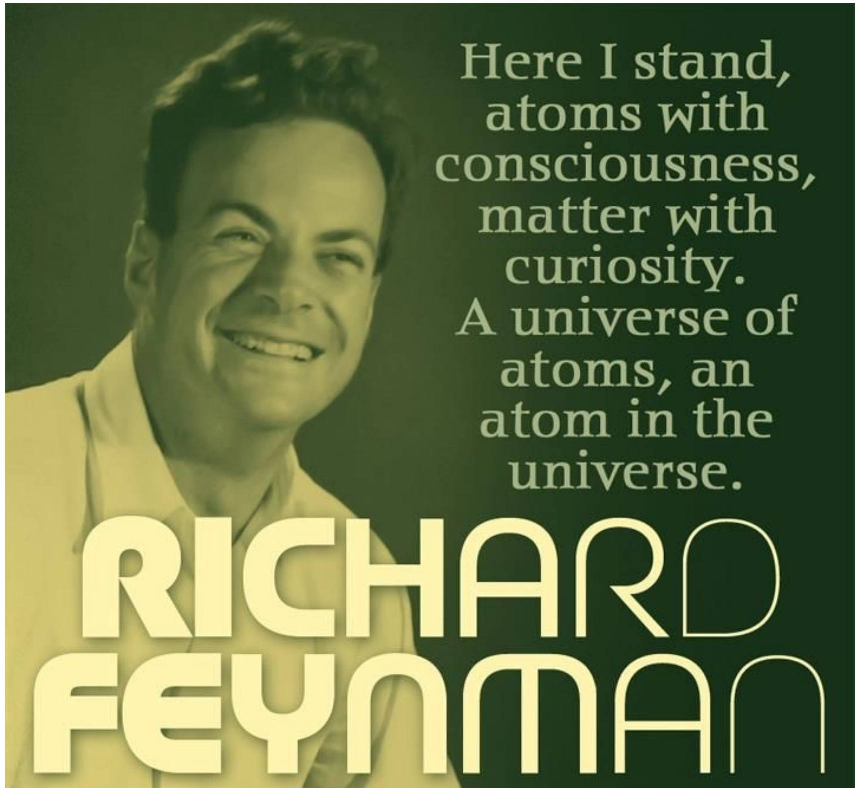
Fundamental Units of Life

Lecture 3



SURELY YOU MUST BE JOKING MR FEYNMAN

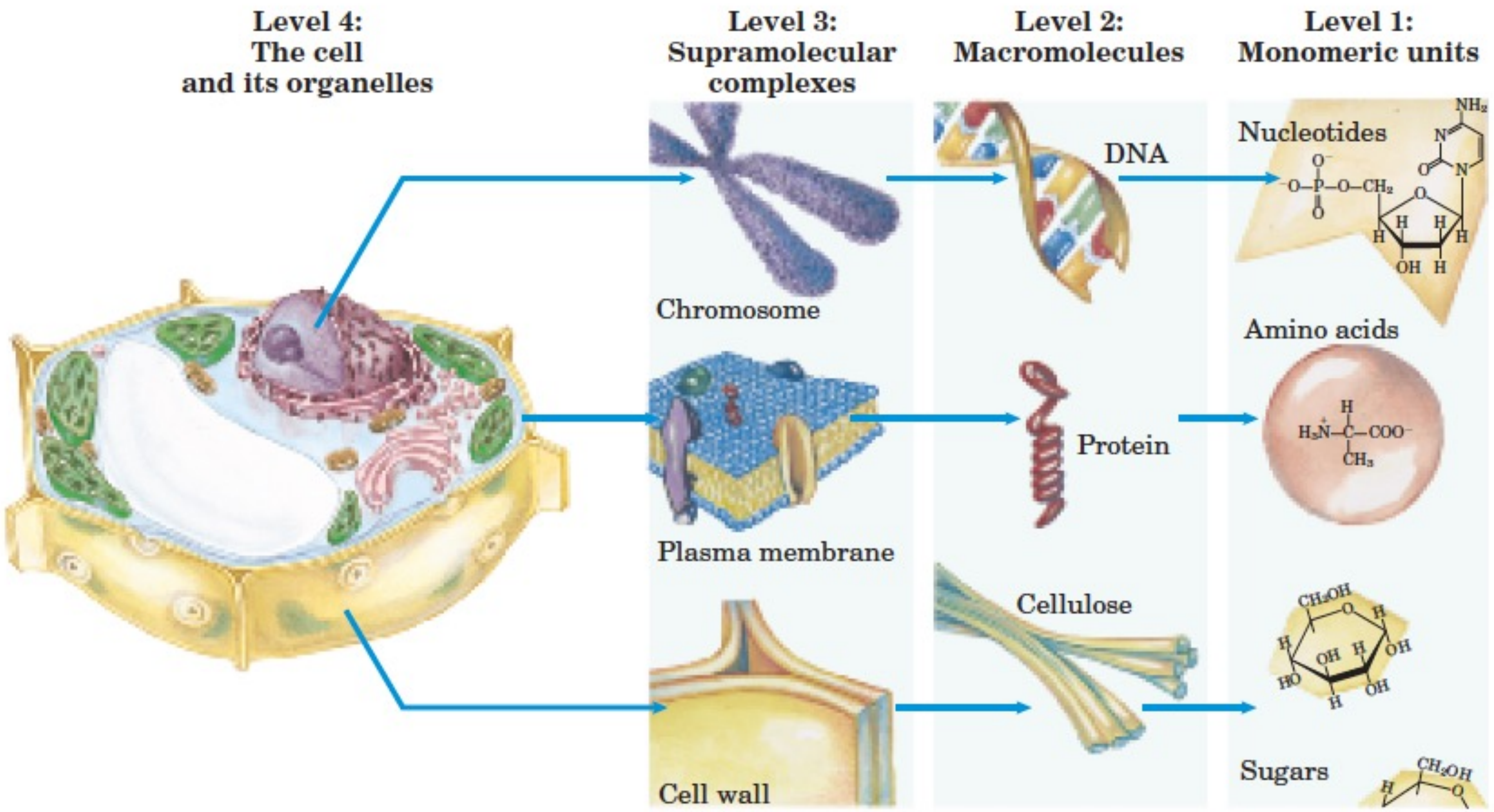
“Life is an emergent, rather than an inherent, property of matter. Although it arises from the material world, it cannot be reduced to it”

All organisms are like a machine; while a machine implies a machine maker, an organism is a self-organizing entity

Outline of the lecture

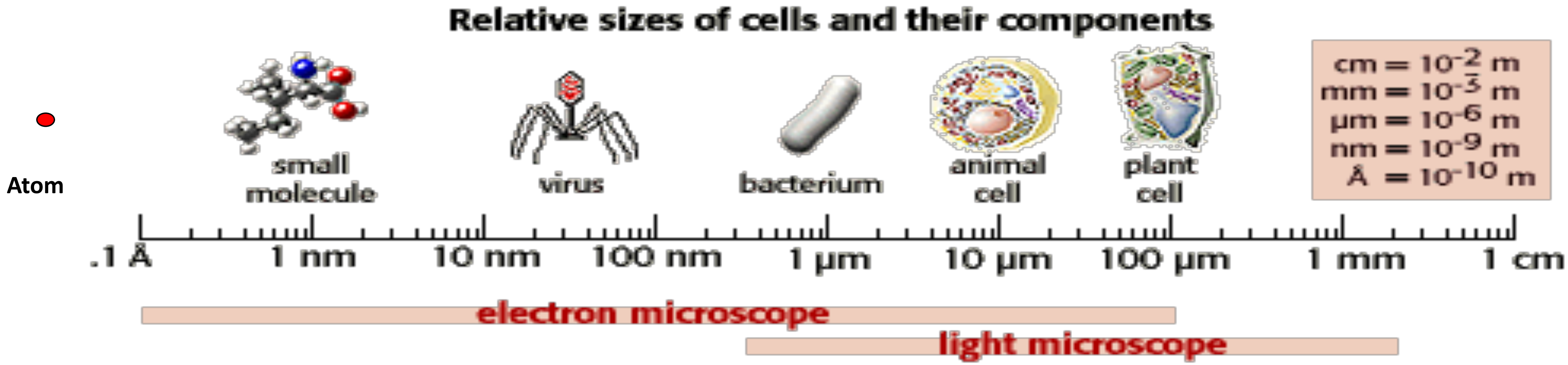
Objective: to learn about the main biomolecules that are part of the building blocks of cells

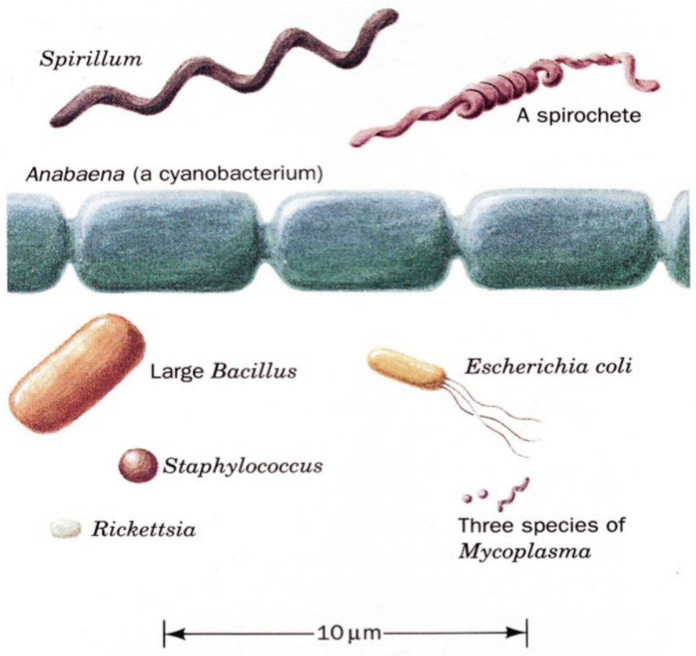
- Carbohydrates and Lipids – cell structure
- Amino acids – proteins
- Nucleotides – DNA and RNA



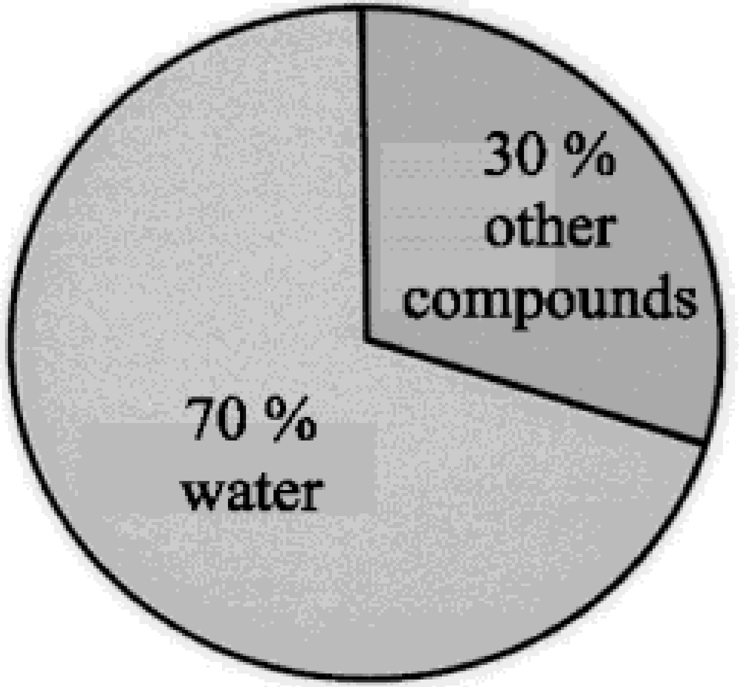
Look at some applications

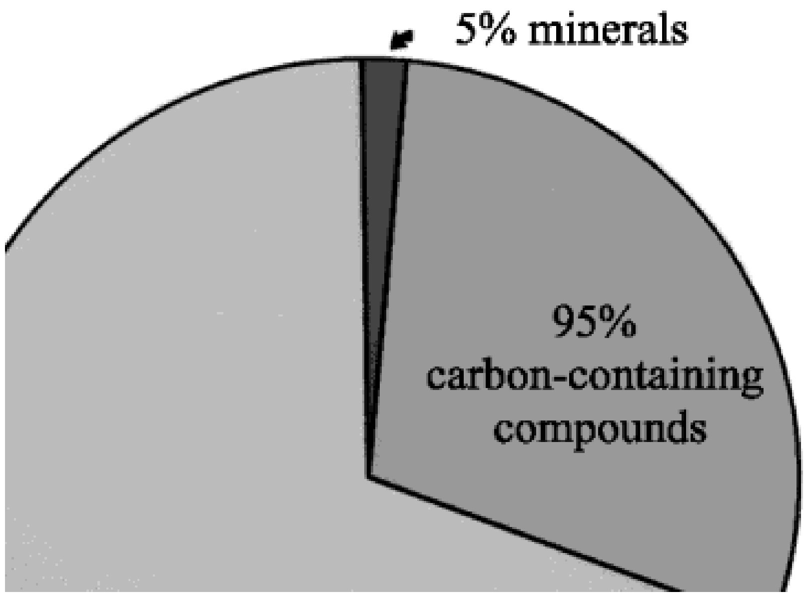
Sizes of Things





Chemical composition of the cell, the main biogenic elements.





- The bulk of cell's mass is made up by water

- Carbon containing compounds are degraded to CO_2 and H_2O by combustion, mineral compounds remain

Fatty Acids

Saturated fatty acids are relatively simple lipids with the general formula

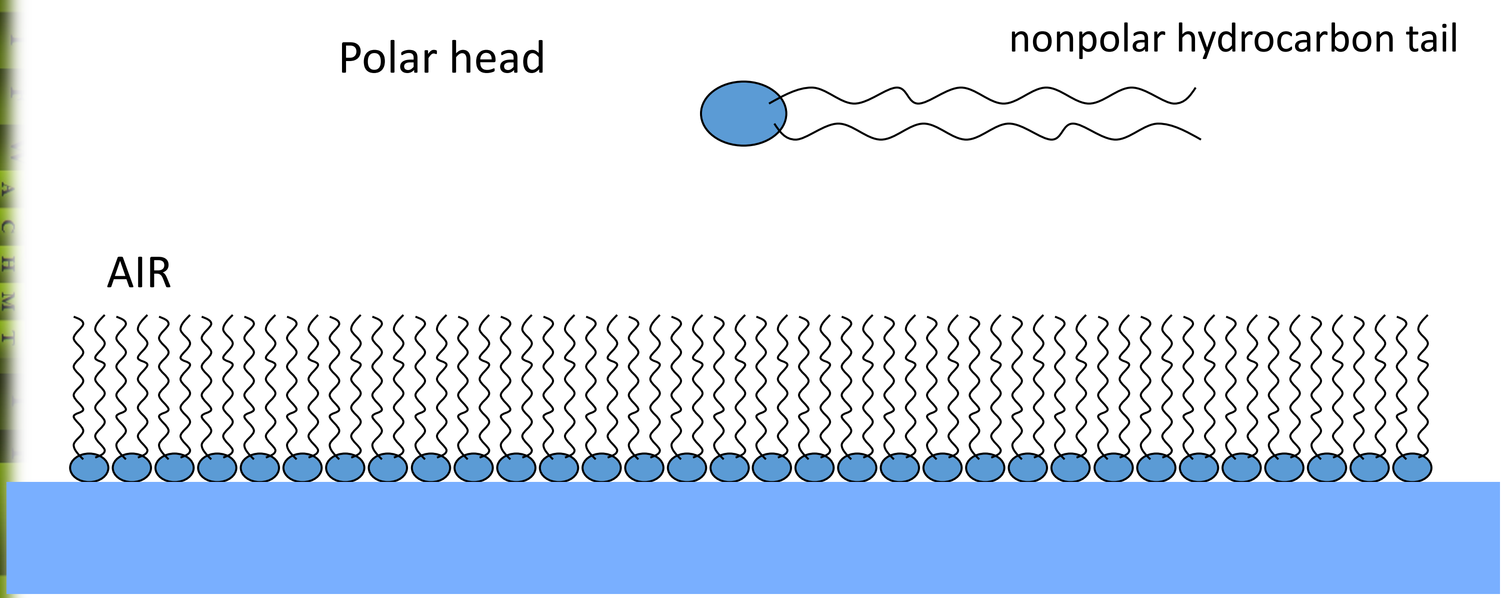
$$CH_3—(CH_2)_n—COOH$$

The value of *n* is typically between 12 and 20 (Even Numbers in biological systems)

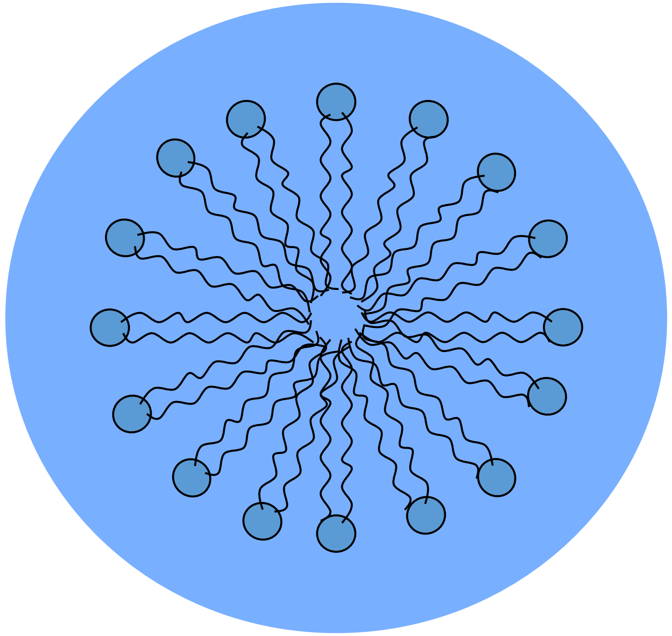
Stearic Acid (saturated) : $CH_3—(CH_2)_{16}—COOH$

Oleic acid (unsaturated): $CH_3—(CH_2)_7—HC=CH—(CH_2)_7—COOH$

Configurations of Fatty Acids in Water



Lipid monolayer at the air water interface

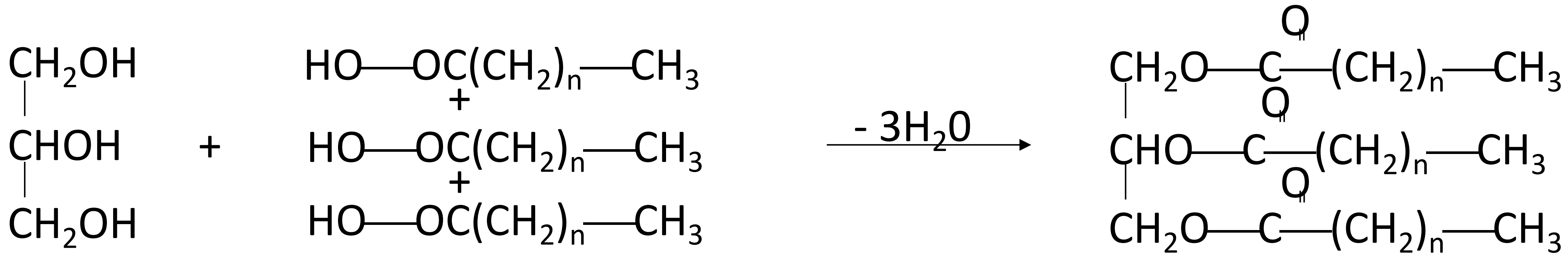


Lipid micelle in water

Lipid molecules have a very small solubility and elevation of the solution concentration above the monomolecular solubility results in the condensation of the excess solute into larger ordered structures called *micelles* ($\Delta G < 0$)

Fats

Fats are condensation products of fatty acids and glycerols (esters)



glycerol Fatty acids Fat

Monosaccharides

ALDOSES

TRIOSE

$$\begin{array}{c} \mathrm{CHO} \\ | \\ \mathrm{HCOH} \\ | \\ \mathrm{CH_2OH} \end{array}$$

D-glyceraldehyde

PENTOSE

$$\begin{array}{c} \mathrm{CHO} \\ | \\ \mathrm{HCOH} \\ | \\ \mathrm{HCOH} \\ | \\ \mathrm{HCOH} \\ | \\ \mathrm{CH_2OH} \end{array}$$

D-ribose

HEXOSE

$$\begin{array}{c} \mathrm{CHO} \\ | \\ \mathrm{HCOH} \\ | \\ \mathrm{HOCH} \\ | \\ \mathrm{HCOH} \\ | \\ \mathrm{HCOH} \\ | \\ \mathrm{CH_2OH} \end{array}$$

D-glucose

$$\begin{array}{c} \mathrm{CHO} \\ | \\ \mathrm{HOCH} \\ | \\ \mathrm{HOCH} \\ | \\ \mathrm{HCOH} \\ | \\ \mathrm{HCOH} \\ | \\ \mathrm{CH_2OH} \end{array}$$

D-mannose

$$\begin{array}{c} \mathrm{CHO} \\ | \\ \mathrm{HCOH} \\ | \\ \mathrm{HOCH} \\ | \\ \mathrm{HOCH} \\ | \\ \mathrm{HCOH} \\ | \\ \mathrm{CH_2OH} \end{array}$$

D-galactose

KETOSES

TRIOSE

$$\begin{array}{c} \mathrm{CH_2OH} \\ | \\ \mathrm{C{=}O} \\ | \\ \mathrm{CH_2OH} \end{array}$$

Dihydroxyacetone

PENTOSE

$$\begin{array}{c} \mathrm{CH_2OH} \\ | \\ \mathrm{C{=}O} \\ | \\ \mathrm{HCOH} \\ | \\ \mathrm{HCOH} \\ | \\ \mathrm{CH_2OH} \end{array}$$

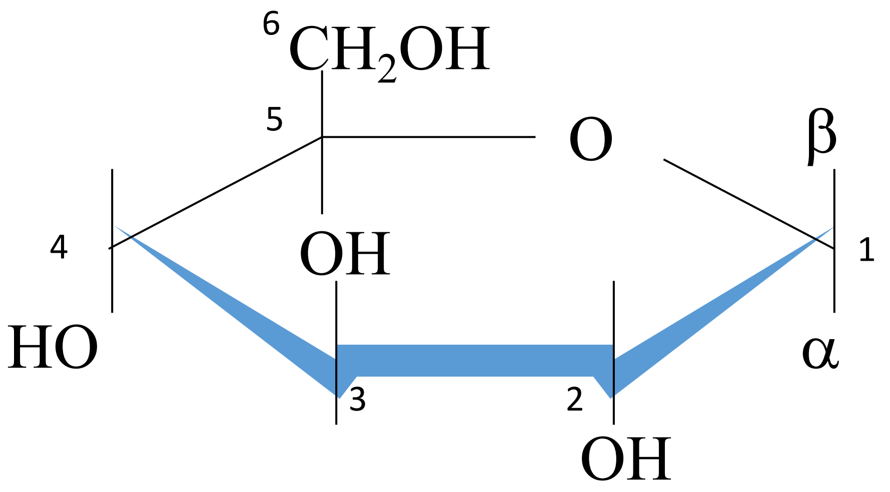
D-ribulose

HEXOSE

$$\begin{array}{c} \mathrm{CHO} \\ | \\ \mathrm{C{=}O} \\ | \\ \mathrm{HOCH} \\ | \\ \mathrm{HCOH} \\ | \\ \mathrm{HCOH} \\ | \\ \mathrm{CH_2OH} \end{array}$$

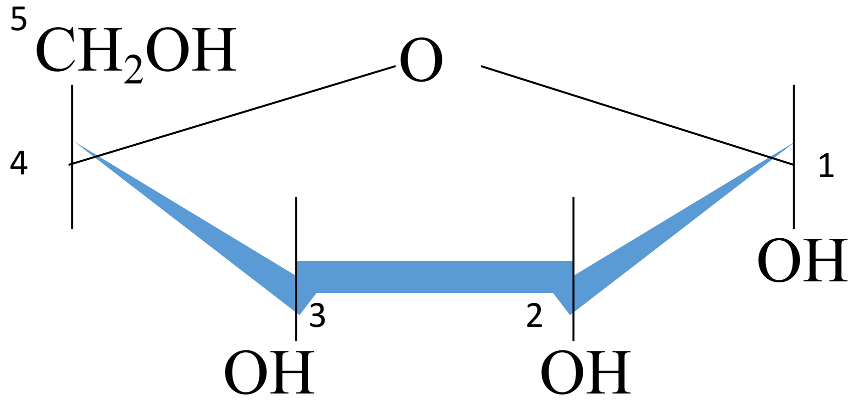
D-frucose

- D-glucose is the most common monosaccharide found in living organisms
- Simple sugars are found either in the aldehyde or keto form: For example, glucose is an aldohexose
- D- is the optical isomer almost exclusively found in living organisms

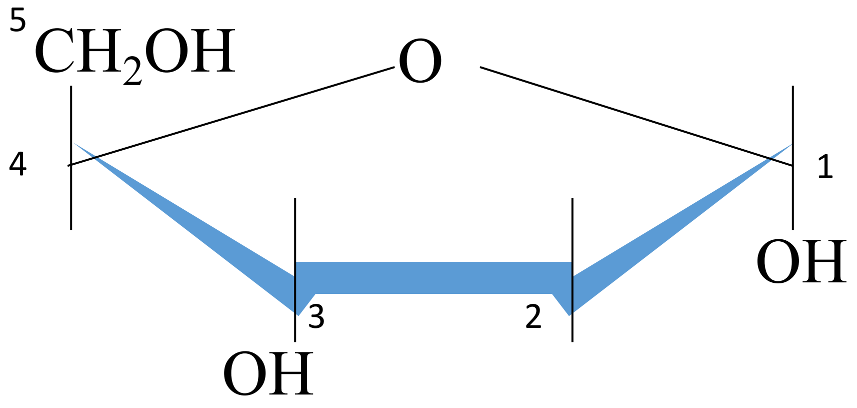


D-glucose

D-ribose



deoxyribose



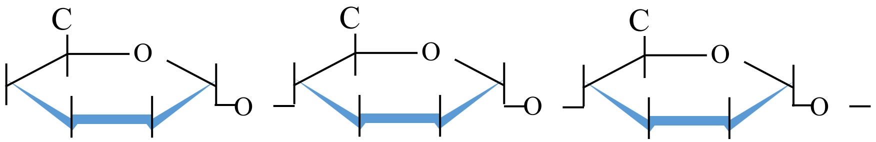
- The five membered rings, D-ribose and deoxyribose are the primary components of the nucleic acid monomers DNA and RNA

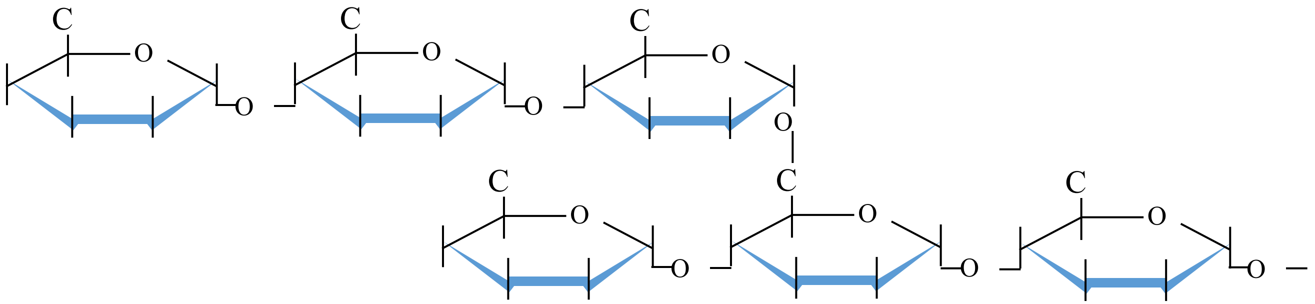
Polysaccharides – Starch and Cellulose

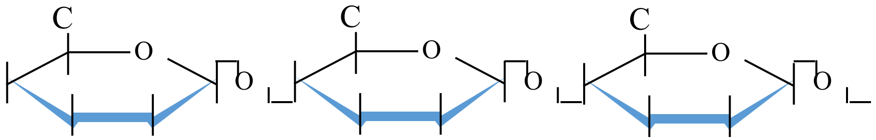
- Amylose – continuous α-1,4-glucosidic bonds
  - Storage material
  - Amylose is straight water insoluble
  - Average molecular weight of amylose is $0.5–1 \times 10^6$
- Amylopectin is crosslinked polymer
  - with branches occuring every 25 glucose units by condensation with the C_6 –OH group
  - Average molecular weight of amylopectin is $1–2 \times 10^6$
- Glycogen – storage material in animals (livers)
  - Granules having amylopectin structure but more cross-linked; almost every 12 glucose units
- Cellulose – continuous β-1,6-glucosidic bonds
  - Structural material

Polysaccharides

- Draw the structure of amylose
- Draw the structure of amylopectin
- Draw the structure of cellulose



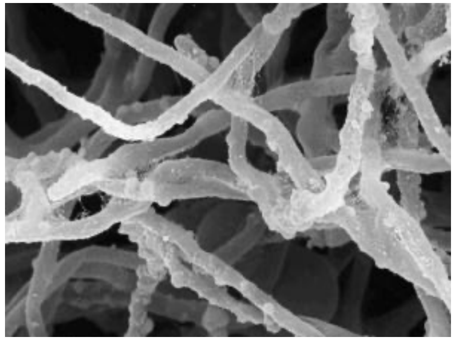




Brown Rot Versus White Rot fungi

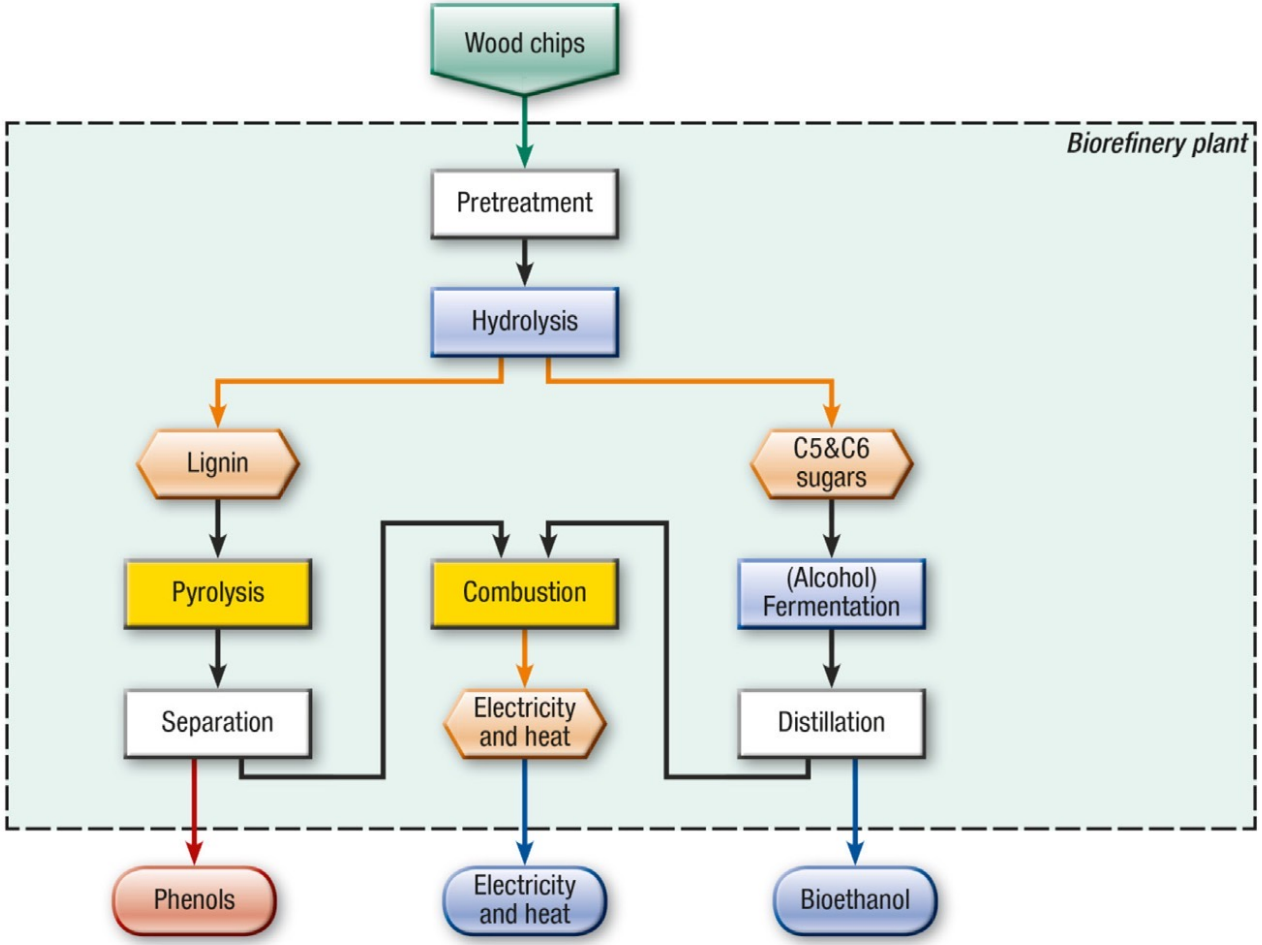
Cellulose is eaten away

Lignin is eaten away



Phanerochaete chrysosporium

Biorefinery using wood as feed-stock



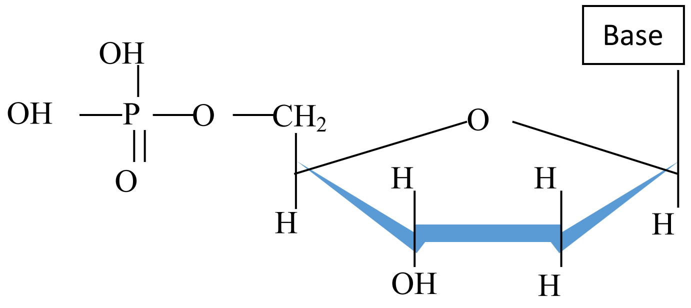
https://doi.org/10.1016/B978-0-12-813056-8.00005-4

Production of Bioethanol

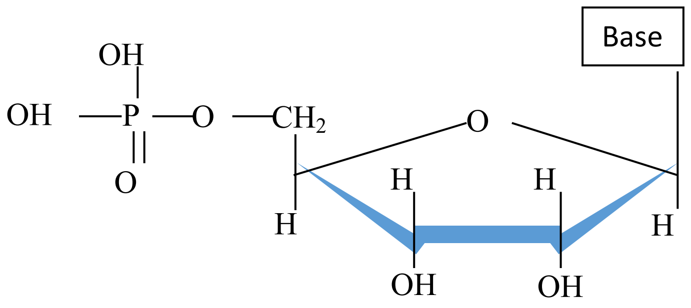
Nucleotides, RNA and DNA

Nucleotides

- Present in nucleic acids
- Made up of three components
  - Phosphoric acid
  - Ribose or deoxyribose 5-C sugars
  - Nitrogenous base either purine or pyrimidine

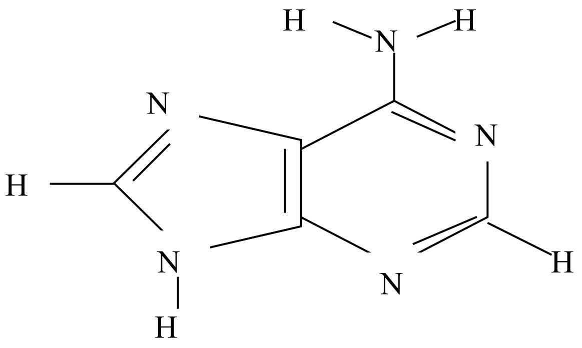
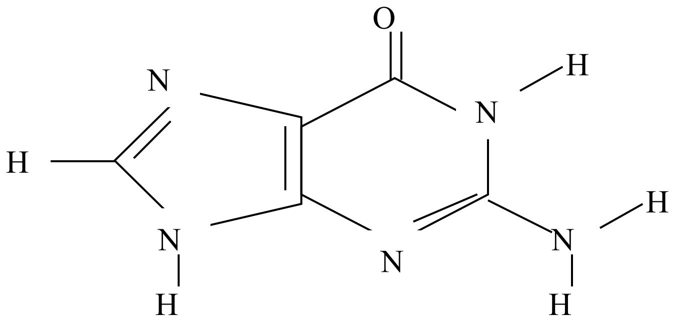
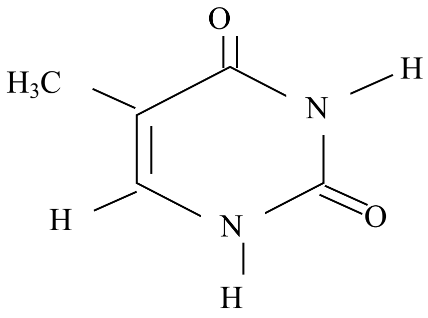
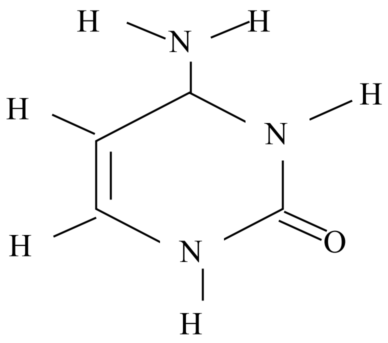
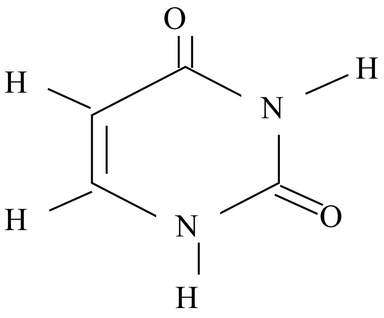


Deoxyribonucleotide



ribonucleotide

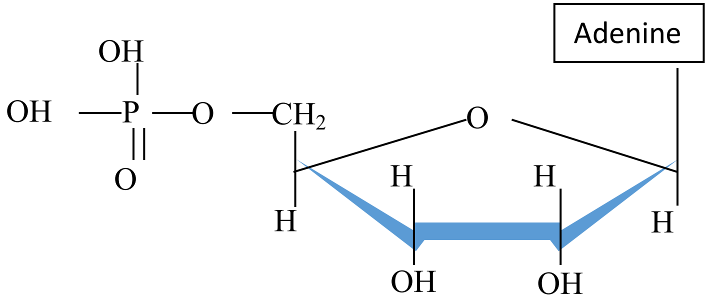
Purines and Pyrimidines

	DNA only	DNA & RNA	RNA only
Purines		 Adenine  Guanine	
Pyrimidines	 Thymine	 Cytosine	 Uracil

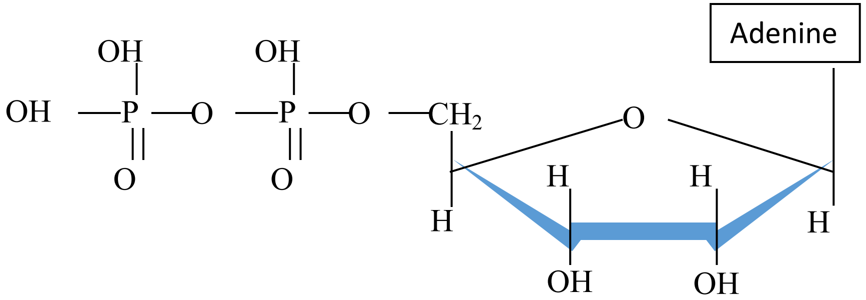
Nomenclature of Nucleosides and Nucleotides

Base	Nucleoside	Nucleotide
Adenine (A)	Adenosine	Adenylate (AMP)
Cytosine (C)	Cytosine	Cytidylate (CMP)
Guanine (G)	Guanosine	Guanulate (GMP)
Uracil (U)	Uridine	Uridylate (UMP)
Thymine (T)	Deoxythymidine	Deoxythymidylate dTMP)

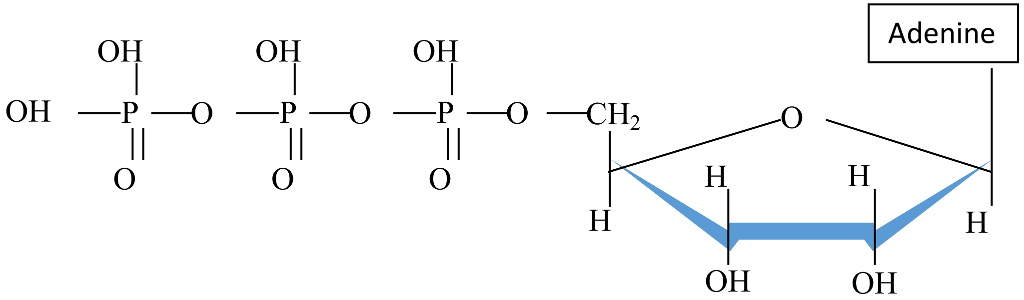
The Phosphates of Adenosine



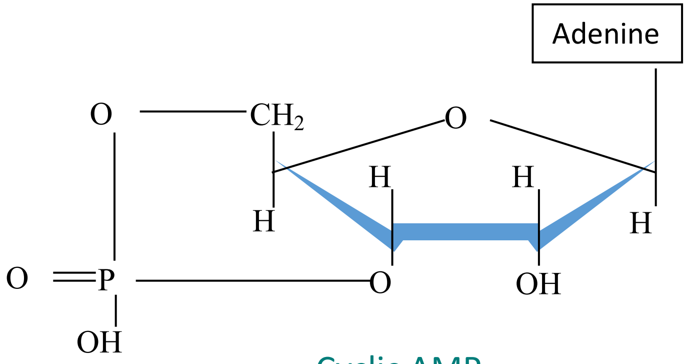
Adenine Monophosphate (AMP)



Adenine diphosphate (ADP)



Adenine triphosphate (ATP)

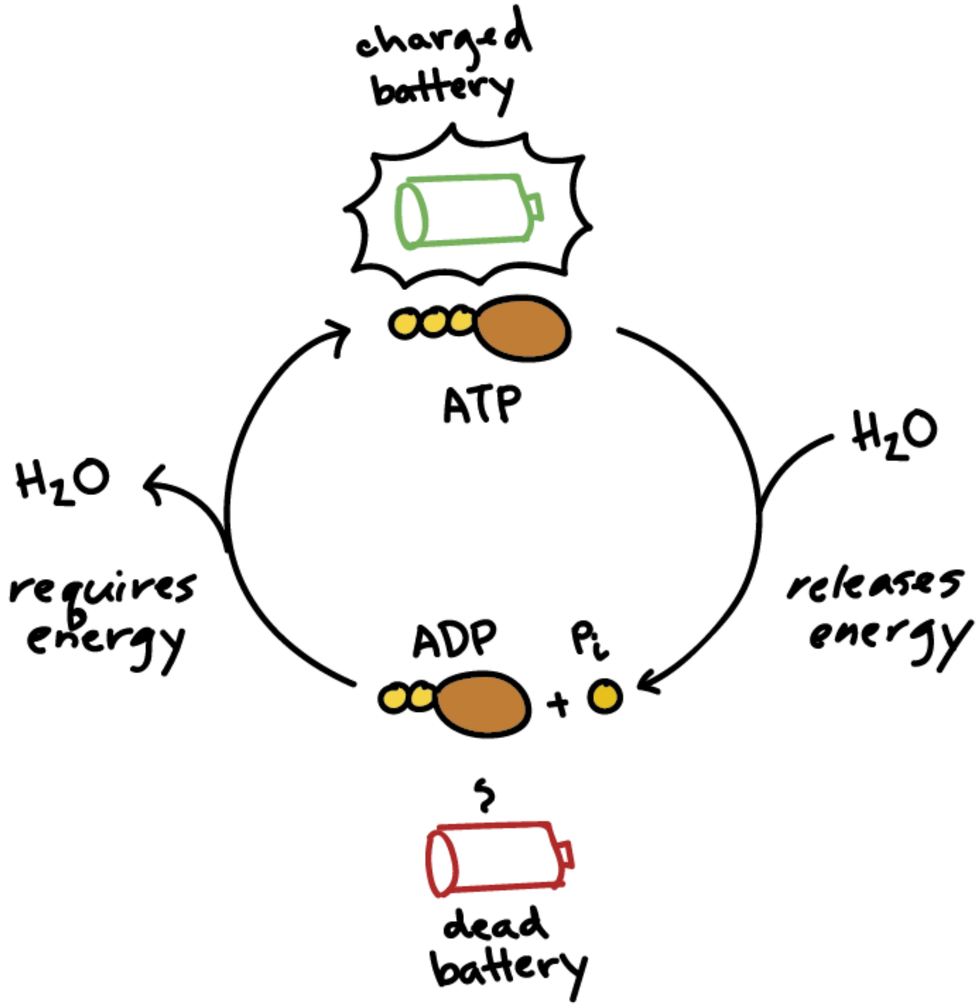


Cyclic AMP

- AMP, ADP and ATP are important in cellular energy transfer processses
- Cyclic AMP serves in regulatory functions

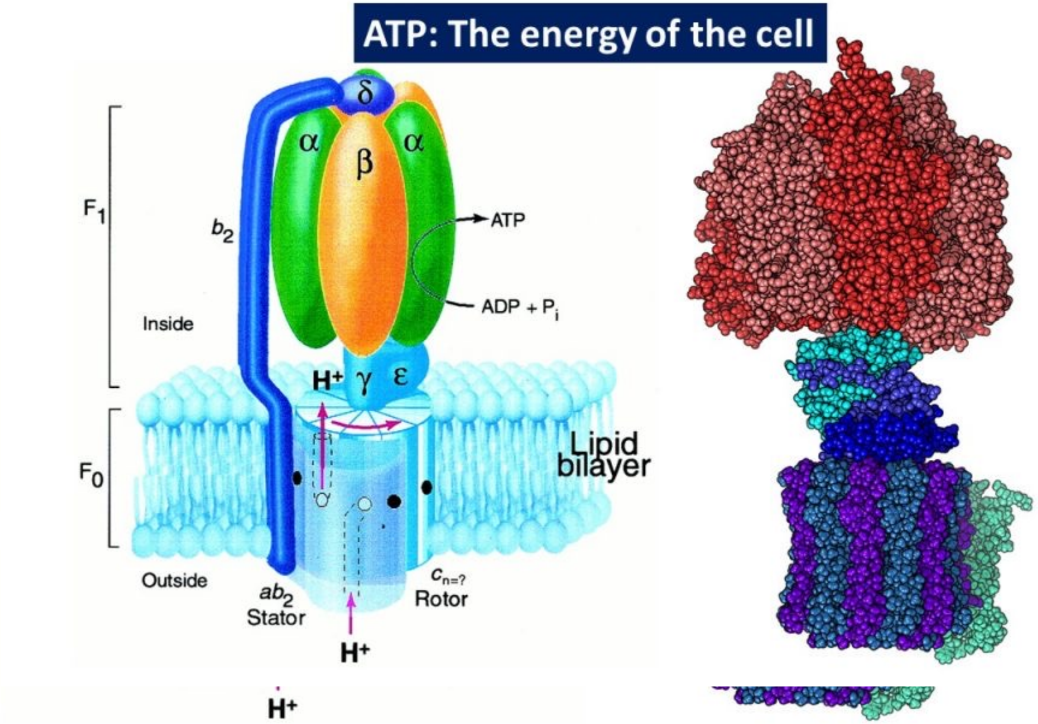
ATP the Energy Currency

- The conversion of ATP to ADP and phosphate is accompanied by a standard free energy of –7.3 kcal/mol at 37ºF and pH 7
- Energy derived from nutrients or sunlight is stored as ATP in cells
- Cyclic AMP serves as a regulator in many cellular reactions

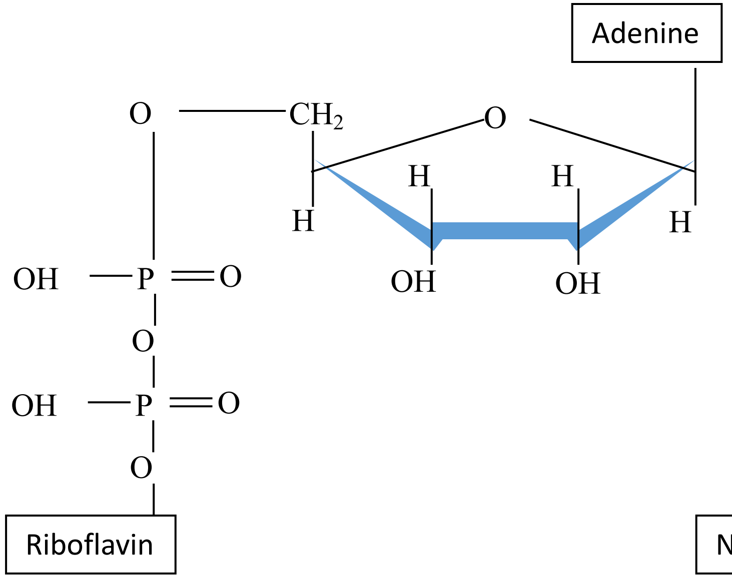


The ATP-DNA Paradox

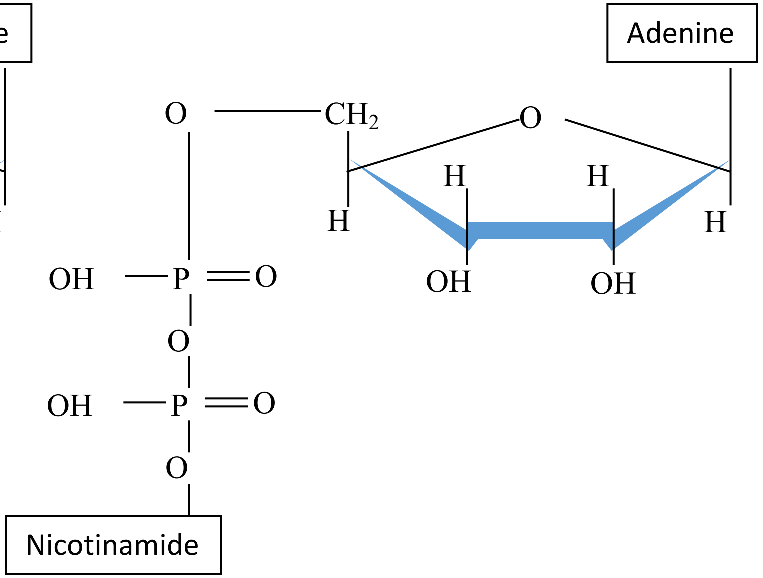
ATP is synthesized by a molecular machine called the ***ATP* Synthase**. This machine has to be built from information contained in DNA. But converting this information and stitching amino-acids together require ATP as energy currency.



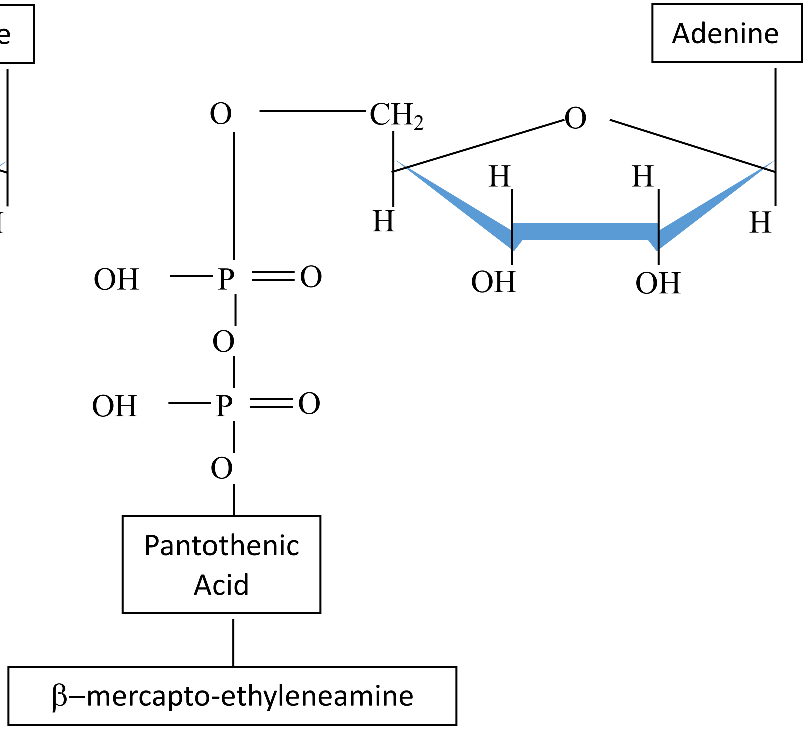
Co-enzymes Derived from Nucleotides



Flavin adenine dinucleotide (FAD)
Oxidized form



Nicotinamide adenine dinucleotide (NAD)

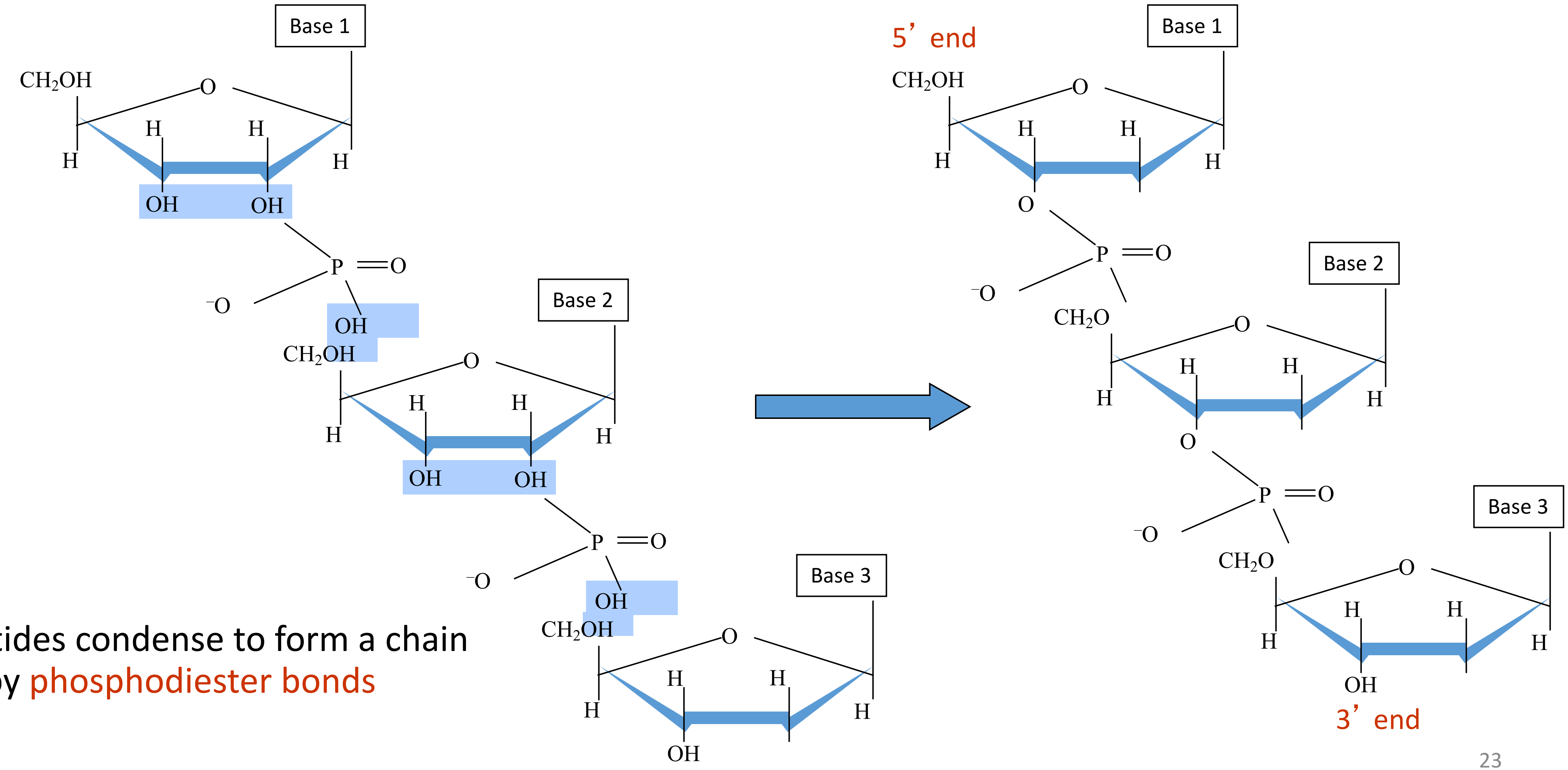


Co-enzyme A

Three important co-enzymes derived from nucleotides

DAO-FAD

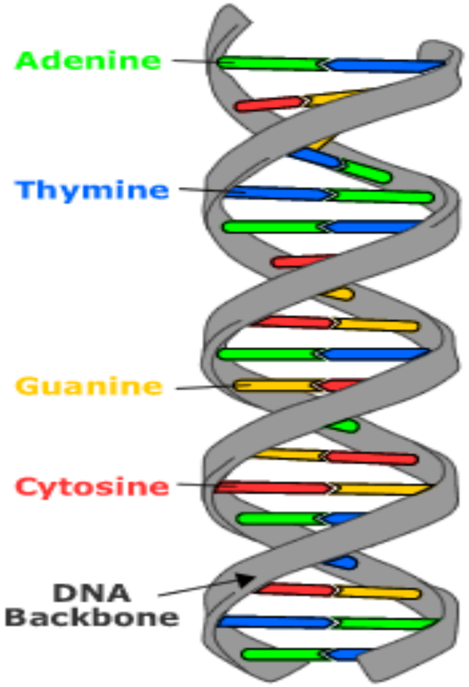
Biological Information Storage

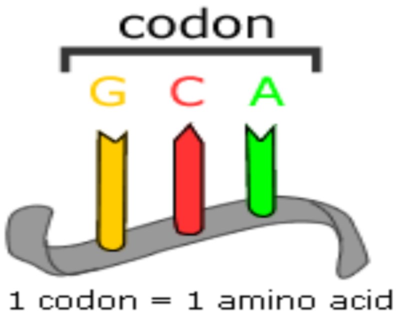


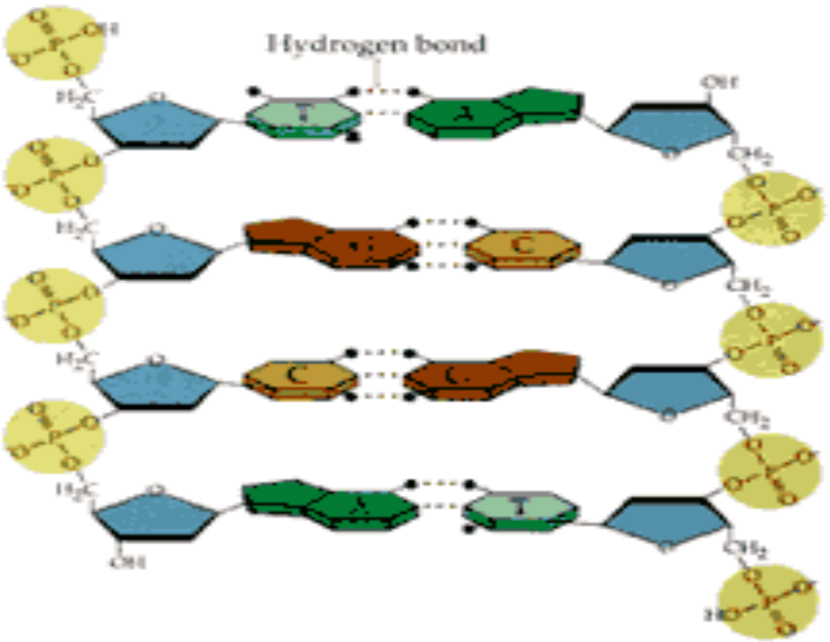
Nucleotides condense to form a chain linked by phosphodiester bonds

Double Helix Structure of DNA

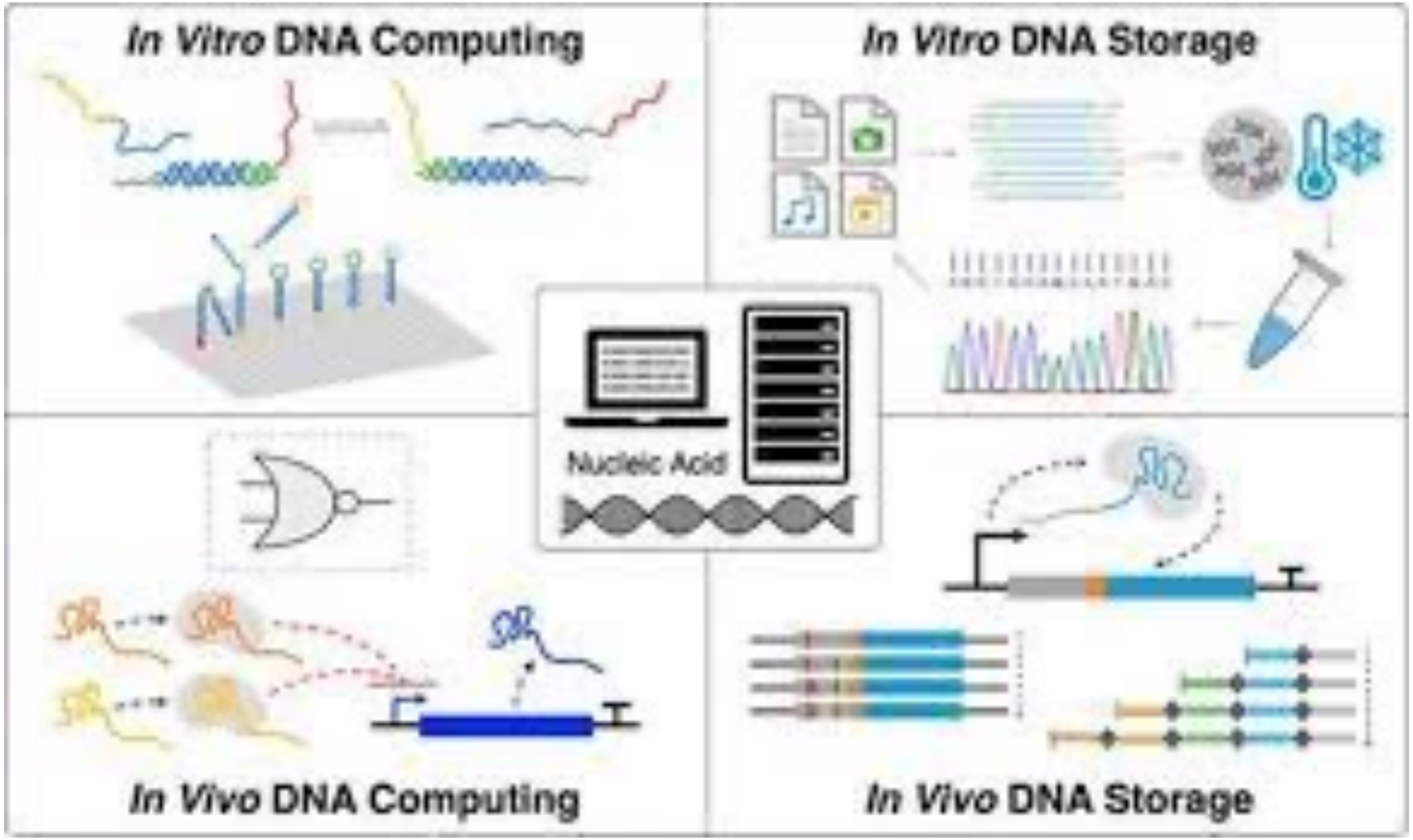
- James Watson and Francis Crick deduced in 1953, the DNA molecule consists of two polynucleotide chains coiled into a double helix
- The regular backbone of the molecule is composed of sugar and phosphate units
- In the interior of the double helix are the purine and pyrimidine bases



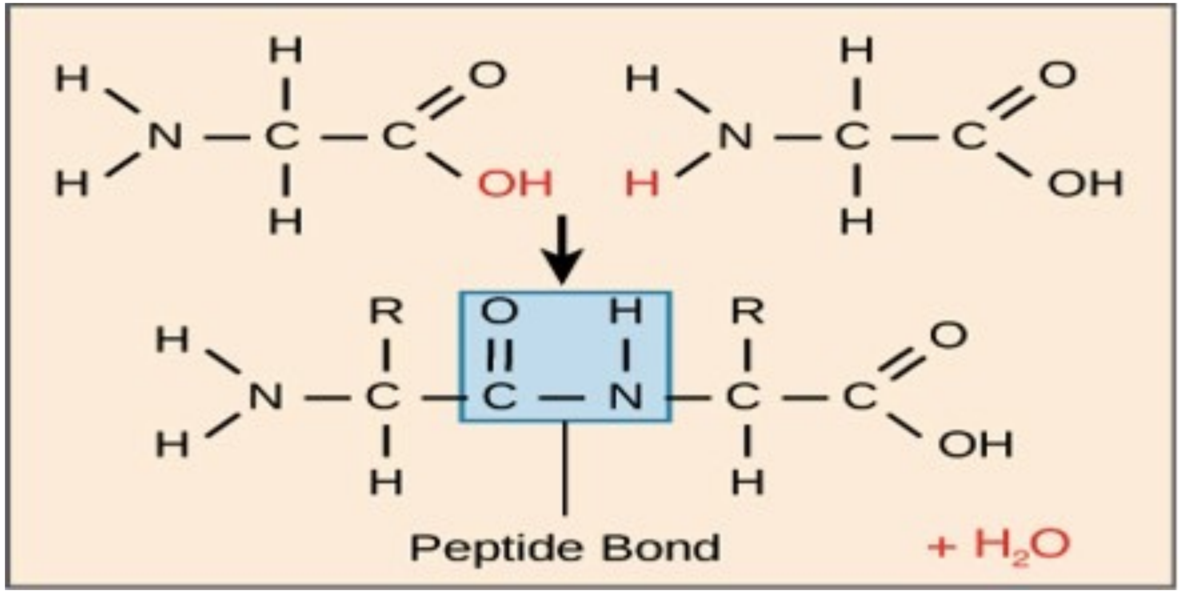


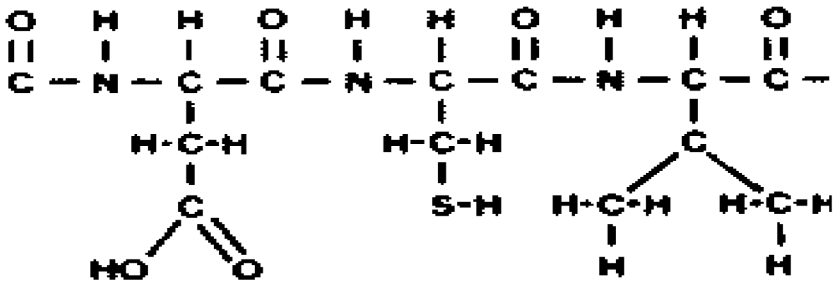


DNA Computing



Chemical composition of the cell …



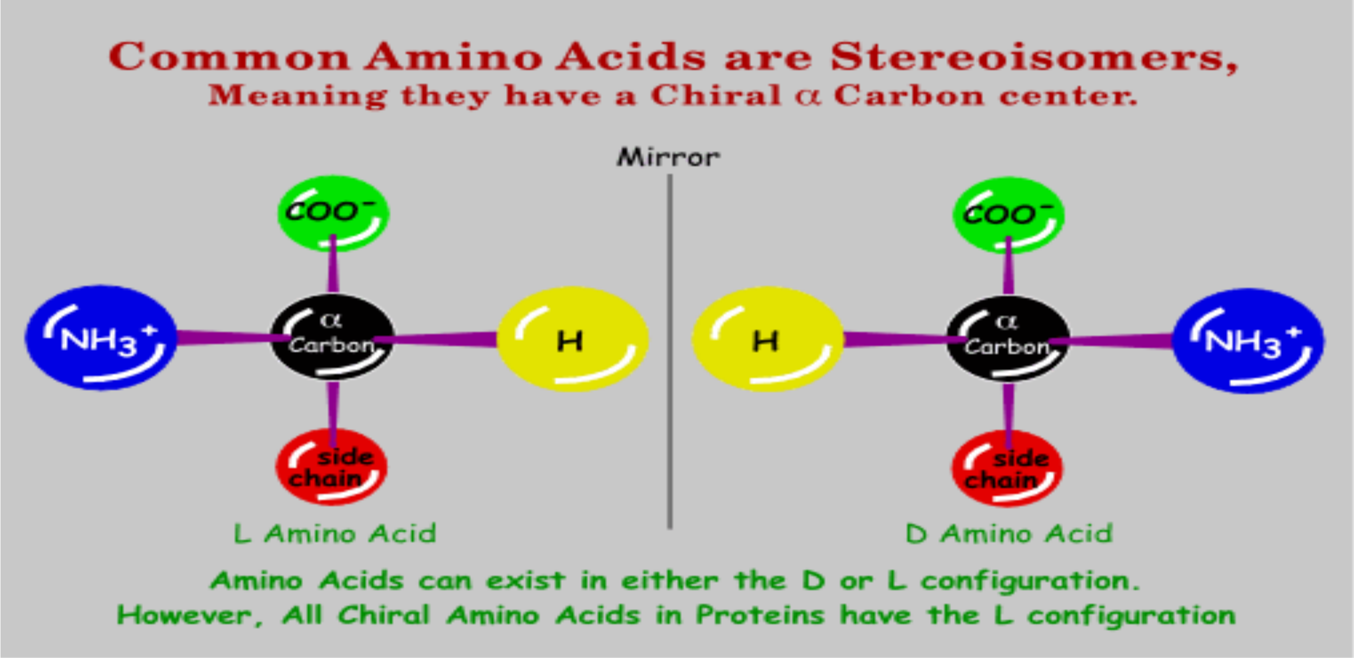


Proteins

- Amino acids are the building blocks of proteins
- There are 20 amino acids commonly found in proteins
- Simple proteins are polymers formed by the condensation of amino acids by forming the peptide bond

L and D Forms of Amino Acids

- The L and D forms are not superimposable
- Glycine where R=H is the only exception
- Living organisms only have the L-form with very rare exception in the cell wall of some bacteria



Individual Properties of Amino Acids

amino acid			mass	surface [b]	volume [c]	pK_a [d]	pI [e]	solubility [e]	density [e]
Alanine	ALA	A	71.09	115	88.6	-	6.107	16.65	1.401
Arginine	ARG	R	156.19	225	173.4	~12	10.76	15	1.1
Aspartic Acid	ASP	D	115.09	150	111.1	4.5	2.98	0.778	1.66
Asparagine	ASN	N	114.11	160	114.1	-	-	3.53	1.54
Cysteine	CYS	C	103.15	135	108.5	9.1-9.5	5.02	very high	-
Glutamic Acid	GLU	E	129.12	190	138.4	4.6	3.08	0.864	1.460
Glutamine	GLN	Q	128.14	180	143.8	-	-	2.5	-
Glycine	GLY	G	57.05	75	60.1	-	6.064	24.99	1.607
Histidine	HIS	H	137.14	195	153.2	6.2	7.64	4.19	-
Isoleucine	ILE	I	113.16	175	166.7	-	6.038	4.117	-
Leucine	LEU	L	113.16	170	166.7	-	6.036	2.426	1.191
Lysine	LYS	K	128.17	200	168.6	10.4	9.47	very high	-
Methionine	MET	M	131.19	185	162.9	-	5.74	3.381	1.340
Phenylalanine	PHE	F	147.18	210	189.9	-	5.91	2.965	-
Proline	PRO	P	97.12	145	112.7	-	6.3	162.3	-
Serine	SER	S	87.08	115	89.0	-	5.68	5.023	1.537
Threonine	THR	T	101.11	140	116.1	-	-	very high	-
Tryptophan	TRP	W	186.12	255	227.8	-	5.88	1.136	-
Tyrosine	TYR	Y	163.18	230	193.6	9.7	5.63	0.0453	1.456
Valine	VAL	V	99.14	155	140.0	-	6.002	8.85	1.230

[a] mass [dalton], surface [Å^2], volume [Å^3], pK_a [side chain], pI [at 25°C], solubility [g/100g, 25°C], density [crystal density, g/ml],

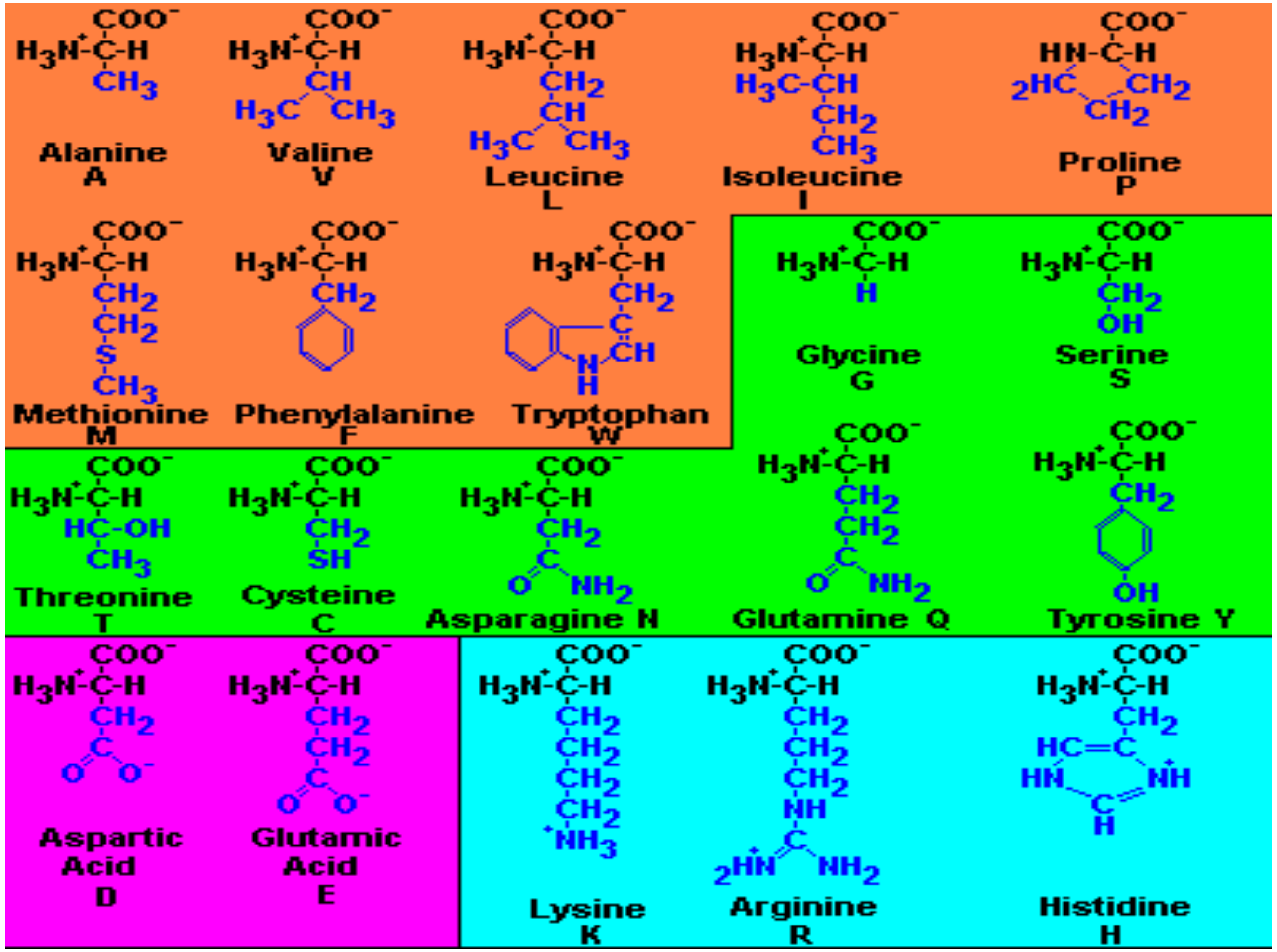
name: information from NIST Chemistry WebBook, three letter code: GIF, one letter code: VRML

Amino Acid Table

- The R groups are ionizable
- Hydrophobic, hydrophilic, acidic and basic
- Condensation reaction between the amino group of one acid and the carboxyl group of another results in the formation of the peptide bonds

Non-polar

Polar



Acidic

Basic

Proteins – Food Industry

The hamburger was made from 20,000 muscle fibres grown from stem cells. Photgraph: David Parry/EPA

Dr Post's team at Maastricht University. These fibres were extracted from individual culture wells and then painstakingly pressed together to form the hamburger that was eaten. The objective is to create meat that is biologically identical to beef but grown in a lab rather than in a field as part of a cow.

Chemical composition of the cell …

Elements that make up life

- ❖ 92 elements are found in nature (118 total elements)
- ❖ Living objects are composed of 25 – 26 elements.

Elements of life…

Elements	Symbols	%
Oxygen	**O**	**65**
Carbon	**C**	**18**
Hydrogen	**H**	**10**
Nitrogen	**N**	**3**
Calcium	**Ca**	**1,5**
Phosphorus	**P**	**1,0**
Sulphur	**S**	**0,25**
Potassium	**K**	**0,2**
Sodium	**Na**	**0,15**
Chlorine	**Cl**	**0,15**
Magnesium	**Mg**	**0,05**
Others		**0,75**

- **The concentration (%) of most important elements (macro-elements) in human body**

Elements of Life …

Approximate amounts of important microelements within 70 kg mass human body

Element	Symbol	Amount	Role in the organism
Iron	**Fe**	4 – 5 g	Red-ox reactions; oxygen transportation within erythrocytes
Zinc	**Zn**	1,4 – 2,3 g	Regulation of the growth and development, synthesis of hormones and proteins (hair, skin).
Copper	**Cu**	75 – 150 mg	Oxidation reactions, biosynthesis of the skin pigment melanin
Manganese	**Mn**	12 – 20 mg	Formation of skin and mucous layers, development of blood cells
Molybdenum	**Mo**	5 – 9 mg	Red-ox reactions at respiration
Cobalt	**Co**	1 – 1,5 mg	Metabolic processes, the component of vitamin B_{12}
Chromium	**Cr**	0,6 – 1,4 mg	Sugar turnover, action of insulin

Elements of life…

- Other important microelements:

Lithium (Li) – regulation of nerve functions;

Selenium (Se) – protein biosynthesis, hair;

Fluorine (F) – development of bones and teeth;

Iodine (I) – hormone biosynthesis, neural regulation.

Ultramicroelements:

Arsenic (As) and Gold (Au) – regulation of growth and metabolism

Living organisms operate within laws of physics and chemistry

- Conservation of Mass, Energy
- Laws of Chemical Kinetics
- Principles of Chemical Reactions

- Converts energy to work
- Catalyzes chemical transformations
- Assembles complex molecules from simple subunits.
- Complex molecules combine to form supra molecular components, organelles and finally assemble into a cell
- Cells store and pass on instructions for the assembly of all future generations from simple non-living precursors