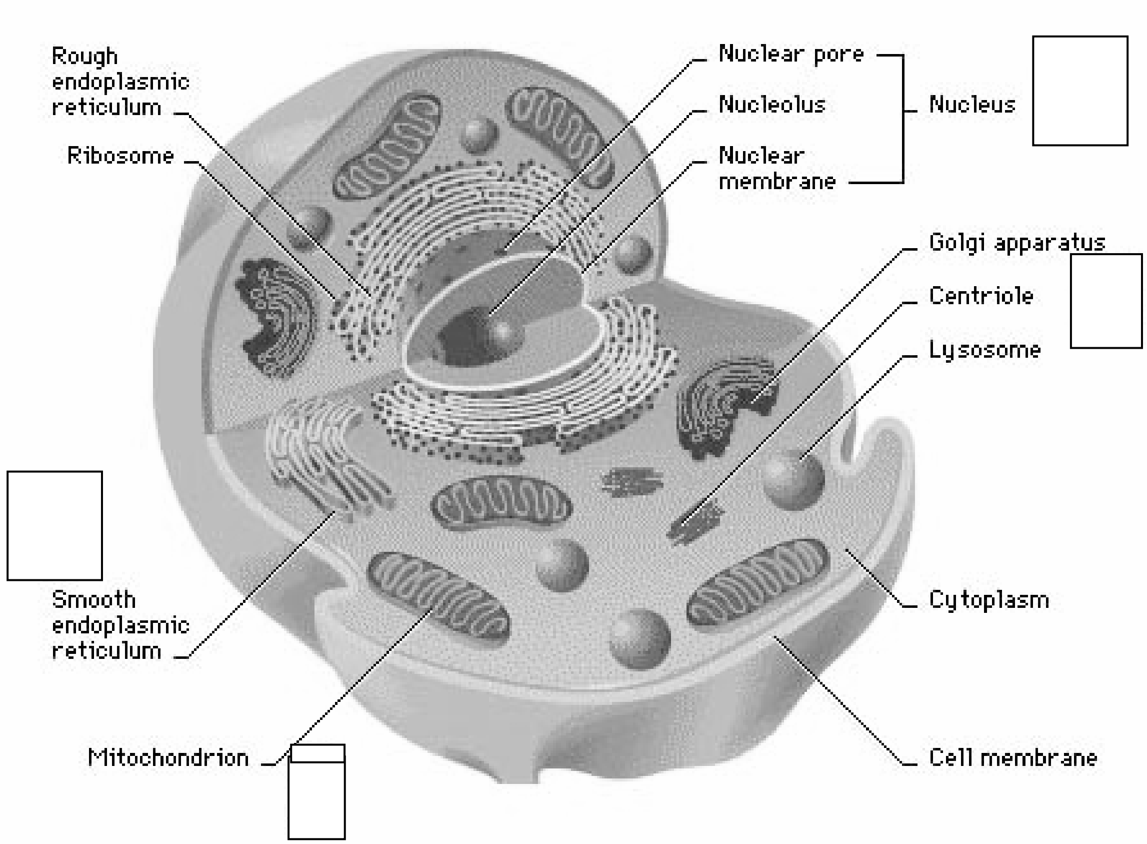
Life

What is necessary for life?

Most life familiar to us: Eukaryotes

FREE LIVING
Or Parasites

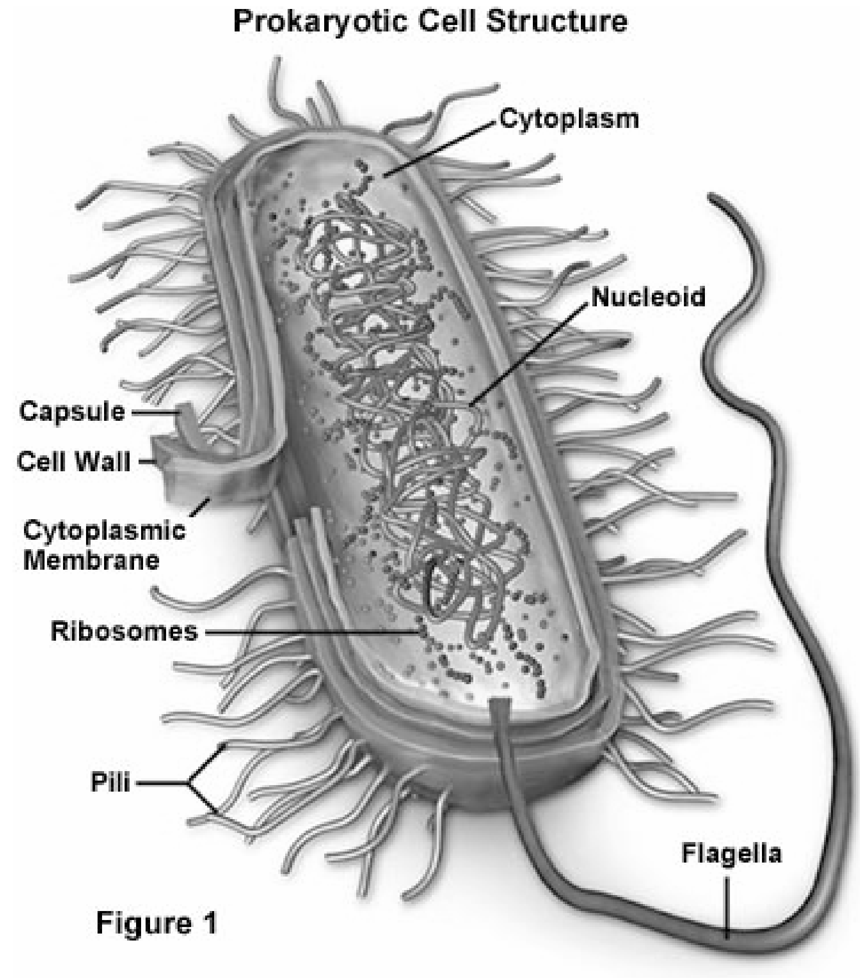


First appeared ~ 1.5 - 2 $\times$ 10^9 years ago
Requirements: DNA, proteins, lipids, carbohydrates, complex structure, ~ 10^4 - 10^5 genes

Prokaryotes (Bacteria and Archaea)

First appeared

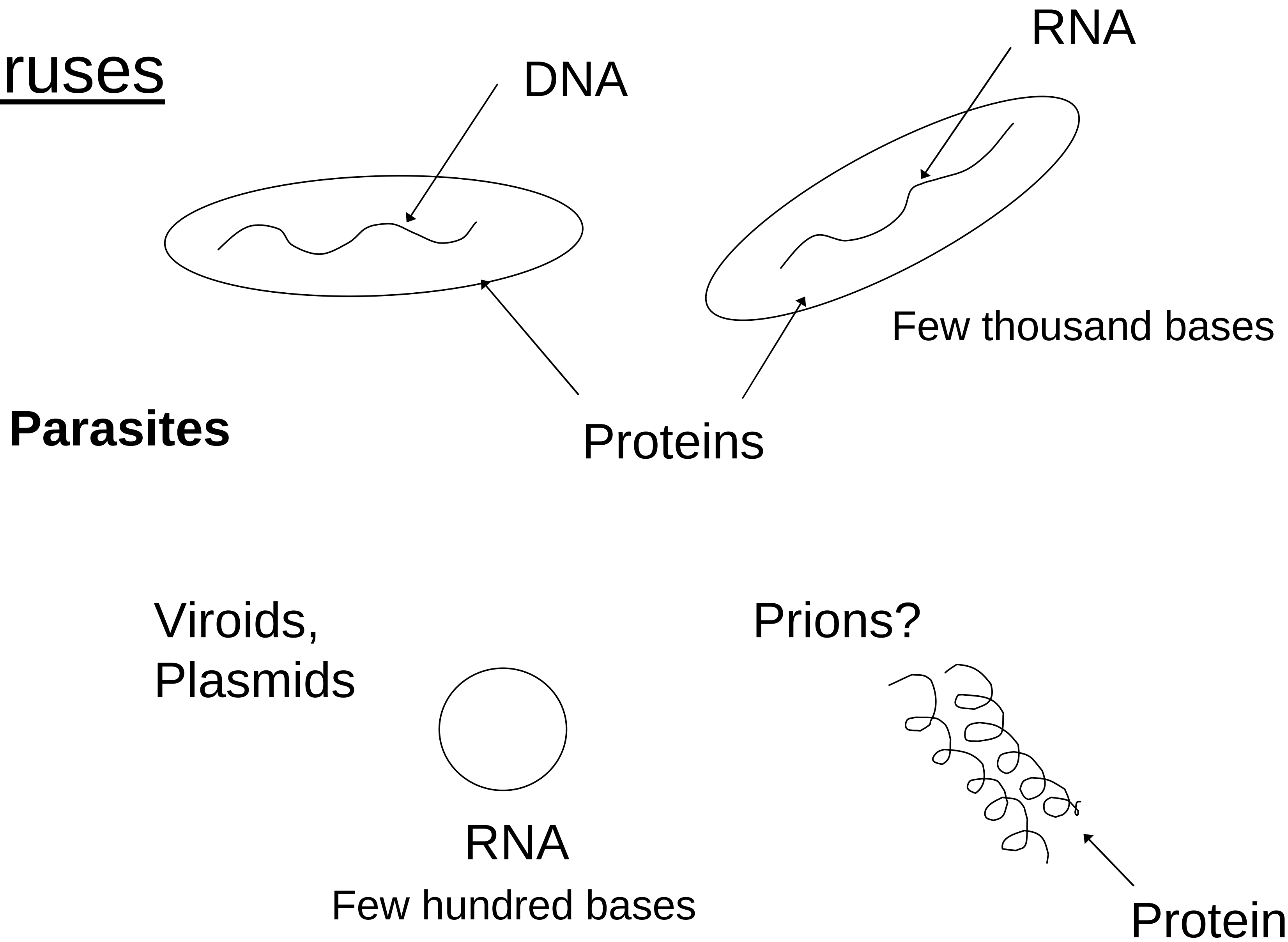
~ 3 - 4 $\times 10^9$ years ago



FREE LIVING
Or Parasites

Requirements: DNA, protein, lipids, carbohydrates, simpler structure, few thousand genes

Viruses



DNA
RNA
Few thousand bases
Parasites
Proteins
Viroids,
Plasmids
Prions?
RNA
Few hundred bases
Protein

Minimum Requirements for Life

Proteins and Nucleic Acids for simplest

Or maybe only one.

Lipids and Carbohydrates for any thing more complex than a virus.

These are all macromolecules.

Macromolecules

H, C, N, O
(S)

Proteins made of amino acids (20)

Construction and catalysis (enzymes)

H, C, N, O
(P)

Nucleic acids made of nucleotides

base sugar phosphate

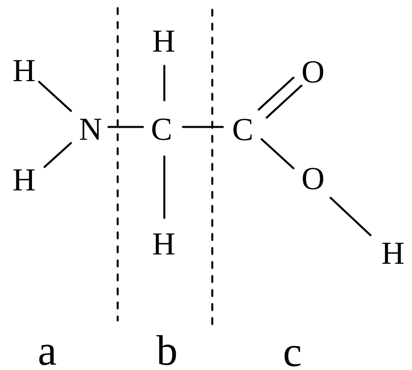
Polymers and Monomers

Proteins

Monomers are amino acids

20 kinds

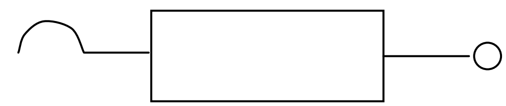
Glycine



Amino group

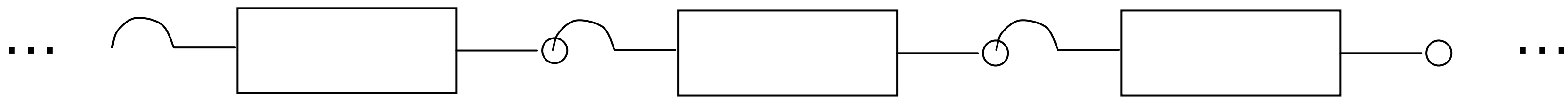
carboxyl group

Schematic



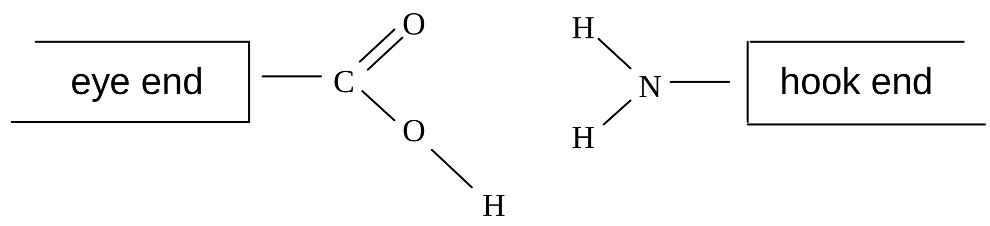
Amino group (hook)

carboxyl group (eye)

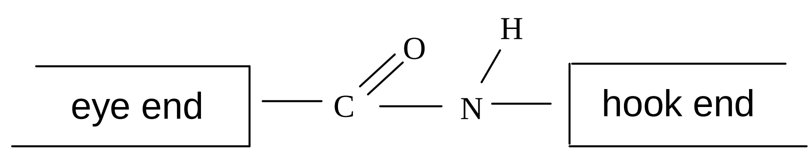


Section of Protein

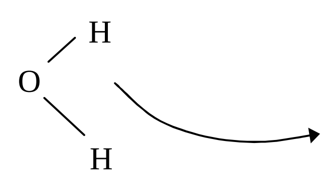
A Peptide Bond at the Chemical Level



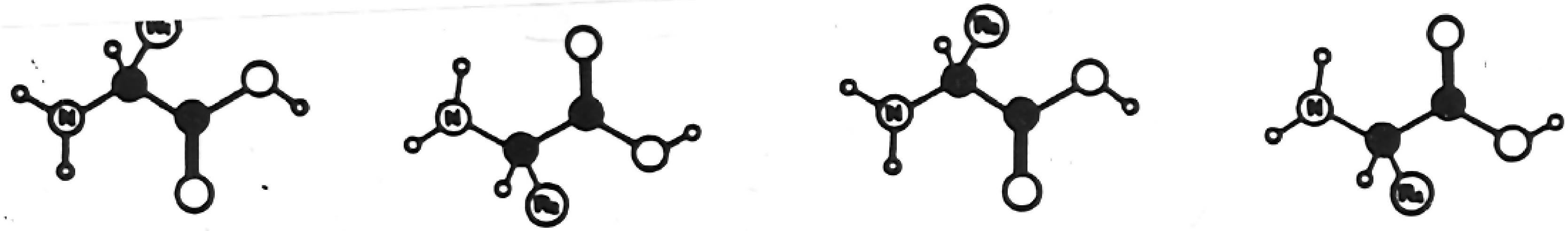
Before



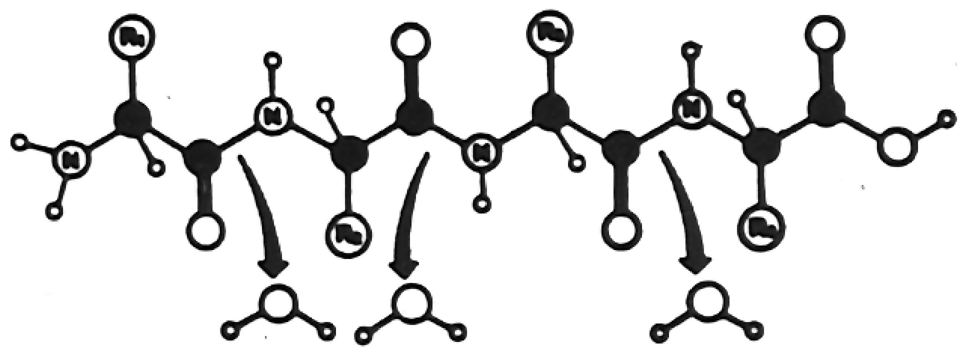
After



Note that a water molecule must be removed



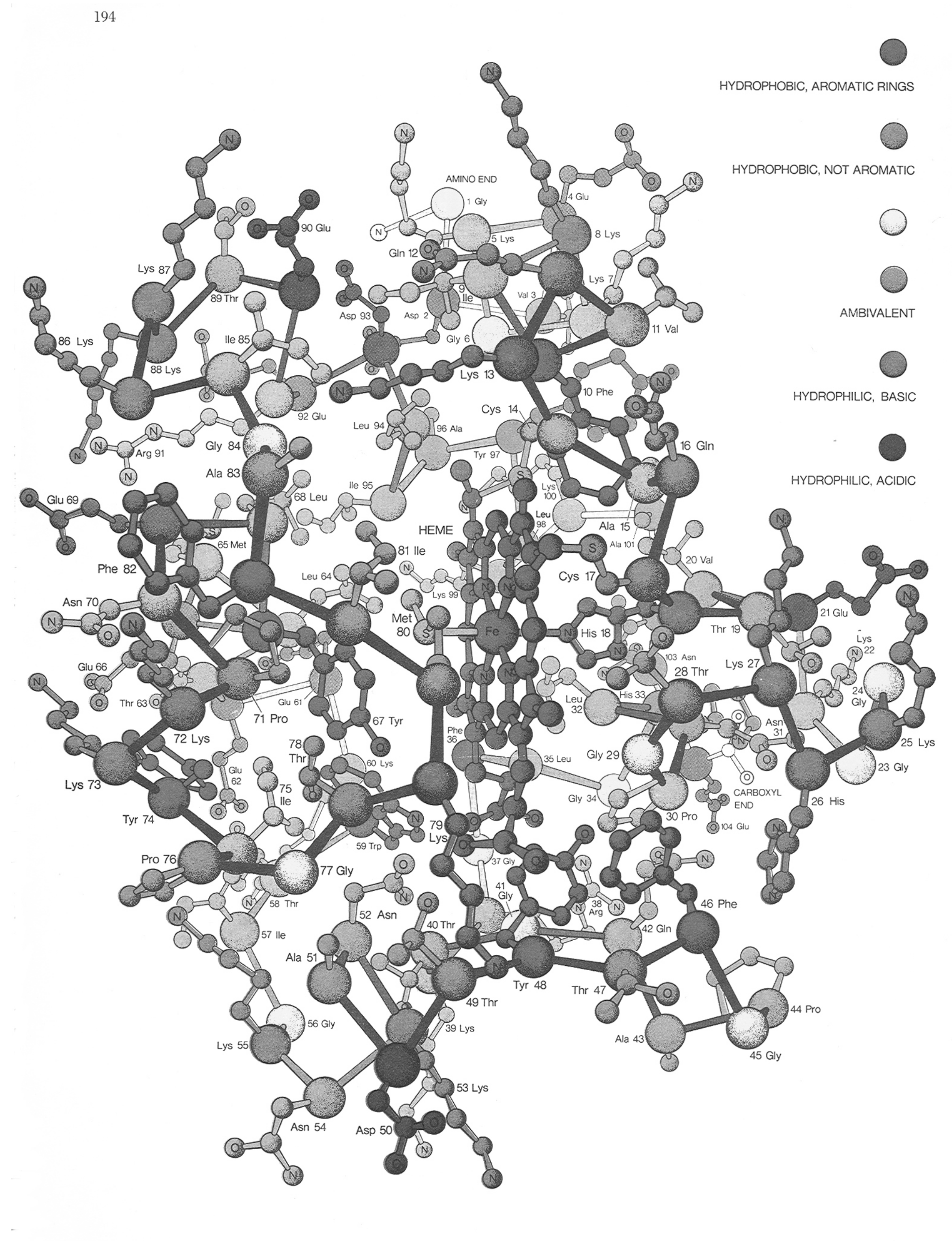
amino acids



protein

A complex protein:

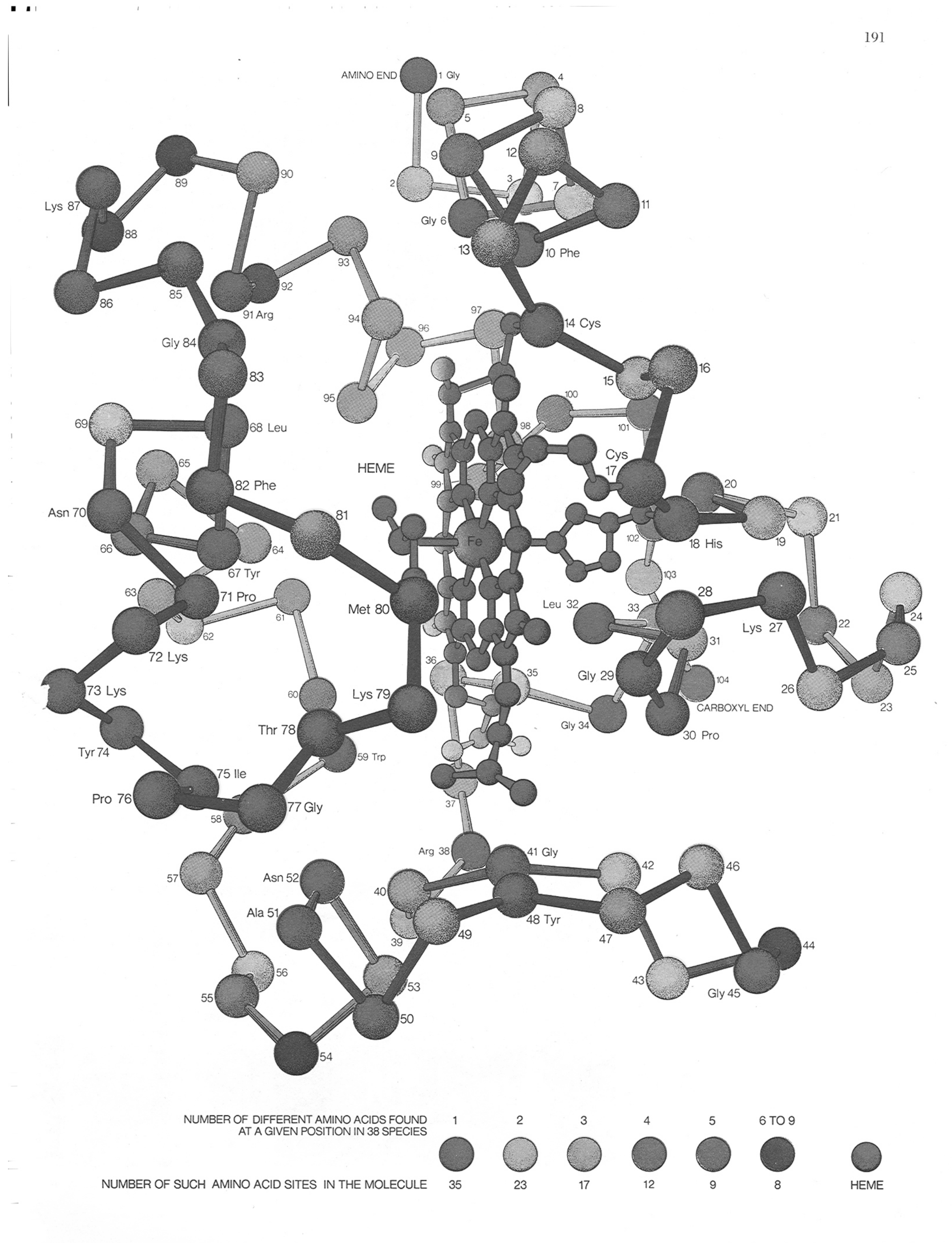
Involved in oxygen use Each circle is an amino acid



Stripped down view
Can you find the amino end and the carboxyl end?

Note the “heme”, containing iron.

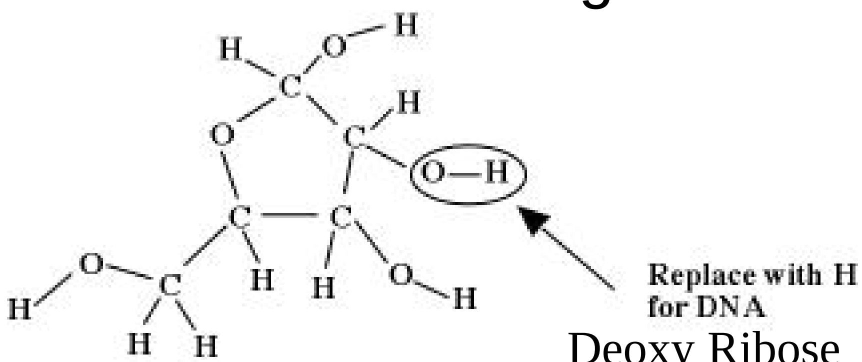
Function depends on structure, which depends on folding, which depends on order of amino acids



Nucleic Acids (DNA, RNA)

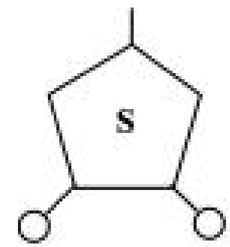
Made of sugars, phosphates, bases

Sugar



Deoxy Ribose

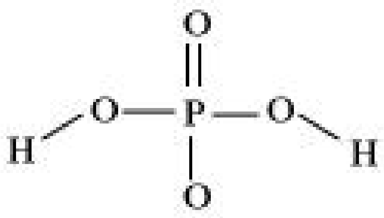
Schematic

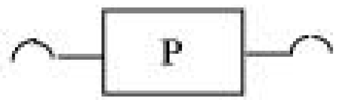


Ribose Sugar
5 C, 5 O, 10 H

Ribonucleic acid (RNA) uses ribose sugar;
Deoxyribonucleic acid (DNA) uses deoxyribose sugar

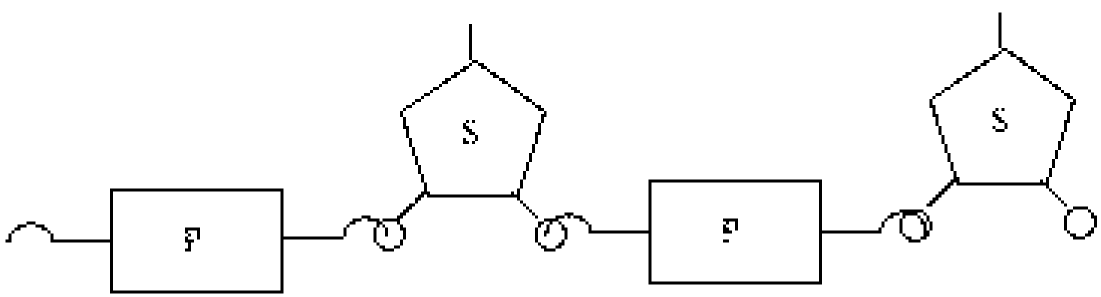
phosphate





sugars & phosphates linked

phosphodiester bonds

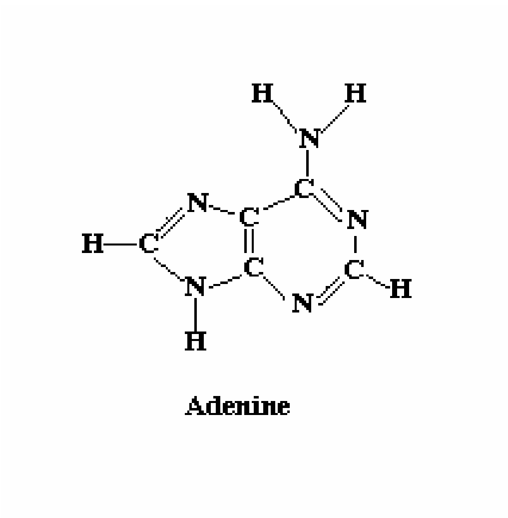


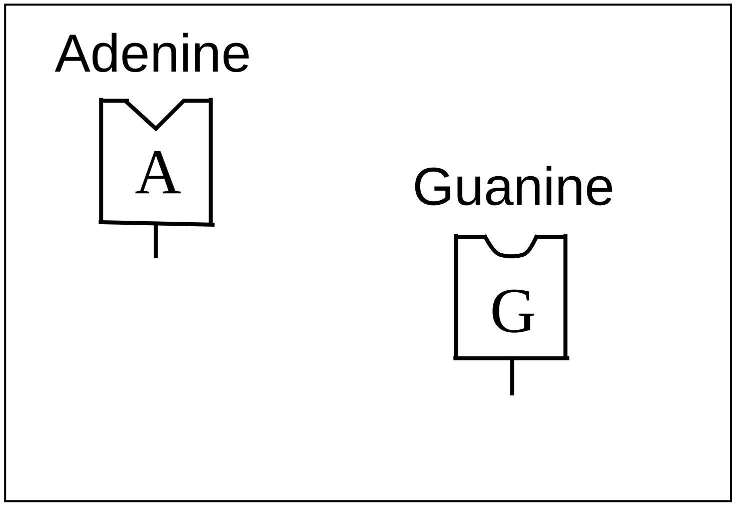
Segment of side of ladder structure

Nucleic Acids (cont.)

Bases: Carry Genetic Code

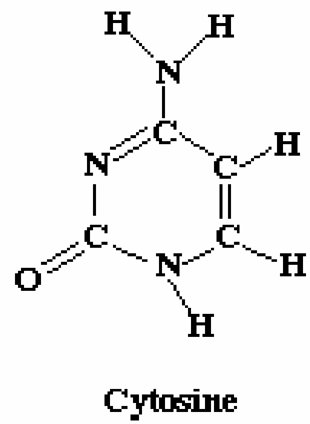
Purines



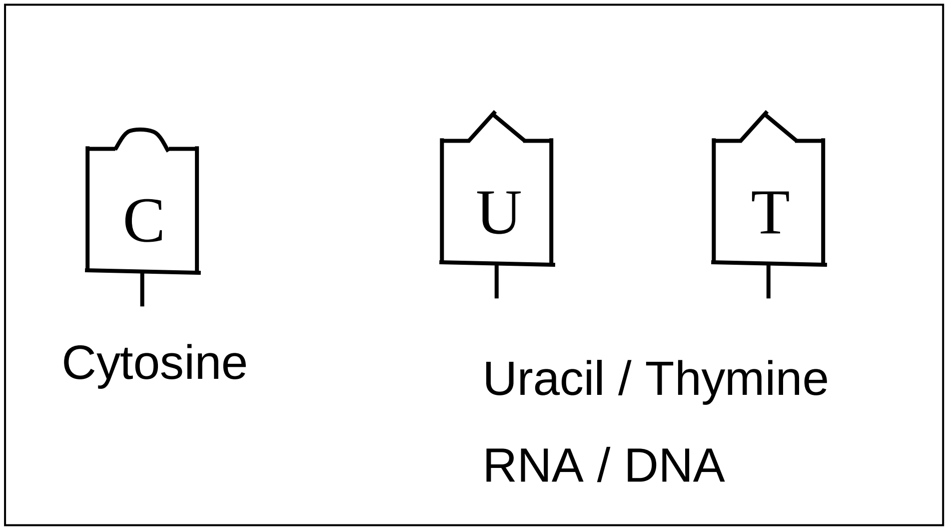


Equal numbers of C and N

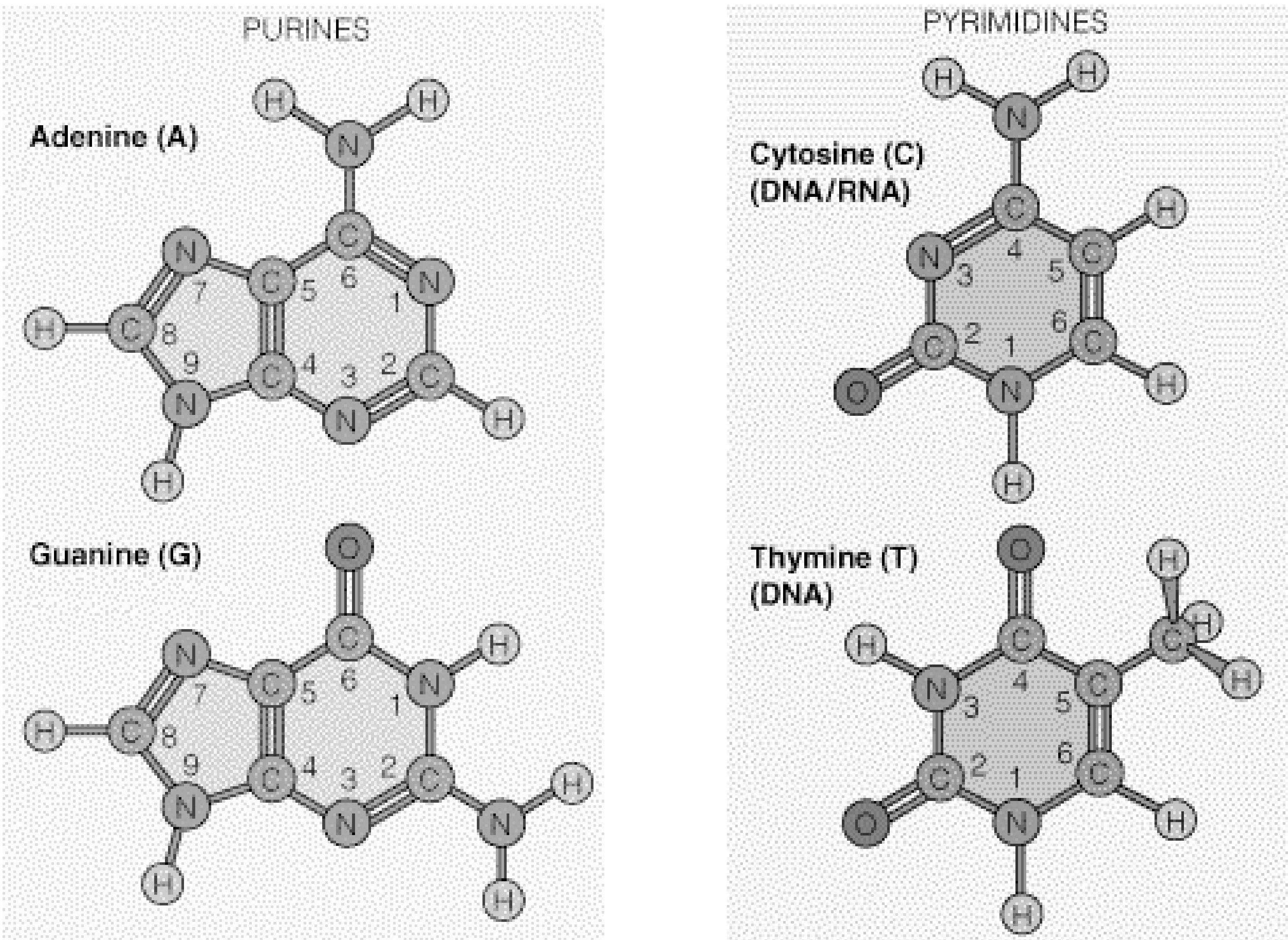
Pyrimidines

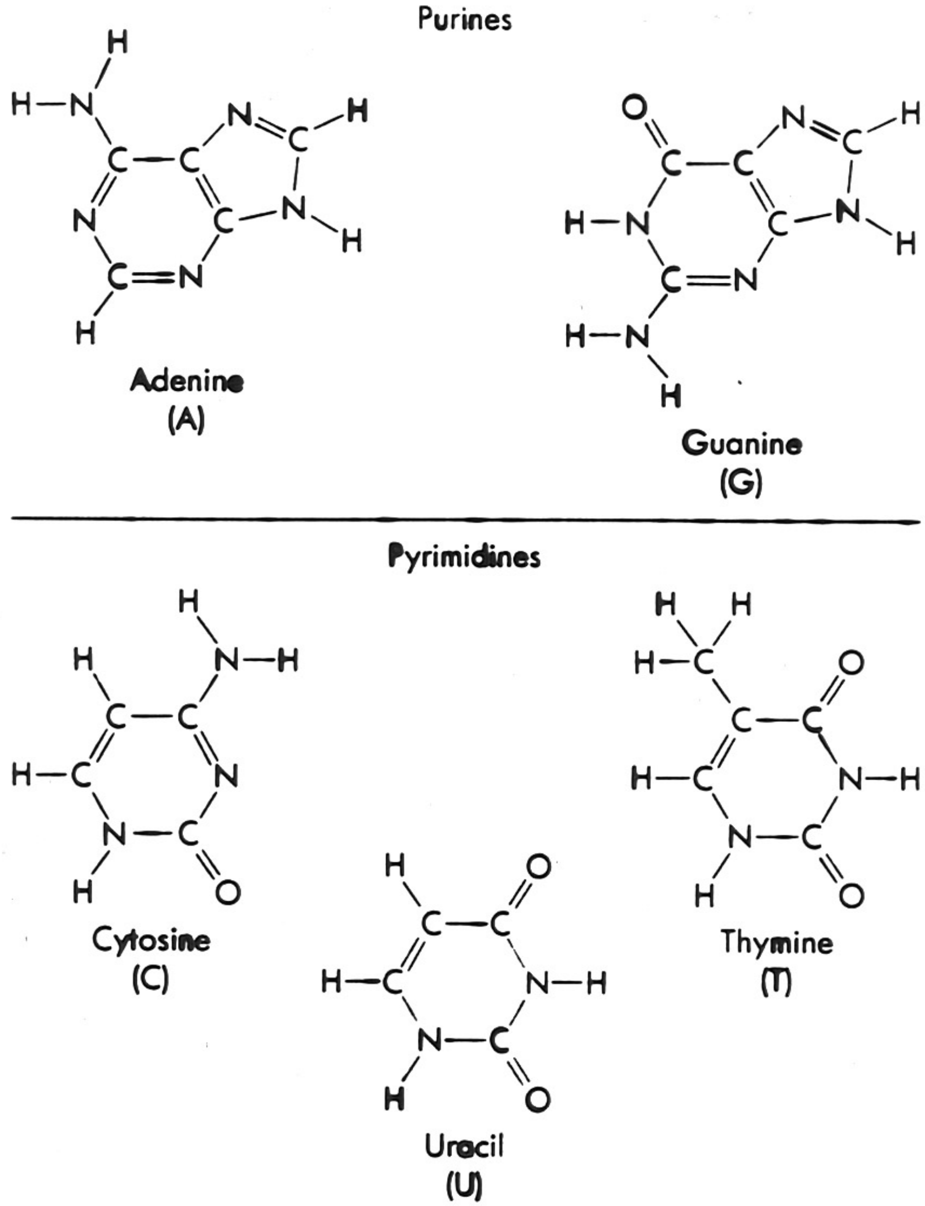


More C than N



Bases in Nucleic acids: Purines and Pyrimidines





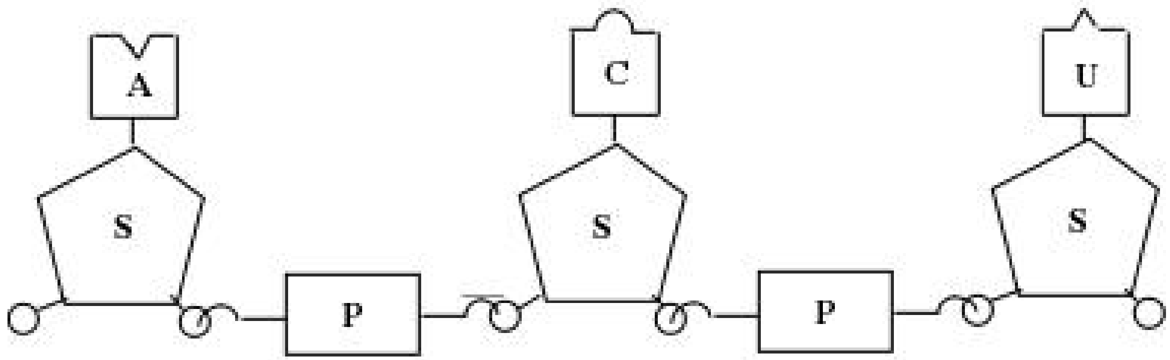
Purines

Pyrimidines

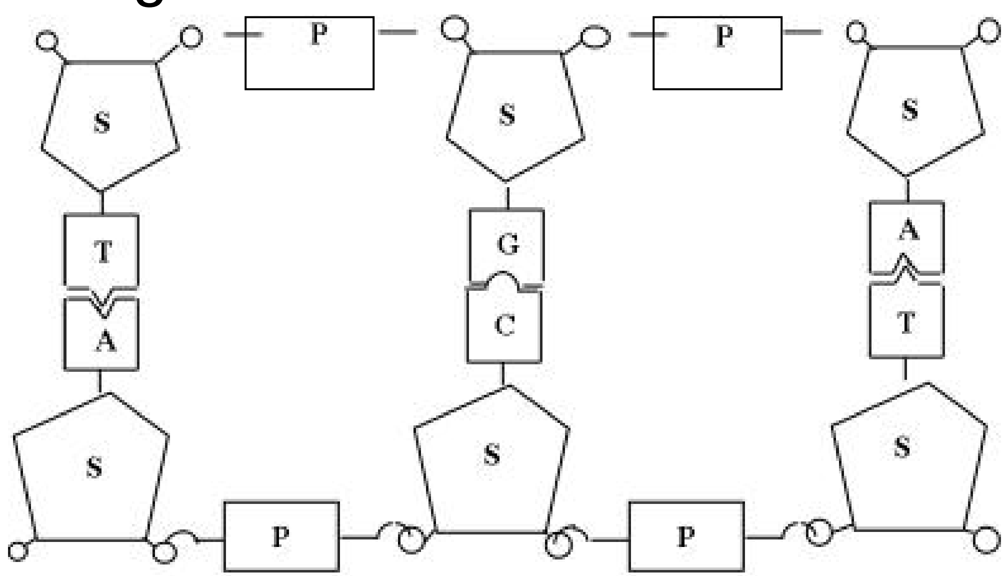
Note Uracil

Nucleic Acids (cont.)

Segment of RNA

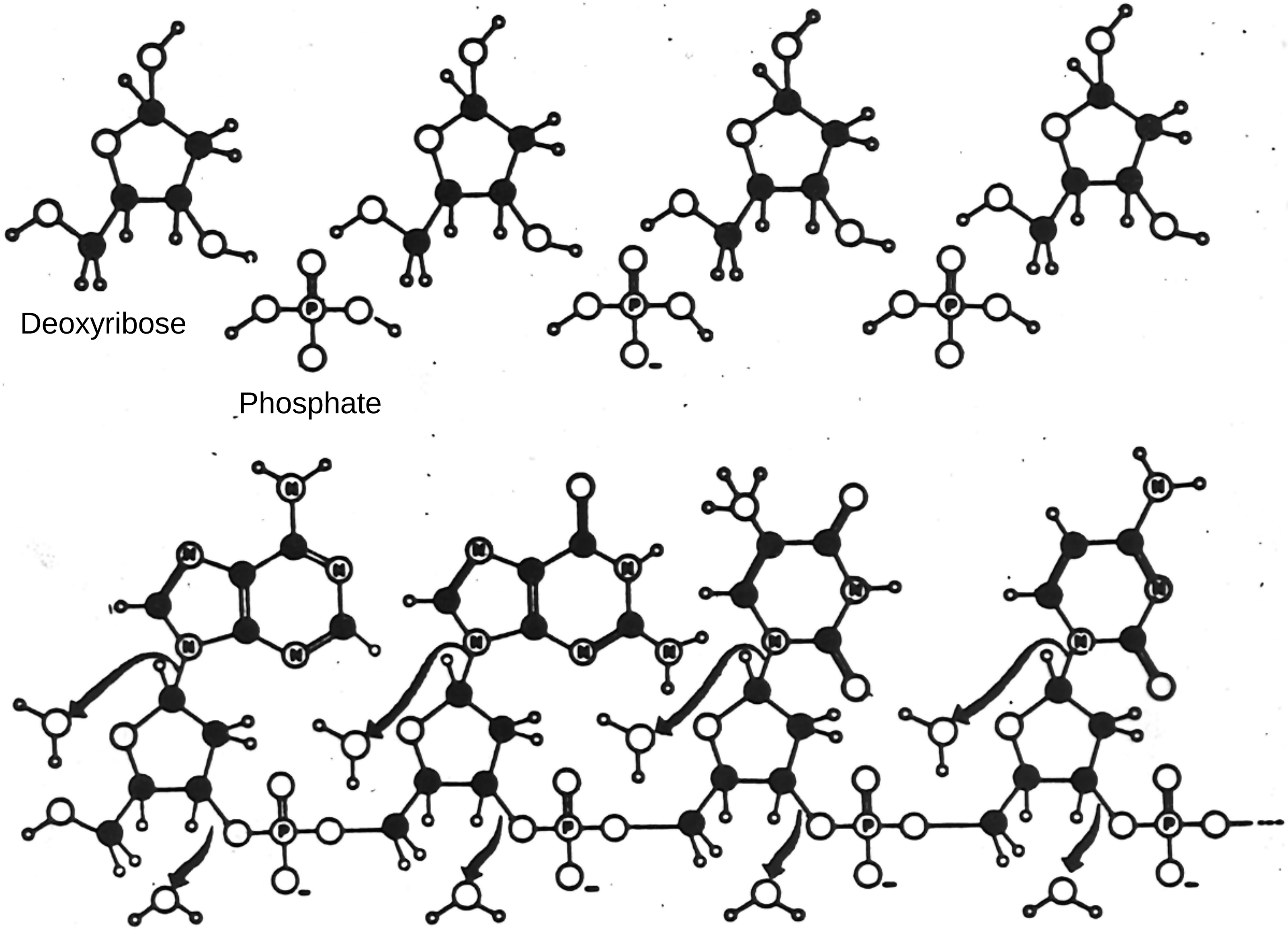


Segment of DNA

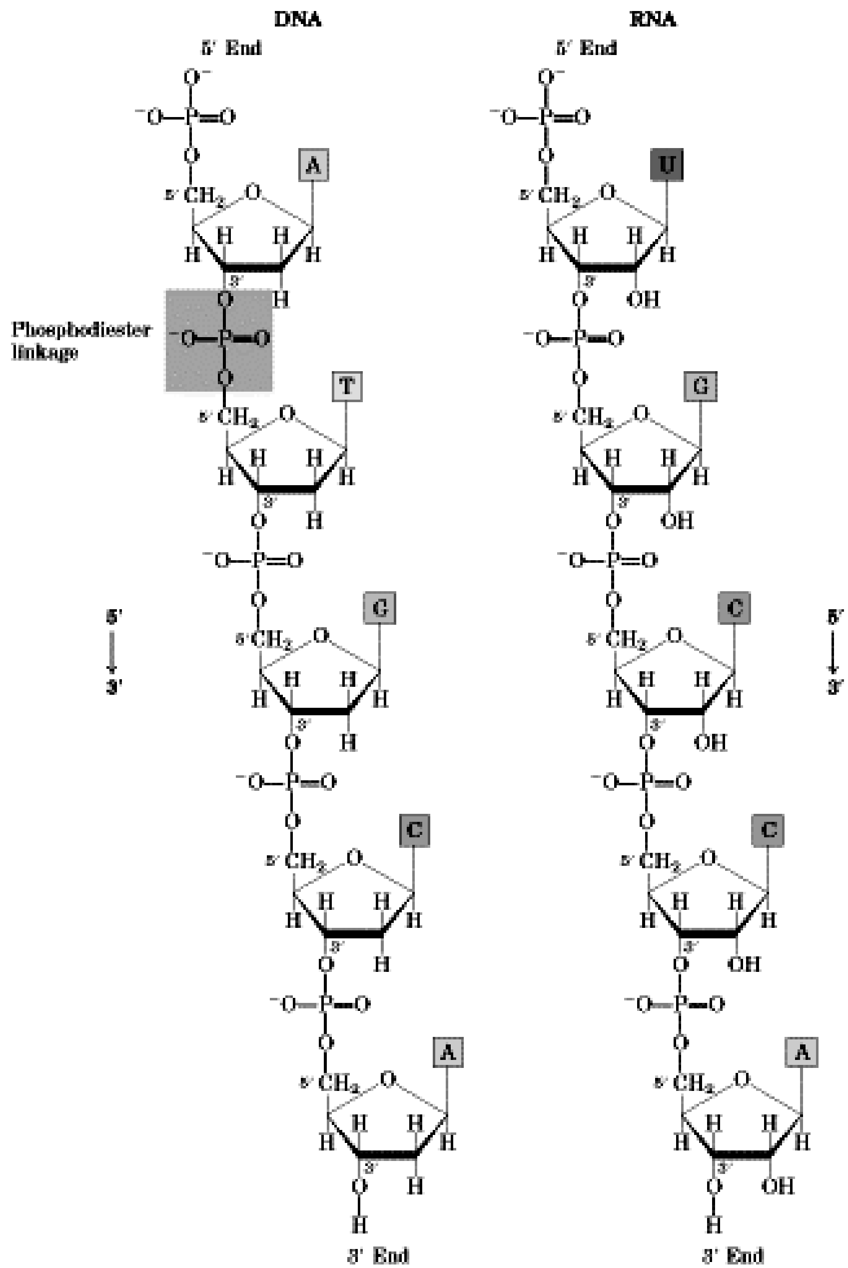


Note that T replaces U in DNA

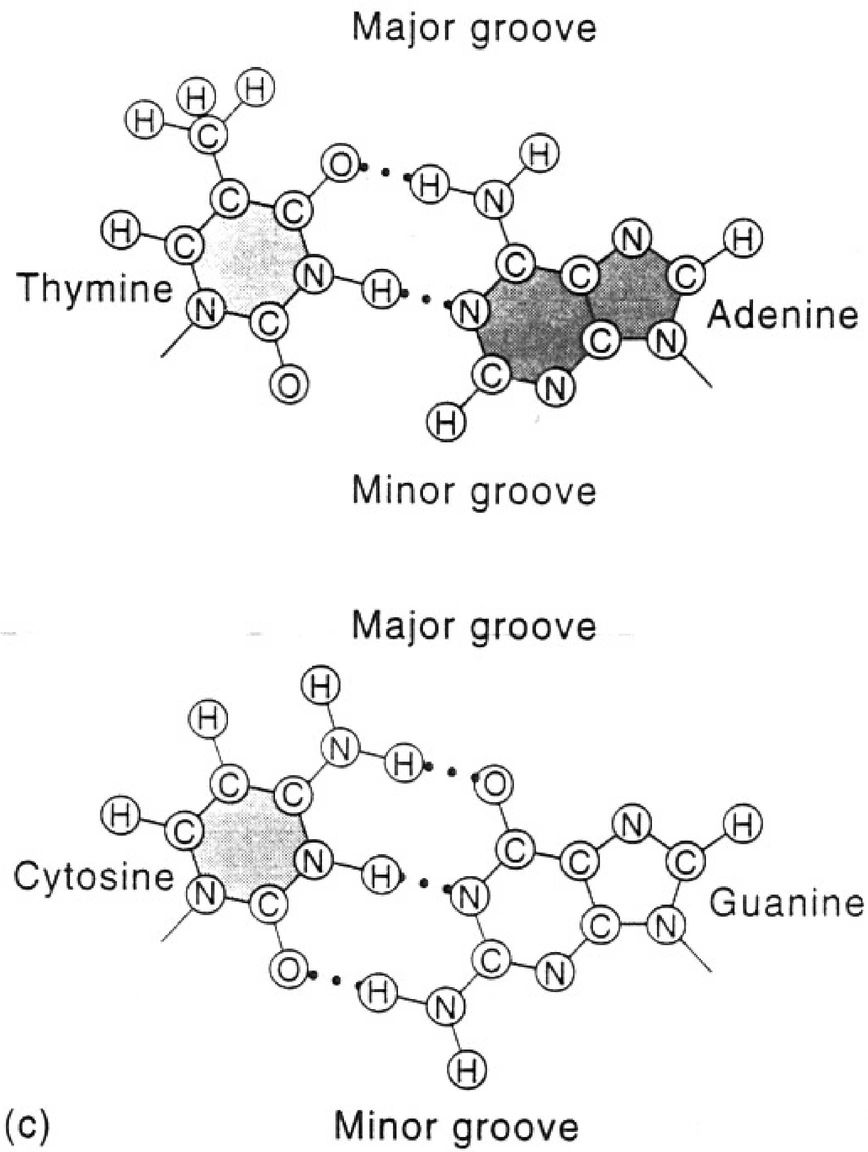
At the Chemical Level



Deoxyribonucleic Acid (DNA)

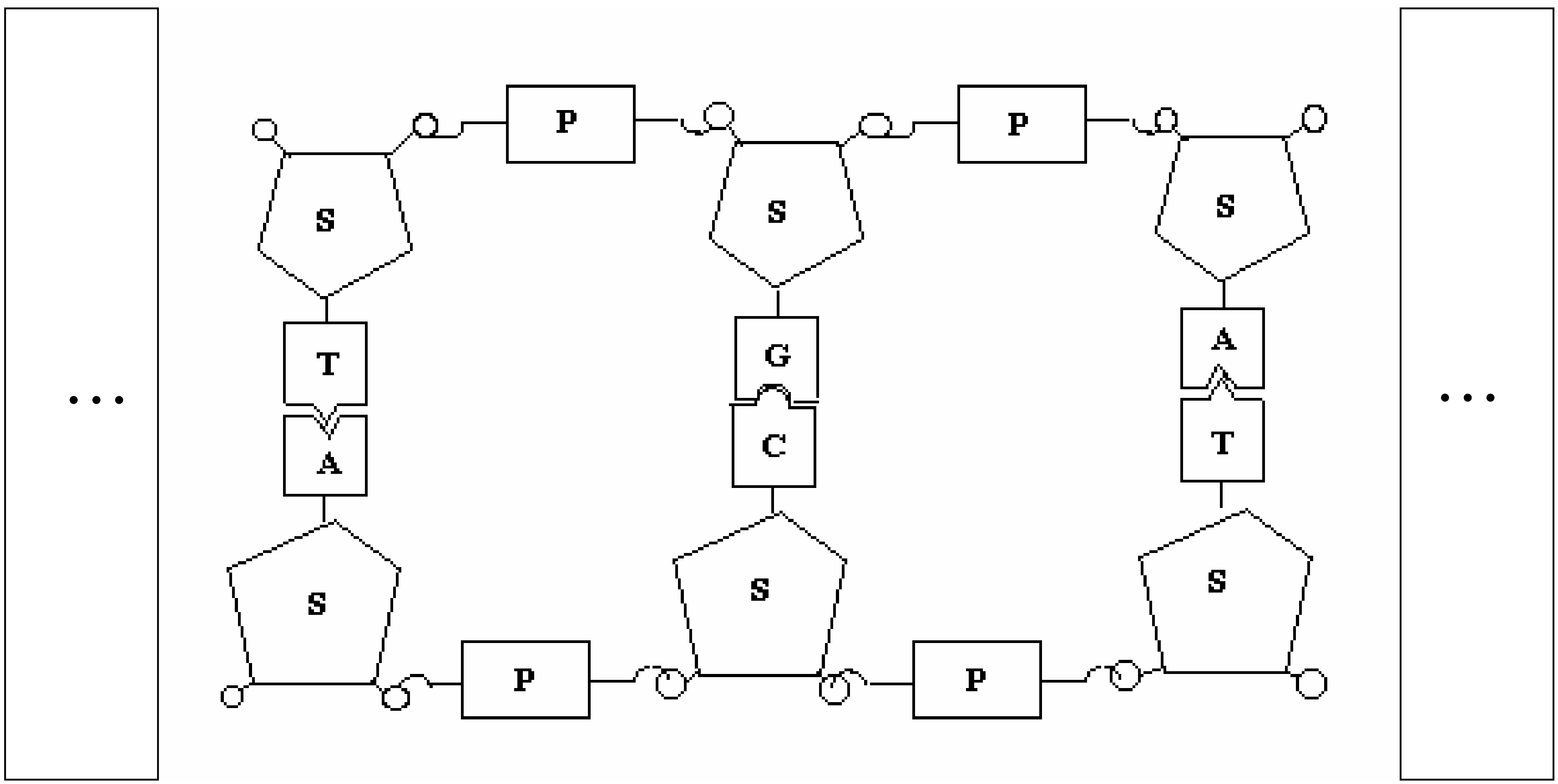

DNA
RNA
5′ End
3′ End
Phosphodiester linkage
5′
3′
A
T
G
C
U

Hydrogen Bonds (weak) connect the bases across the two sides of DNA

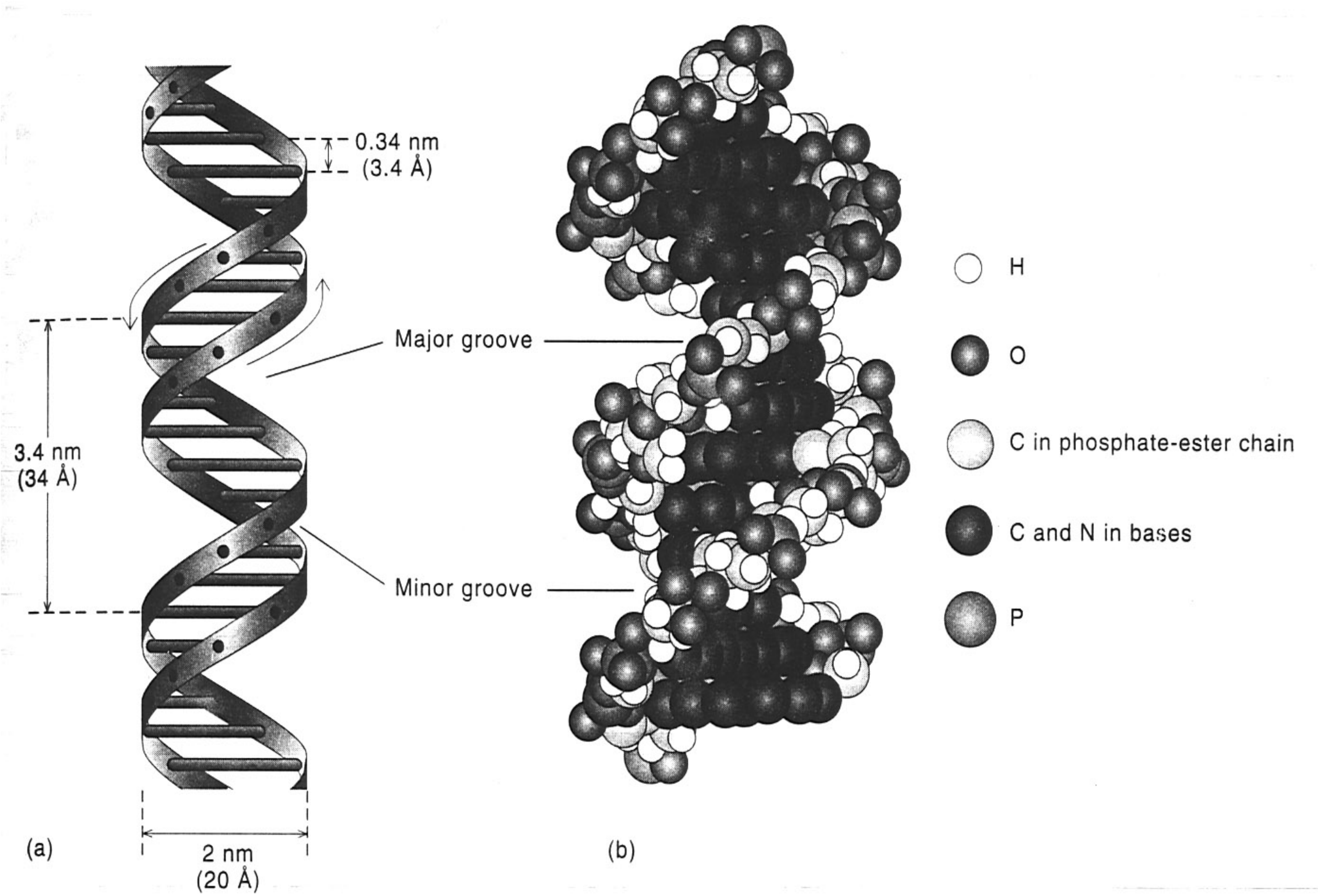


(c)

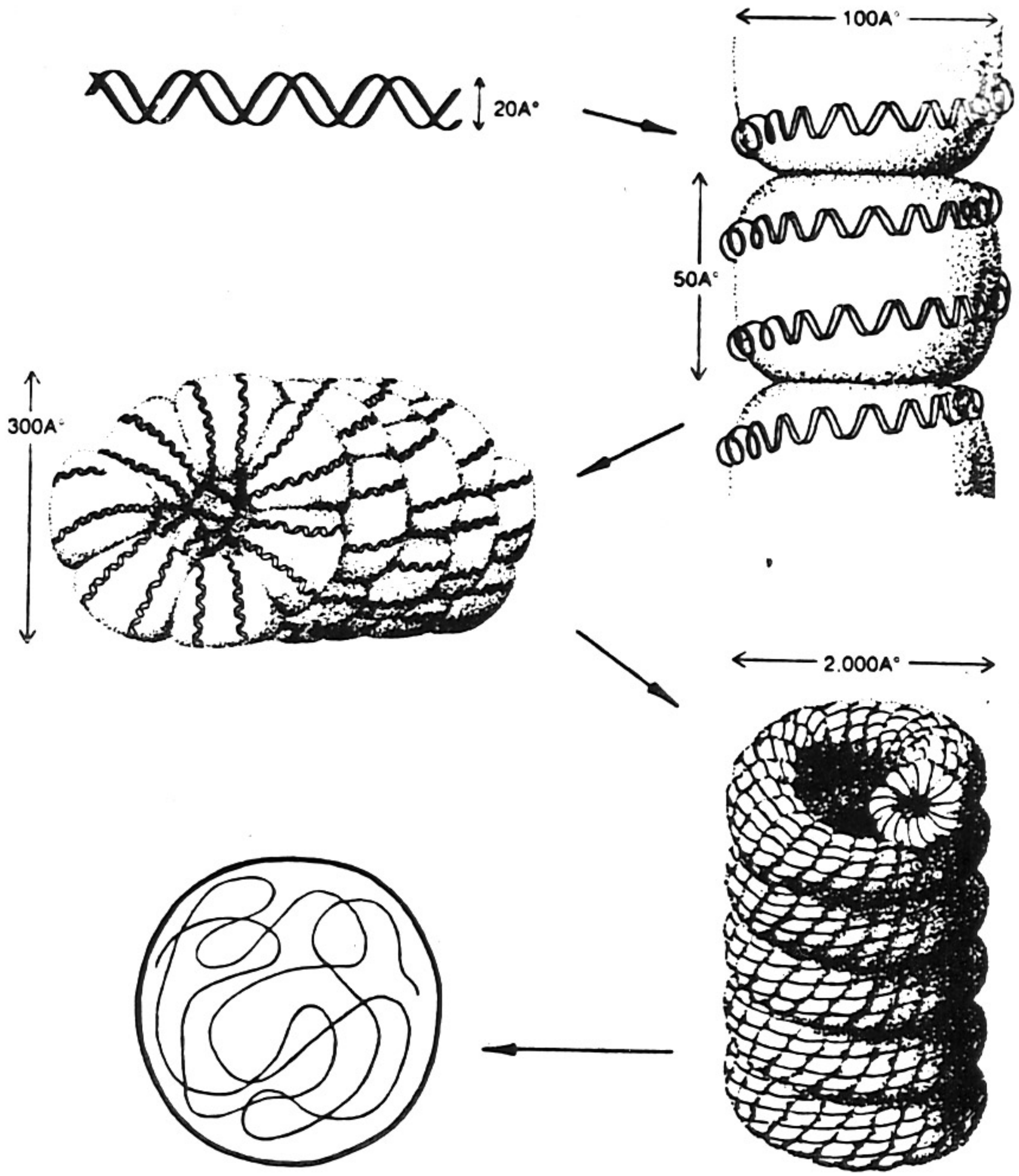
Segment of DNA



The two strands of DNA form a double helix, connected between bases by hydrogen bonds



Further wrapping to make compact chromosome



Information Storage

- Nucleic acids store information
- The information specifies proteins
- The information can be replicated
- This allows inheritance

Base pairing rules

A - T   G - C

- U

$\Rightarrow$ Replication of order (reproduction)

Nucleic Acid - Protein

↳ Genetic Code ↗

Codon

3 base sequence ⟶ Amino Acid

Gene

Sequence of codons ⟶ Protein

1 gene ⟶ 1 protein

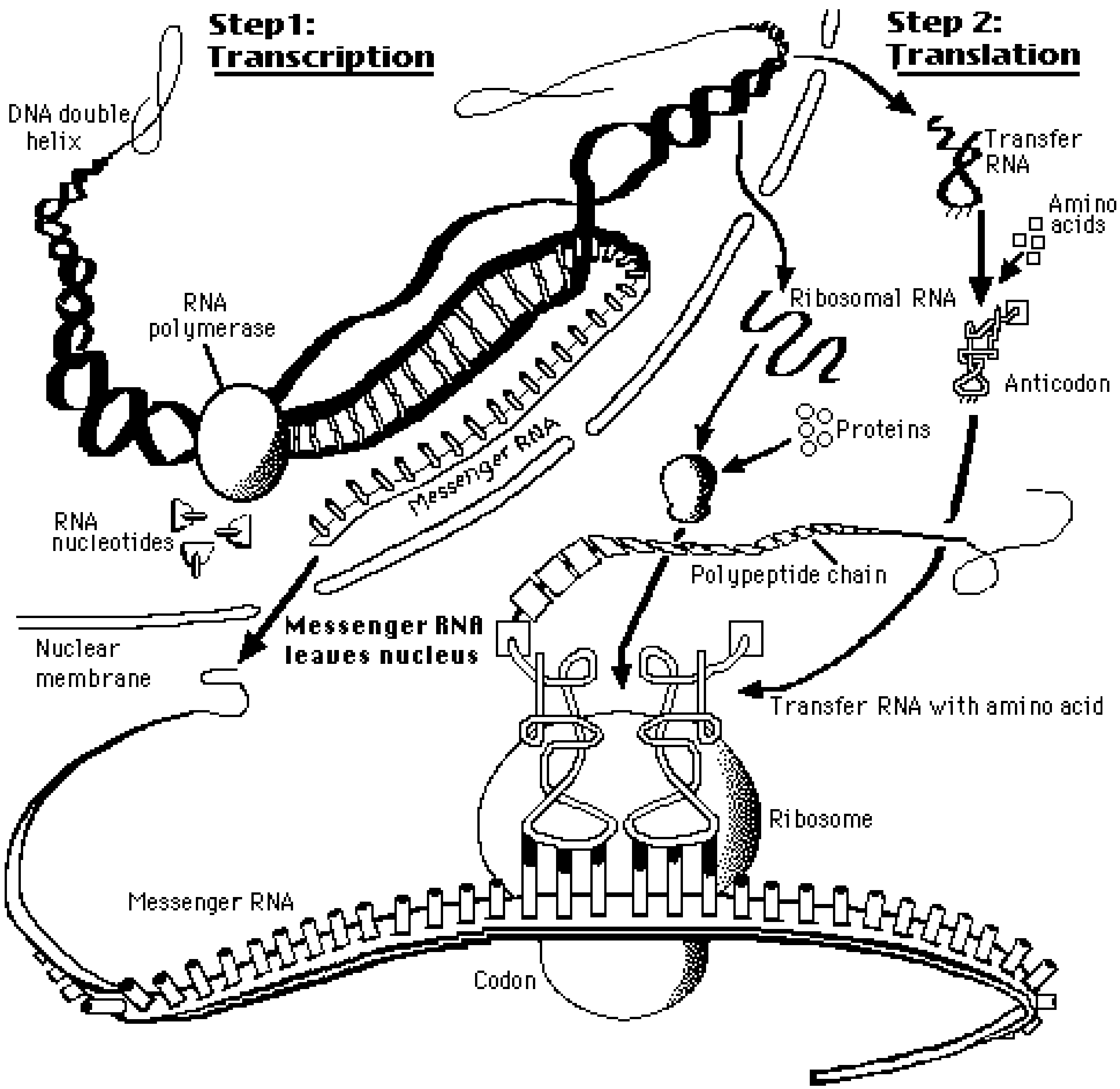
e.g.	tobacco mosaic virus	4 genes
	bacteria	~ 10^3 genes
	human cell	~ 25,000 genes (update)

For mRNA Genetic Code

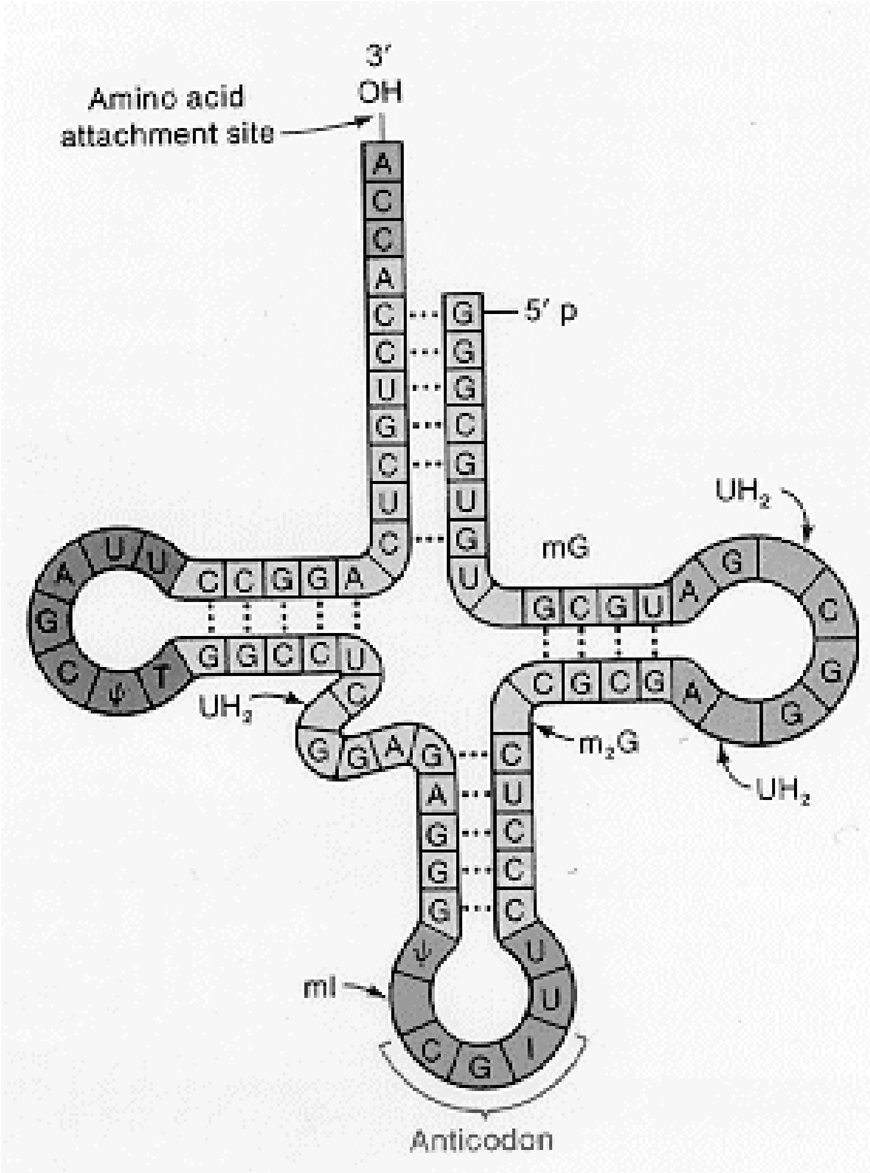
First RNA Base	U	C	A	G	Third RNA BASE
U	Phenylalanine	Serine	Tyrosine	Cysteine	U
	Phenylalanine	Serine	Tyrosine	Cysteine	C
	Leucine	Serine	Stop	Stop	A
	Leucine	Serine	Stop	Tryptophan	G
C	Leucine	Proline	Histidine	Arginine	U
	Leucine	Proline	Histidine	Arginine	C
	Leucine	Proline	Glutamine	Arginine	A
	Leucine	Proline	Glutamine	Arginine	G
A	Isoleucine	Threonine	Asparagine	Serine	U
	Isoleucine	Threonine	Asparagine	Serine	C
	Isoleucine	Threonine	Lysine	Arginine	A
	Start/Methionine	Threonine	Lysine	Arginine	G
G	Valine	Alanine	Aspartic Acid	Glycine	U
	Valine	Alanine	Aspartic Acid	Glycine	C
	Valine	Alanine	Glutamic Acid	Glycine	A
	Valine	Alanine	Glutamic Acid	Glycine	G

Amino Acids

PROTEIN SYNTHESIS



Structure of a tRNA



Video

- http://www.teachersdomain.org/9-12/sci/life/cell/proteinsynth/index.html

Variations in the Code

1. "Wobble" Bases

   The third base in a codon can sometimes vary.

tRNA	mRNA
U	A or G
G	C or U

Comparison to genetic code $\Rightarrow$ no change in amino acids

For mRNA Genetic Code

First RNA Base	U	C	A	G	Third RNA BASE
U	Phenylalanine	Serine	Tyrosine	Cysteine	U
	Phenylalanine	Serine	Tyrosine	Cysteine	C
	Leucine	Serine	Stop	Stop	A
	Leucine	Serine	Stop	Tryptophan	G
C	Leucine	Proline	Histidine	Arginine	U
	Leucine	Proline	Histidine	Arginine	C
	Leucine	Proline	Glutamine	Arginine	A
	Leucine	Proline	Glutamine	Arginine	G
A	Isoleucine	Threonine	Asparagine	Serine	U
	Isoleucine	Threonine	Asparagine	Serine	C
	Isoleucine	Threonine	Lysine	Arginine	A
	Start/Methionine	Threonine	Lysine	Arginine	G
G	Valine	Alanine	Aspartic Acid	Glycine	U
	Valine	Alanine	Aspartic Acid	Glycine	C
	Valine	Alanine	Glutamic Acid	Glycine	A
	Valine	Alanine	Glutamic Acid	Glycine	G

Amino Acids

2. Some organisms use slightly different codes, with one or more changes in codon translation.

   First seen in mitochondrial DNA.

   Now known in some nuclear DNA

   The code has evolved since the last common ancestor (But not much).

Summary

1. Atoms needed: H, C, O, N, small amounts of P (phosphorus), S (sulfur)

2. Two basic molecules needed for life: proteins, nucleic acids

3. Both are polymers - made of simpler monomers. The monomers function as words or letters of alphabet. Information is the key.

Summary (cont.)

4. Proteins and nucleic acids closely linked at fundamental level. Communicate through genetic code. All organisms have almost the same genetic code. It must have originated very early in evolution of life.

5. In present day organisms, protein synthesis must be directed by nucleic acids, but nucleic acid reading or replication requires enzymes (proteins). Chicken-Egg problem

Origin of Life: I
Monomers to Polymers

Synthesis of Monomers

Life arose early on Earth (within 0.7×10^9 y)

1. Conditions
   1. Liquid Water
   2. Reducing or Neutral Atmosphere
   3. Energy Sources

2. Originally thought atmosphere was

NH_3, CH_4, H_2O, H_2

Miller -Urey Experiment

Now Believe CO_2, H_2O, N_2

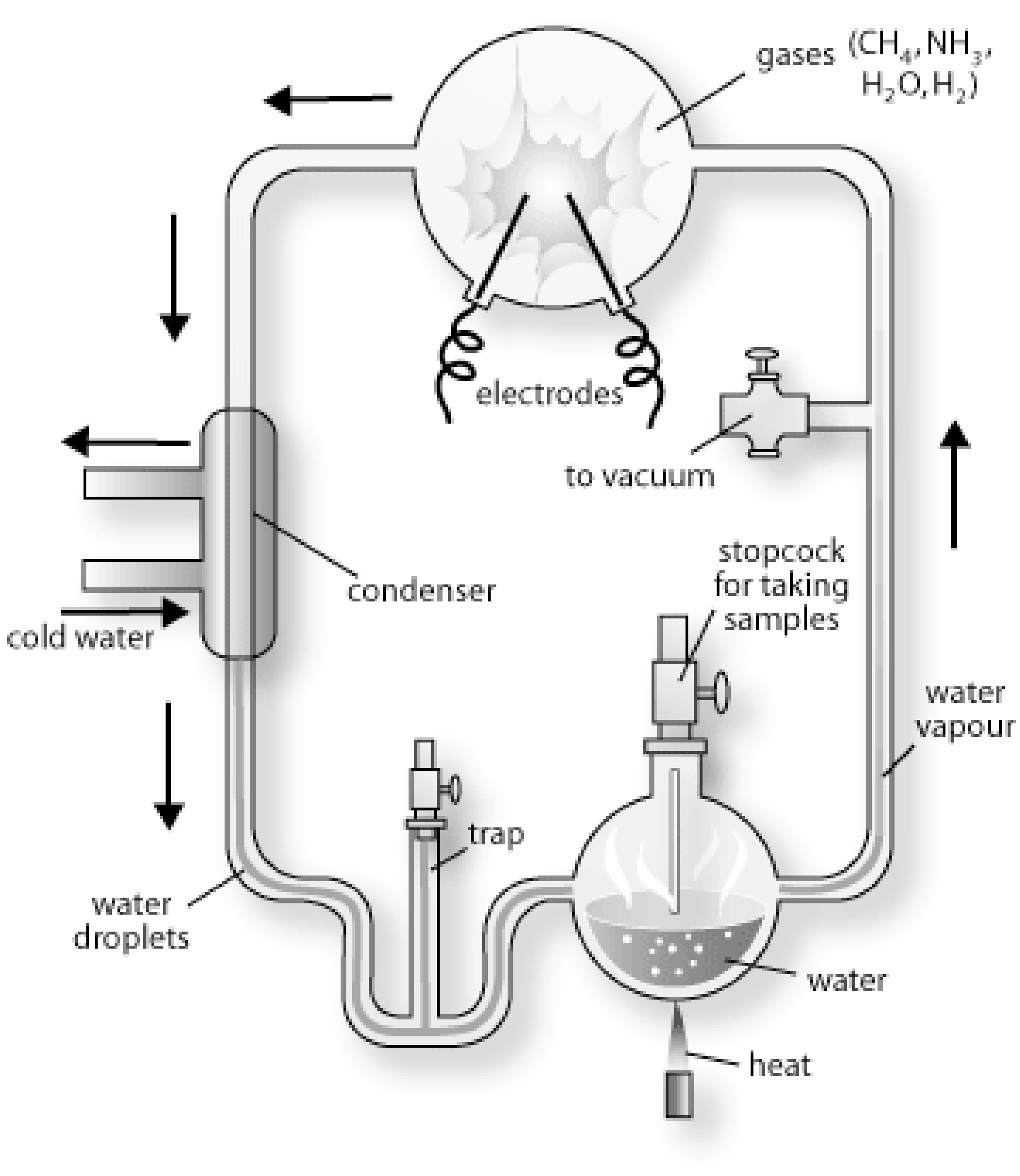
3. Energy Sources

Ultraviolet Light (No Ozone)

Lightning

Geothermal (Lava, Hot Springs, Vents, …)

Miller -Urey Experiment



COMPOUND	Relative Yield
Glycine	270
Sarcosine	21
Alanine	145
N-methylalanine	4
Beta-alanine	64
Alpha-amino-n-butyric acid	21
Alpha-aminoisobutyric acid	0.4
Aspartic acid	2
Glutamic acid	2
Iminodiacetic acid	66
Iminoacetic0propionic acid	6
Lactic acid	133
Formic acid	1000
Acetic acid	64
Propionic acid	56
Alpha-hydroxybutyric acid	21
Succinic acid	17
Urea	8
N-methyl urea	6

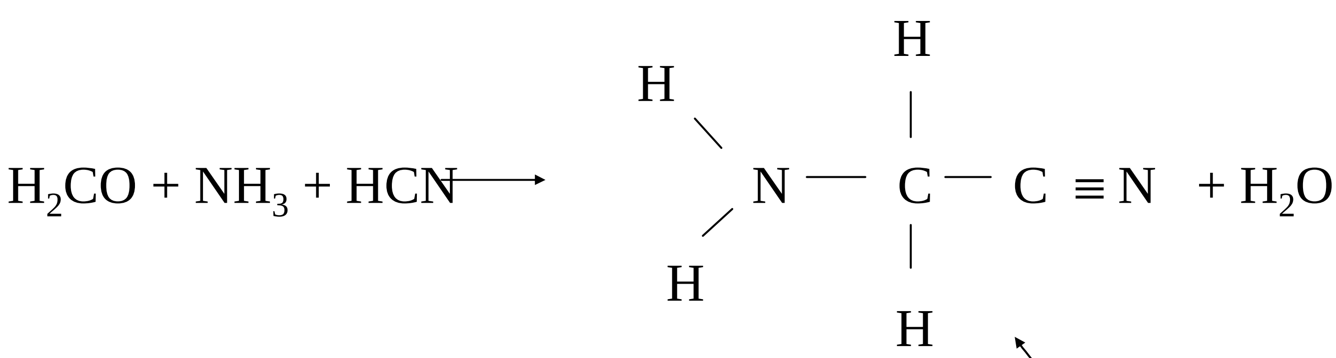
How did Amino Acids form in Miller -Urey Experiment?

Strecker Synthesis

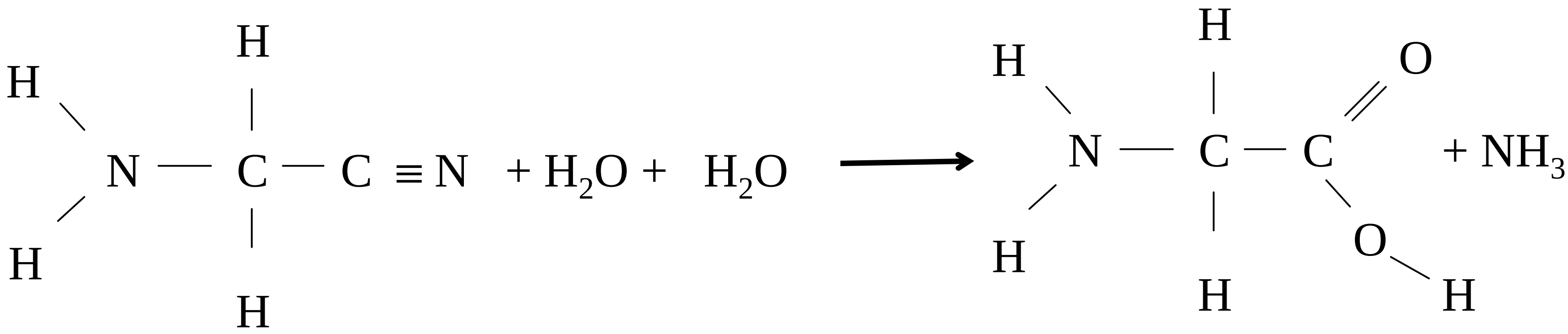
CH_4, H_2, NH_3 + Energy $\longrightarrow$ H_2CO, HCN, HC_3N, Urea (H_2NCONH_2)

e.g. Glycine Synthesis

Reactive

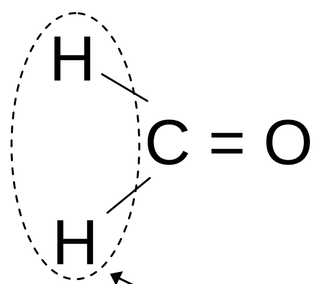


Aminoacetonitrile



glycine

H_2CO



form Aldehyde

More complex group - other aldehydes

↓

more complex amino acids

Lower yield if atmosphere was N_2, CO_2, H_2O

(If $H_2/CO_2 > 2$, get good yield)

Problems with Miller - Urey

Atmosphere was N_2, CO_2, H_2O

NH_3, CH_4 would react $\longrightarrow$ N_2, CO_2

Try N_2, CO_2, H_2O in Miller - Urey simulation

Only get trace amounts of glycine
Need CH_4 to get more complex amino acids

Need $H_2/CO_2 > 2$ to get much of any amino acid

Miller - Urey with Cosmic Rays

A group in Japan has obtained good yields of amino acids from slightly reducing gases (CO_2, CO, N_2, H_2O)

When they used high energy protons (simulate cosmic rays)

Apparently not Strecker Synthesis (Low abundance of aminoacetonitrile)

Building Blocks of Nucleic Acids

Not formed in Miller - Urey But some intermediates were

1. Ribose Sugar:

   $5\ H_2CO + \text{Heat} \longrightarrow H_{10}C_5O_5$

   [Clay Catalyst]

2. Bases

   a) Purines $5\ HCN \rightarrow H_5C_5N_5$ (Adenine)

   b) Pyrimidines

   $HC_3N + \text{Urea} \longrightarrow H_5C_4N_3O$ (Cytosine)

   (1995) Cyanoacetaldehyde + Urea $\longrightarrow$ Uracil

3. Phosphate

Rock Erosion

Less understood than amino acids

Other Possibilities:

Seafloor Vents

Interstellar Molecules

Comets

Alternative Delivery

Molecular clouds - strongly reducing, contain many molecules used in Miller-Urey (H_2, NH_3, H_2O, CH_4) and intermediates (HCN, H_2CO, HC_3N) and possibly glycine

Problem: These would not have survived in part of disk where Earth formed

But interstellar ices ⟶ comets

Evidence from similar molecules

(e.g. C_2H_2, CH_4, HNC, …)

Clearly indicates interstellar chemistry

Cratering record on moon, …

$\Rightarrow$ heavy bombardment early in history

Comets and their debris could have brought large amounts of “organic” matter to Earth

(and maybe oceans)

Some evidence for non-biological amino acids in layer depostied after asteroid impact 65 million years ago

Sources of Organic Molecules

Quantitative comparison by Chyba & Sagan, Nature 1992, Vol. 355, p. 125

Currently, Earth accretes ~ 3.2×10^6 kg y^{-1} from interplanetary dust particles (IDP)

~ 10 % organic carbon $\Rightarrow 3.2 \times 10^5$ kg y^{-1}

~ 10^3 kg y^{-1} comets

~ 10 kg y^{-1} meteorites

~ $10^3 \times$ more at 4.5×10^9 yr ago (?)
(cratering record)

UV + reducing atmosphere 2×10^{11} kg y^{-1}

But if $H_2/CO \lesssim 0.1$ IDP's dominant source

Alternative Sites

Locally reducing environments

1. Ocean vents

   Sources of CH_4 and H_2S

   Current Vents have ecosystems based on energy from chemicals - not photosynthesis

   $H_2S \longrightarrow$ Bacteria $\longrightarrow$ Clams, Tube Worms

   Pre-biotic amino acid synthesis?

2. Inside Earth

Many bacteria now known to live deep (~ 2 miles) in Earth. Again, on chemicals, adapted to high temperature genetic makeup very ancient

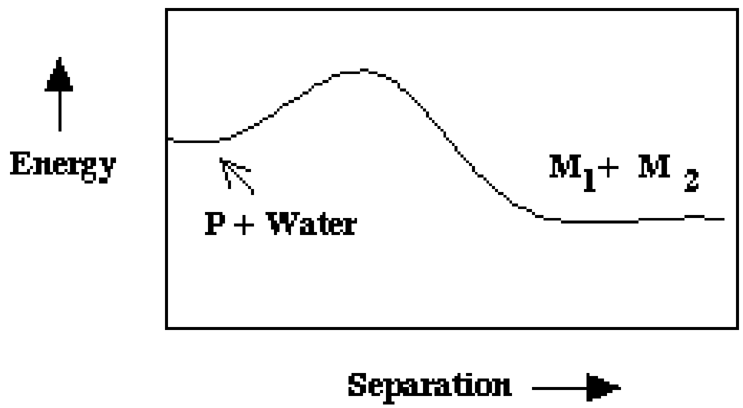
3. Hot Springs

Bacteria may be important in precipitating minerals. again adapted to high T and ancient

Synthesis of Polymers

$M_1 + M_2 \longrightarrow P + H_2O$

$\longleftarrow$ more likely in liquid H_2O



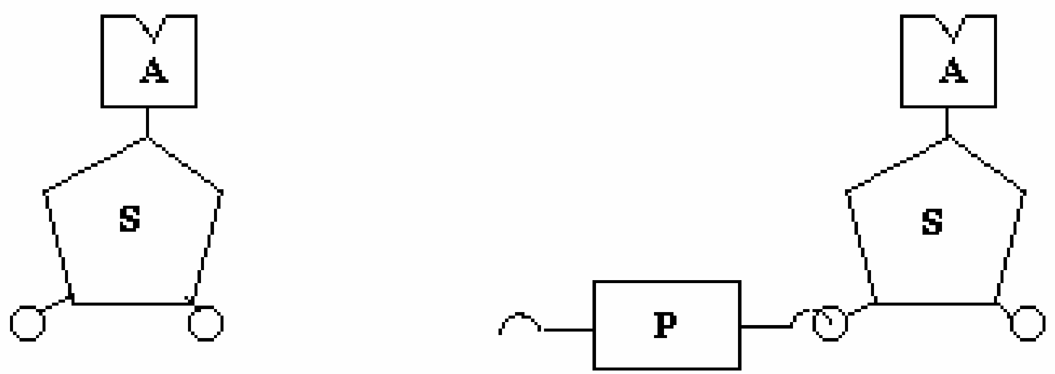
Solutions — Remove H_2O (Drying, Heat)

Sydney Fox $\longrightarrow$ Proteinoids

Energy Releasing Reactions (H_2NCN or HC_3N)

Catalysts: Clays

Problem is worse for Nucleic acids because more complex



nucleoside

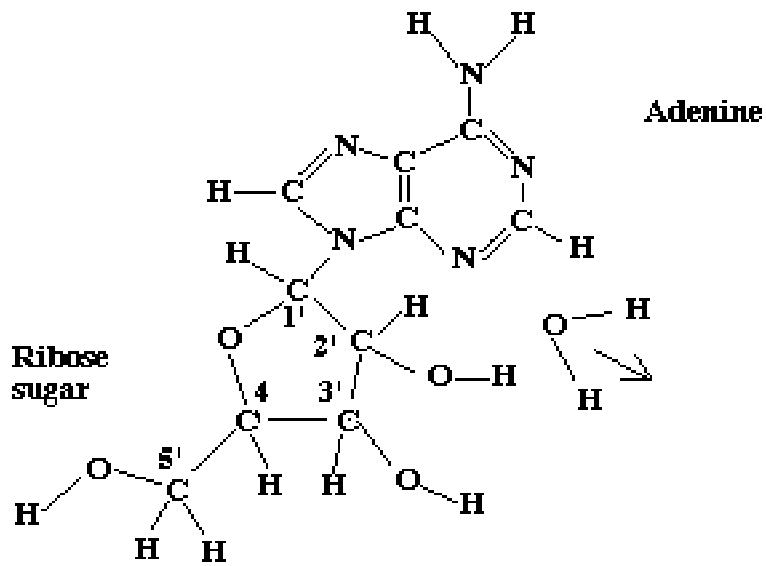
nucleotide

↑

Monomers of nucleic acids

Synthesis of Adenosine

Base on 1' Carbon (Why?)

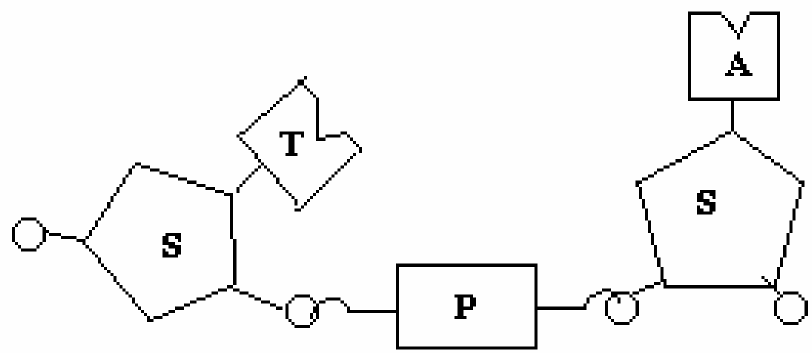


Adenine + ribose sugar ⟶ adenosine + H_2O

Also phosphates 3' & 5' carbons

Otherwise

Misalignment



Leslie Orgel has had some success in getting high percentage of correct linkages, in presence of Zinc ions.

Experimental Results

Sugar + base + heat yield some nucleosides

Activated nucleosides + phosphoric acid + Zn^{+2}

Get polymers up to 50 nucleotides in length

linkages (mostly) correct