of nucleotides.

DNA is a linear polymer of nucleotides. Backbone is held together by covalent sugar-phosphate bonds.

DNA Backbone is negatively charge.
(One charge per nucleotide)

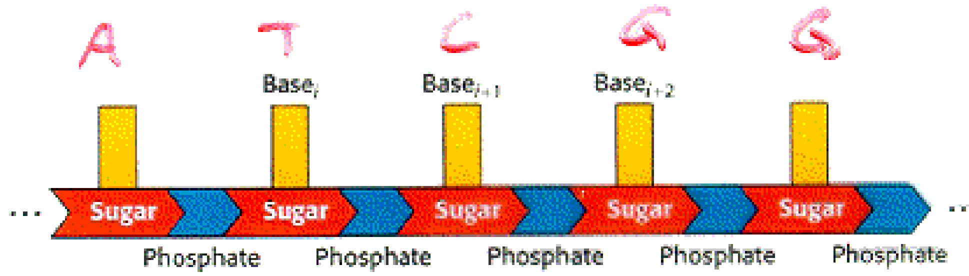
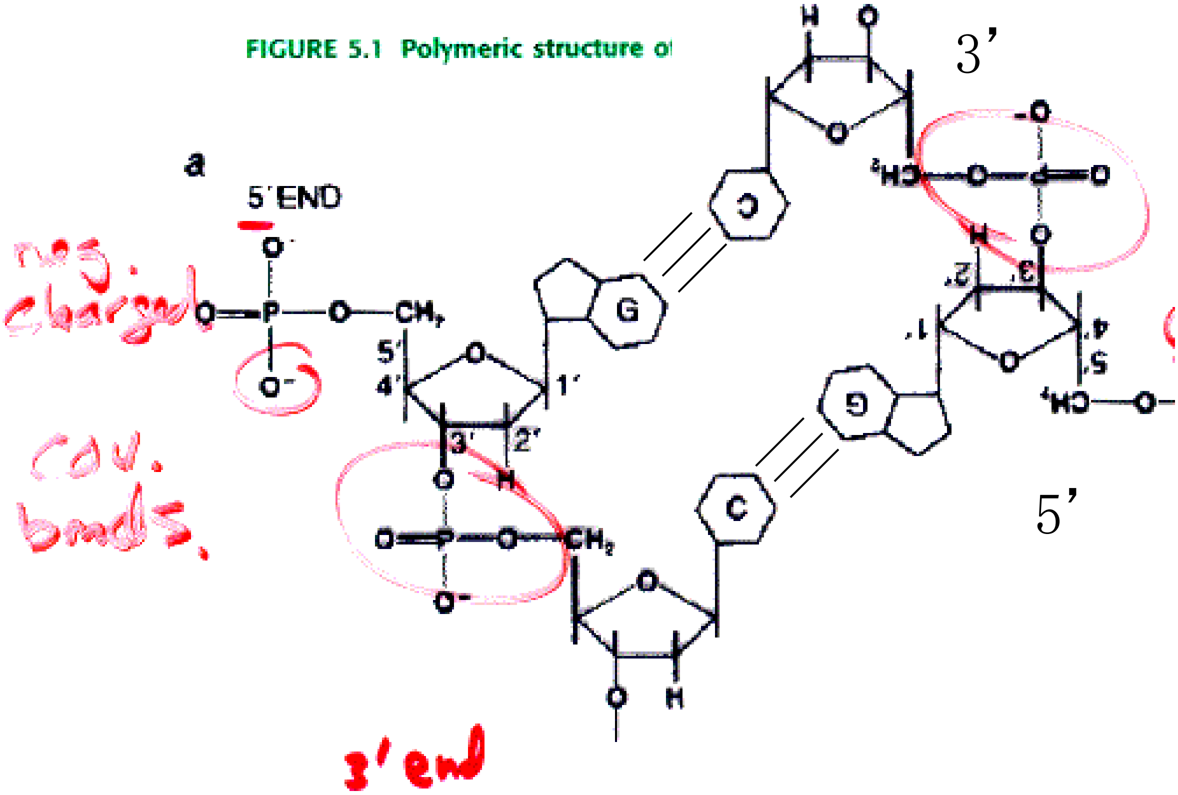


FIGURE 5.1 Polymeric structure of



The storage of information is in the linear arrangement of nucleotides.

If add salt to solution, what is effect on melting Temp?

Melting temp = Temp. at which DNA strands come apart.

DNA is twisted & antiparallel for base pairing

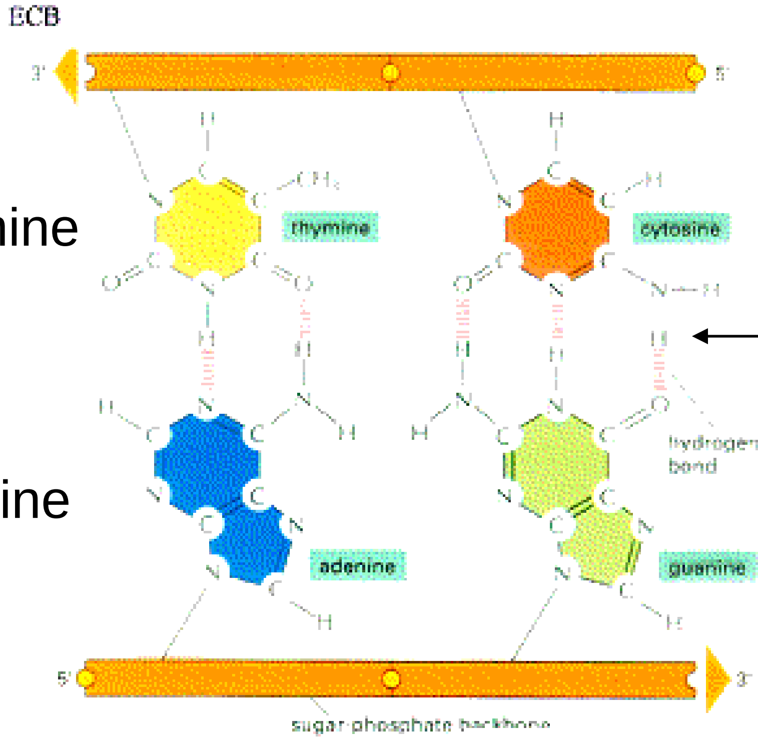
Thymine

Cytosine

Hydrogen Bonds (2kT)

Adenine

Guanine

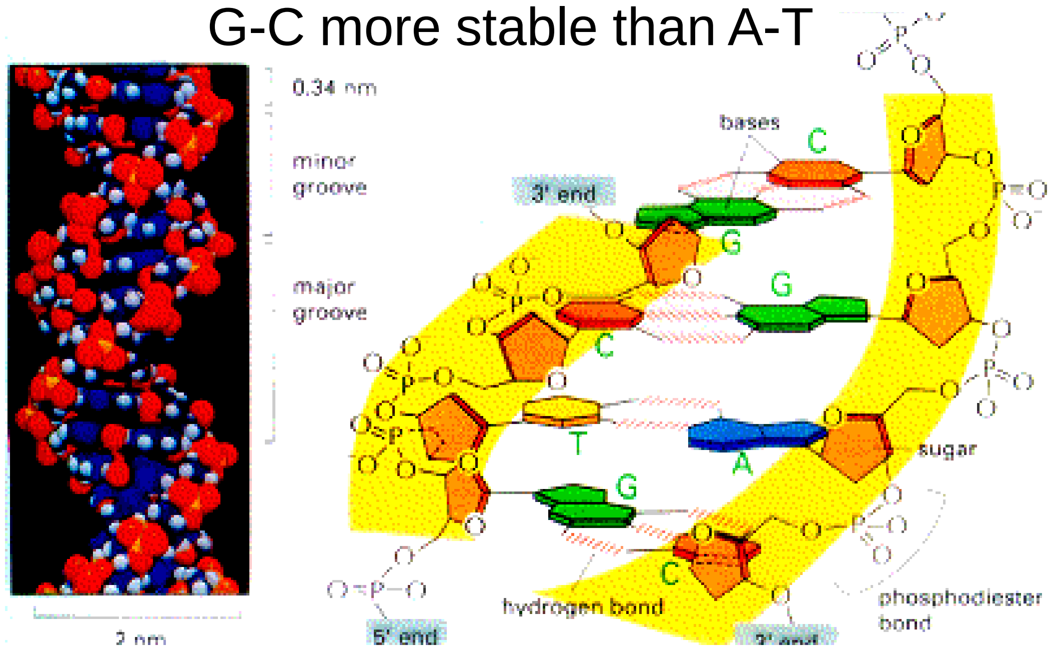


A = T (2 H bonds) G ≡ C (3 H bonds)

G-C more stable than A-T

Minor grove

Major grove



$\pi - \pi$ stacking keeps it together (Grease);

Phosphate negative charge makes it water soluble

(Sort of like soap)

Need to know Chemical Bonding

4 types

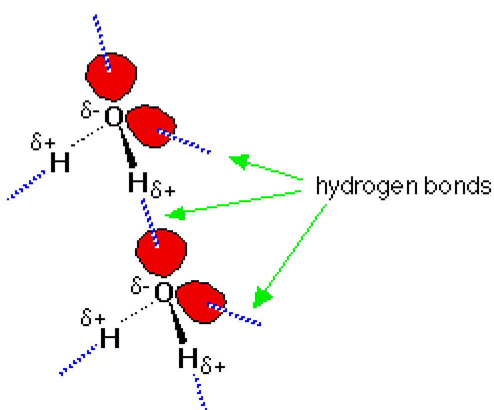
1. Covalent – 100kT. Sharing of electrons. C-H

Is light enough to break covalent bond?

1um =1eV; kT=1/20eV. 1um= 20kT: close (yup)

2. Ionic – varies tremendously, 100kT to few kT.
+ and – attract, but depends on solvent.
Na^+ Cl^- = few kT (break up easily)

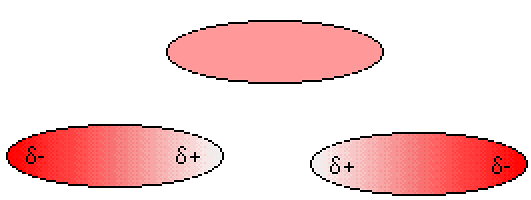
3. Hydrogen – few kT, up to 5kT

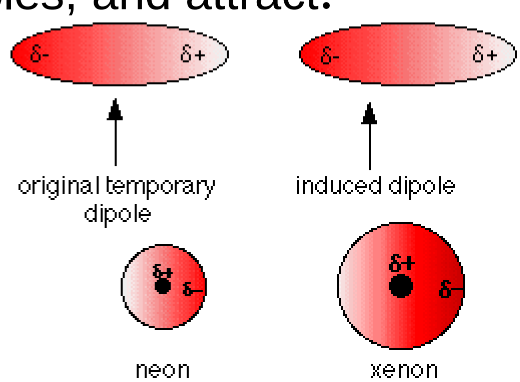


1. Hydrogen attached to a very electro-negative elements, (O, N) causing the hydrogen to acquire a significant amount of positive charge.
2. Lone pair- electrons in relatively small space, very negative.

Result is H is (+) and O is (-). Will bind to other molecules

4. Van der Waals –kT (weakest, but many of them together--significant). Two neutral atoms have instantaneous dipoles, and attract.





Neon: -246° C; Xenon: -108° C

www.chemguide.co.uk/atoms/bonding/hbond.html#top

Two states: To be bound or not-bonded: DNA

A – B bonded: E ~ -5 kT 0 ew H-bonds)

A , B not bonded: E = ??

$$A + B \rightleftarrows A - B$$

3

149 molecules

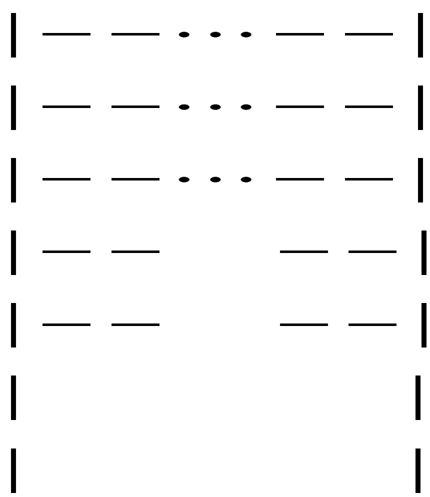
148 will be A - B

1 will be A, B

DNA double helix: Many weak (H-bonds), makes for very stable structure.

If you have many weak bonds (e.g. each bond only few kT) you can get a biomolecule that will <u>not</u> fall apart.

H bonded $\sim$ 2 kT



Zipped vs. unzipped

What if just one bond? Bond/unbound? $e^{-2} \sim 1/8$

What if 10 weak bonds? e^{-20}

Many base pairs, essentially completely stable.
Still have end-fraying, but probability that whole thing comes apart– essentially zero.

Homework

Due by:
beginning of class on Monday, Jan 30th

1. Read Chpt 4 of Campbell

2. Do web-site homework on reading, Chpt 4

Homework Set #1

On web-site under HW 1.
(PDF is there.)

Evaluate class

1. What was the most interesting thing you learned in class today?
2. What are you confused about?
3. Related to today's subject, what would you like to know more about?
4. Any helpful comments.

Put your name in upper right-corner.

Then tear off your name before turning in.
(That way you can be brutally honest!)

Answer, and turn in at the end of class.

(I'll give you ~5 minutes.)