

Chem 352 - Lecture 1

Introduction to Biochemistry

Question for the Day: What characteristics distinguishes living systems from non-living systems?

1

Introduction


- * Biochemistry involves the study of biological system at the molecular level.

Chem 352, Lecture 1 - Introduction to Biochemistry 2

2-1

Introduction

- * Biochemistry involves the study of biological system at the molecular level.
- * What biological systems should we study?




The Garden Of Eden...Paradise

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2-2

Introduction

- * Biochemistry involves the study of biological system at the molecular level.
- * What biological systems should we study?



The Garden Of Eden...Paradise

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Anything found to be true of *E. coli* must also be true of elephants.
-Jacques Monod

2-3

Introduction

In this introduction we will consider

- * History of biochemistry
- * Molecules
 - Families of organic molecules and the functional groups that define them
 - Polymers (Macromolecules)
- * Energy
- * Cells and cellular structures

Chem 352, Lecture 1 - Introduction to Biochemistry 3

3-1

Introduction

Question:

What is a polymer?

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3-2

Introduction

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Chem 352, Lecture 1 - Introduction to Biochemistry 3

3-3

A brief history of Biochemistry

Biochemistry, as with all the sciences, is a human endeavor.

- It is worth recognizing some of the early contributors to biochemistry.

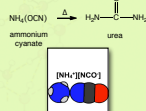
Chem 352, Lecture 1 - Introduction to Biochemistry 4

4

A brief history of Biochemistry

•Friedrich Wöhler
(1800-1882)

- Demonstrated that urea, a compound that had only been associated with living cells, could be synthesized from an inorganic compound outside of a living cell.
- This led to the recognition that the chemistry that takes place inside a living cell is the same chemistry that takes place outside of the cell.



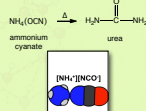
Chem 352, Lecture 1 - Introduction to Biochemistry 5

5-1

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5-2

A brief history of Biochemistry

•Eduard Buchner (1860-1917)

- Showed that the fermentation of sugars by yeast, a process that occurs when making beer, wine and bread, could be carried out with the cell extracts from yeast cells.
- Living cells were not required to carry out this complex series of reactions.



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6

A brief history of Biochemistry

•Emil Fischer (1852-1919)

- Characterized the catalytic components of yeast extracts that were carrying out the fermentation reactions.
- We now refer to these biological catalysts as enzymes.
- His descriptions of the molecular interactions that take place between an enzyme and its substrates and products are, in hindsight, remarkably insightful.



Received the
2nd Nobel Prize
awarded in Chemistry
(1902)

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7

A brief history of Biochemistry

•Fischer's enzymes turned out to be proteins.

- Proteins are a major class of biological molecules and turn out to be the real workhorses of a living cell.
- It was not until the late 1950s that we were first construct models for the 3-dimensional structures of proteins.



Max Perutz (left)
John Kendrew (right)
shared the 1962
Nobel Prize in Chemistry
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Chem 352, Lecture 1 - Introduction to Biochemistry 8

8-1

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8-2

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A brief history of Biochemistry

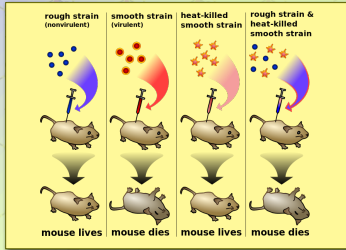
• In the mid-20th century, the important role that nucleic acids play was elucidated.

- In 1944, Oswald Avery, Colin MacLeod and Maclyn McCarty demonstrated that the infectious component of *Streptococcus pneumoniae*, the bacterium that causes pneumonia, was the molecule **deoxyribonucleic acid** (DNA), and not protein.
- This significant finding provided evidence that DNA is the carrier of the biological information.

Chem 352, Lecture 1 - Introduction to Biochemistry 9

9-1

A brief history of Biochemistry



Chem 352, Lecture 1 - Introduction to Biochemistry 9

9-2

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9-3

A brief history of Biochemistry

• In 1953, James Watson and Francis Crick proposed an atomic level structure for DNA.

- Their model met with immediate acceptance because their structure readily explained how DNA can function as an information carrying molecule that is capable of replicating itself as cells divide and multiply.



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Chem 352, Lecture 1 - Introduction to Biochemistry 10

10-1

A brief history of Biochemistry



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10-3

A brief history of Biochemistry

- Francis Crick went on to propose that the general flow of information is from DNA to RNA to protein.
- His model has become known as the "central dogma" of molecular biology.

DNA → RNA → Protein

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11

A brief history of Biochemistry

• Darwin's theory of evolution

- All of modern biology rests on a foundation that Darwin laid with his theory of natural selection.
- Even though Darwin's theory helps us to understand how all of the forms of life currently found on earth could have evolved from a single cell, starting 3.5 billion years ago,
- It does not shed light on how that first cell arose.

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12

A brief history of Biochemistry

• Darwin's thoughts on the origins of life:

- "Probably all the organic beings which have ever lived on this earth have descended from some one primordial form, into which life was first breathed." (from *The Origin of the Species*, 1859)

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13

A brief history of Biochemistry

• Darwin's thoughts on the origins of life:

- "But if (and Oh!, what a big if!) we could conceive in some warm little pond, with all sorts of ammonia and phosphoric salts, light heat, electricity, etc., present, that a protein compound was chemically formed ready to undergo still more complex changes, at the present day such matter would be instantly devoured or absorbed, which would not have been the case before living creatures were formed." (Letter to botanist Joseph Hooker, 1871)

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14

A brief history of Biochemistry

- The origin of life on earth is still one of the big questions in biology.
- In the Zimmer essay, there is a discussion of the current progress being made to discover how that first cell arose. It is a good introduction to some of the major molecular players that we will encounter this semester.

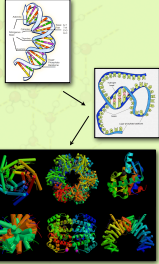
Carl Zimmer, "On the Origin of Life on Earth", Science 2009, 323, 198-199.

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15

A brief history of Biochemistry

- Just about all organisms use DNA to encode genetic information.
- They copy this information into RNA
- The RNA is used to make proteins

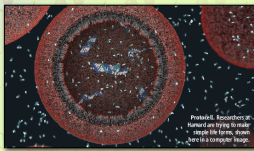


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16

A brief history of Biochemistry

- The other important component of living cells are membranes.
- These are made out of lipids.



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17

The Elements of Life

- Since this is a chemistry class, we should probably start with the elements.
- Approximately 97% of elements found in living systems comprise just six elements:
 - oxygen
 - carbon
 - hydrogen
 - nitrogen
 - phosphorous
 - sulfur

Chem 352, Lecture 1 - Introduction to Biochemistry 18

18

The Elements of Life

1A	2A	3A	4A	5A	6A	7A	8A	9A	10A	11A	12A	13A	14A	15A	16A	17A	18A	19A	20A	21A	22A	23A	24A	25A	26A	27A	28A	29A	30A	31A	32A	33A	34A	35A	36A	37A	38A	39A	40A	41A	42A	43A	44A	45A	46A	47A	48A	49A	50A	51A	52A	53A	54A	55A	56A	57A	58A	59A	60A	61A	62A	63A	64A	65A	66A	67A	68A	69A	70A	71A	72A	73A	74A	75A	76A	77A	78A	79A	80A	81A	82A	83A	84A	85A	86A	87A	88A	89A	90A	91A	92A	93A	94A	95A	96A	97A	98A	99A	100A	101A	102A	103A	104A	105A	106A	107A	108A	109A	110A	111A	112A	113A	114A	115A	116A	117A	118A	119A	120A	121A	122A	123A	124A	125A	126A	127A	128A	129A	130A	131A	132A	133A	134A	135A	136A	137A	138A	139A	140A	141A	142A	143A	144A	145A	146A	147A	148A	149A	150A	151A	152A	153A	154A	155A	156A	157A	158A	159A	160A	161A	162A	163A	164A	165A	166A	167A	168A	169A	170A	171A	172A	173A	174A	175A	176A	177A	178A	179A	180A	181A	182A	183A	184A	185A	186A	187A	188A	189A	190A	191A	192A	193A	194A	195A	196A	197A	198A	199A	200A	201A	202A	203A	204A	205A	206A	207A	208A	209A	210A	211A	212A	213A	214A	215A	216A	217A	218A	219A	220A	221A	222A	223A	224A	225A	226A	227A	228A	229A	230A	231A	232A	233A	234A	235A	236A	237A	238A	239A	240A	241A	242A	243A	244A	245A	246A	247A	248A	249A	250A	251A	252A	253A	254A	255A	256A	257A	258A	259A	260A	261A	262A	263A	264A	265A	266A	267A	268A	269A	270A	271A	272A	273A	274A	275A	276A	277A	278A	279A	280A	281A	282A	283A	284A	285A	286A	287A	288A	289A	290A	291A	292A	293A	294A	295A	296A	297A	298A	299A	300A	301A	302A	303A	304A	305A	306A	307A	308A	309A	310A	311A	312A	313A	314A	315A	316A	317A	318A	319A	320A	321A	322A	323A	324A	325A	326A	327A	328A	329A	330A	331A	332A	333A	334A	335A	336A	337A	338A	339A	340A	341A	342A	343A	344A	345A	346A	347A	348A	349A	350A	351A	352A	353A	354A	355A	356A	357A	358A	359A	360A	361A	362A	363A	364A	365A	366A	367A	368A	369A	370A	371A	372A	373A	374A	375A	376A	377A	378A	379A	380A	381A	382A	383A	384A	385A	386A	387A	388A	389A	390A	391A	392A	393A	394A	395A	396A	397A	398A	399A	400A	401A	402A	403A	404A	405A	406A	407A	408A	409A	410A	411A	412A	413A	414A	415A	416A	417A	418A	419A	420A	421A	422A	423A	424A	425A	426A	427A	428A	429A	430A	431A	432A	433A	434A	435A	436A	437A	438A	439A	440A	441A	442A	443A	444A	445A	446A	447A	448A	449A	450A	451A	452A	453A	454A	455A	456A	457A	458A	459A	460A	461A	462A	463A	464A	465A	466A	467A	468A	469A	470A	471A	472A	473A	474A	475A	476A	477A	478A	479A	480A	481A	482A	483A	484A	485A	486A	487A	488A	489A	490A	491A	492A	493A	494A	495A	496A	497A	498A	499A	500A	501A	502A	503A	504A	505A	506A	507A	508A	509A	510A	511A	512A	513A	514A	515A	516A	517A	518A	519A	520A	521A	522A	523A	524A	525A	526A	527A	528A	529A	530A	531A	532A	533A	534A	535A	536A	537A	538A	539A	540A	541A	542A	543A	544A	545A	546A	547A	548A	549A	550A	551A	552A	553A	554A	555A	556A	557A	558A	559A	560A	561A	562A	563A	564A	565A	566A	567A	568A	569A	570A	571A	572A	573A	574A	575A	576A	577A	578A	579A	580A	581A	582A	583A	584A	585A	586A	587A	588A	589A	590A	591A	592A	593A	594A	595A	596A	597A	598A	599A	600A	601A	602A	603A	604A	605A	606A	607A	608A	609A	610A	611A	612A	613A	614A	615A	616A	617A	618A	619A	620A	621A	622A	623A	624A	625A	626A	627A	628A	629A	630A	631A	632A	633A	634A	635A	636A	637A	638A	639A	640A	641A	642A	643A	644A	645A	646A	647A	648A	649A	650A	651A	652A	653A	654A	655A	656A	657A	658A	659A	660A	661A	662A	663A	664A	665A	666A	667A	668A	669A	670A	671A	672A	673A	674A	675A	676A	677A	678A	679A	680A	681A	682A	683A	684A	685A	686A	687A	688A	689A	690A	691A	692A	693A	694A	695A	696A	697A	698A	699A	700A	701A	702A	703A	704A	705A	706A	707A	708A	709A	710A	711A	712A	713A	714A	715A	716A	717A	718A	719A	720A	721A	722A	723A	724A	725A	726A	727A	728A	729A	730A	731A	732A	733A	734A	735A	736A	737A	738A	739A	740A	741A	742A	743A	744A	745A	746A	747A	748A	749A	750A	751A	752A	753A	754A	755A	756A	757A	758A	759A	760A	761A	762A	763A	764A	765A	766A	767A	768A	769A	770A	771A	772A	773A	774A	775A	776A	777A	778A	779A	780A	781A	782A	783A	784A	785A	786A	787A	788A	789A	790A	791A	792A	793A	794A	795A	796A	797A	798A	799A	800A	801A	802A	803A	804A	805A	806A	807A	808A	809A	810A	811A	812A	813A	814A	815A	816A	817A	818A	819A	820A	821A	822A	823A	824A	825A	826A	827A	828A	829A	830A	831A	832A	833A	834A	835A	836A	837A	838A	839A	840A	841A	842A	843A	844A	845A	846A	847A	848A	849A	850A	851A	852A	853A	854A	855A	856A	857A	858A	859A	860A	861A	862A	863A	864A	865A	866A	867A	868A	869A	870A	871A	872A	873A	874A	875A	876A	877A	878A	879A	880A	881A	882A	883A	884A	885A	886A	887A	888A	889A	890A	891A	892A	893A	894A	895A	896A	897A	898A	899A	900A	901A	902A	903A	904A	905A	906A	907A	908A	909A	910A	911A	912A	913A	914A	915A	916A	917A	918A	919A	920A	921A	922A	923A	924A	925A	926A	927A	928A	929A	930A	931A	932A	933A	934A	935A	936A	937A	938A	939A	940A	941A	942A	943A	944A	945A	946A	947A	948A	949A	950A	951A	952A	953A	954A	955A	956A	957A	958A	959A	960A	961A	962A	963A	964A	965A	966A	967A	968A	969A	970A	971A	972A	973A	974A	975A	976A	977A	978A	979A	980A	981A	982A	983A	984A	985A	986A	987A	988A	989A	990A	991A	992A	993A	994A	995A	996A	997A	998A	999A	1000A	1001A	1002A	1003A	1004A	1005A	1006A	1007A	1008A	1009A	1010A	1011A	1012A	1013A	1014A	1015A	1016A	1017A	1018A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The Compounds of Life

- Water, H_2O , comprises up to 75% of the mass of a living cell.
- Most of the solid material, the other 25%, is made up of carbon-based molecules.

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20

The Compounds of Life

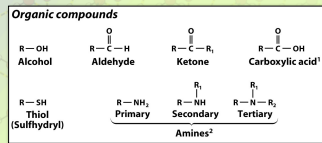
- Organic molecules are grouped into **families** according to the **functional groups** they contain.

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21-1

The Compounds of Life

- Organic molecules are grouped into **families** according to the **functional groups** they contain.

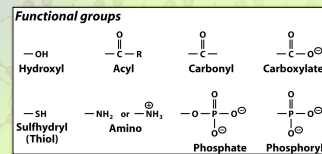


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21-2

The Compounds of Life

- Organic molecules are grouped into **families** according to the **functional groups** they contain.

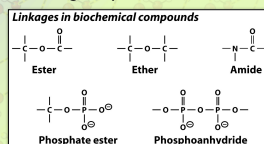


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21-3

The Compounds of Life

- Some of the functional groups combine with others to form new functional groups.



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22

Biological Macromolecules

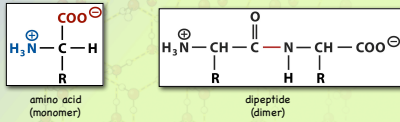
- The large biological molecules (macromolecules), such as proteins, nucleic acids and polysaccharides, are **polymers**.
- Polymers are made by joining together monomers, much like beads on a string.
- Proteins are polymers of **amino acids**
- Polysaccharides are polymers of **monosaccharides**.
- Nucleic acids are polymers of **nucleotides**.

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23

Biological Macromolecules

- Proteins are polymers of **amino acids**

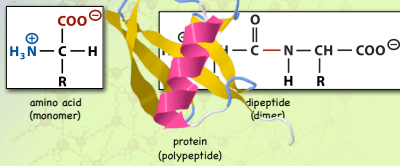


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24-1

Biological Macromolecules

- Proteins are polymers of **amino acids**

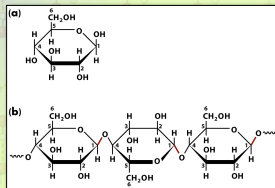


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24-2

Biological Macromolecules

- Polysaccharides are polymers of **monosaccharides**.

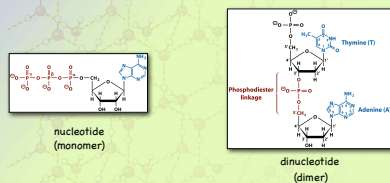


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25

Biological Macromolecules

- Nucleic acids are polymers of **nucleotides**



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26-1

Biological Macromolecules

- Nucleic acids are polymers of nucleotides

nucleotide (monomer)

polynucleotide (polymer)

dinucleotide (dimer)

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26-2

Biological Macromolecules

- Nucleic acids are polymers of nucleotides

nucleotide (monomer)

dinucleotide (dimer)

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26-3

Other Biological Molecules

- Lipids are another important class of biological molecule
 - Lipids are not grouped according to a common structure, but rather are grouped according to a **common physical property**.
 - They are non-polar molecules, which are insoluble in water.

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27

Other Biological Molecules

- An important group of lipids are the phospholipids
 - Phospholipids are not polymers, but they do aggregate in the presence of water to form membranes.

Phospholipid

Fatty acid group

Polar head (hydrophilic)

Nonpolar tail (hydrophobic)

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28-1

Other Biological Molecules

- An important group of lipids are the phospholipids
 - Phospholipids are not polymers, but they do aggregate in the presence of water to form membranes.

Phospholipid

Proteins

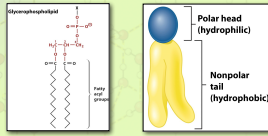
Lipid bilayer

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28-2

Other Biological Molecules

- An important group of lipids are the phospholipids
- Phospholipids are not polymers, but they do aggregate in the presence of water to form membranes.



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28-3

Energy

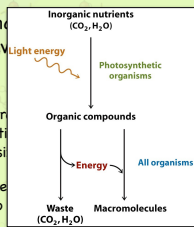
- The sun is the ultimate source of energy for nearly every organism on the earth.
- **Photosynthesis** is the process by which some organisms are able to utilize the light energy from the sun to synthesize organic molecules.
- Other organisms can then extract the energy from these molecules to meet their own needs.

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29-1

Energy

- The sun is the ultimate source of energy for nearly every organism on the earth.
- **Photosynthesis** is the process by which some organisms are able to utilize the light energy from the sun to synthesize organic molecules.
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29-2

Energy

- The sun is the ultimate source of energy for nearly every organism on the earth.
- **Photosynthesis** is the process by which some organisms are able to utilize the light energy from the sun to synthesize organic molecules.
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29-3

Energy

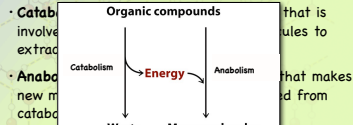
- The sum total of all of the reactions that take place in a living cell is called **metabolism**.
- **Catabolism** is the subset of metabolism that is involved in breaking down organic molecules to extract chemical energy.
- **Anabolism** is the subset of metabolism that makes new molecules using the energy obtained from catabolism.

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30-1

Energy

- The sum total of all of the reactions that take place in a living cell is called **metabolism**.



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30-2

Energy

Thermodynamics vs Kinetics

- Thermodynamics** is used to assess if a system is at equilibrium, and if not, which direction it needs to move to reach equilibrium.
- Kinetics** tells us how fast a system that is not at equilibrium will approach equilibrium

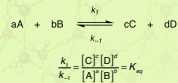
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31

Energy

Reaction Rates

- For chemical reactions, the speed, or rate of a reaction is dependent on the relative concentrations of the reactants and the products of the reaction.
- Enzymes, as catalysts, can speed up the rate of a reaction.
- All reactions are striving to reach equilibrium



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32

Thermodynamics

- Thermodynamic** can be used to tell us where an equilibrium is.
- Thermodynamics is the study the transformations of heat, work and energy.
- There are different ways to measure energy, the one that will be of most useful to us is the **Gibb's free energy (G)**.

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33

Thermodynamics

- All molecules have free energy
- For molecules in solution, the free energy is influenced by composition, temperature and concentration.
- The change in the free energy for a reaction, ΔG , is the difference between the sum of the free energies of the products and reactants in a reaction.

$$\Delta G = (G_C + G_D) - (G_A + G_B)$$

(products) (reactants)

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34

Thermodynamics

- Under the conditions for most reactions that take place in a cell, the ΔG has two components
 - ΔH , the change in **enthalpy** or heat content
 - ΔS , the change in the **entropy**, or order of the system.

$$\Delta G = \Delta H - T \Delta S$$

where T is temperature,
and is constant

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35

Thermodynamics

- If the pressure is also constant, ΔG can be used to tell us which way a reaction needs to proceed order to reach equilibrium.
 - When $\Delta G < 0$ (free energy is released)
 - When $\Delta G > 0$ (free energy is absorbed)
 - When $\Delta G = 0$

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36-1

Thermodynamics

- If the pressure is also constant, ΔG can be used to tell us which way a reaction needs to proceed order to reach equilibrium.
 - When $\Delta G < 0$ (free energy is released)
 $A + B \longrightarrow C + D$
 - When $\Delta G > 0$ (free energy is absorbed)
 - When $\Delta G = 0$

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36-2

Thermodynamics

- If the pressure is also constant, ΔG can be used to tell us which way a reaction needs to proceed order to reach equilibrium.
 - When $\Delta G < 0$ (free energy is released)
 $A + B \longrightarrow C + D$
 - When $\Delta G > 0$ (free energy is absorbed)
 $A + B \longleftarrow C + D$
 - When $\Delta G = 0$

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36-3

Thermodynamics

- If the pressure is also constant, ΔG can be used to tell us which way a reaction needs to proceed order to reach equilibrium.
 - When $\Delta G < 0$ (free energy is released)
 $A + B \longrightarrow C + D$
 - When $\Delta G > 0$ (free energy is absorbed)
 $A + B \longleftarrow C + D$
 - When $\Delta G = 0$
 $A + B \rightleftharpoons C + D$

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36-4

Thermodynamics

• The actual free energies for the reactants and products in a reaction are not knowable.

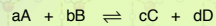
- The free energies, however, do depend in a predictable way on the concentrations of the reactants and products.
- Instead, free energies are determined relative to an arbitrary **standard state**.
- The free energy of the standard state is called **standard state free energy (G°)**.

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37

Thermodynamics

• The free energies at states other than the standard state varies with concentration in a predictable way.



$$\Delta G = \Delta G^\circ + RT \ln \left(\frac{[C]^c [D]^d}{[A]^a [B]^b} \right)$$

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38

Thermodynamics

• For solutions, the standard state is defined as $[A] = [B] = [C] = [D] = 1M$.

$$\Delta G = \Delta G^\circ + RT \ln \left(\frac{[C]^c [D]^d}{[A]^a [B]^b} \right)$$

At the standard state:

$$\Delta G = \Delta G^\circ + RT \ln \left(\frac{(1M)(1M)}{(1M)(1M)} \right)$$

$$\Delta G = \Delta G^\circ + RT \ln(1)$$

$$\Delta G = \Delta G^\circ$$

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39

Energy

• The standard free energy change can be determined from the equilibrium concentrations of the reactants and products in a reaction.

when $\Delta G = 0$ (at equilibrium)

$$\Delta G^\circ = -RT \ln \left(\frac{[C]^c [D]^d}{[A]^a [B]^b} \right)_{eq}$$

$$\Delta G^\circ = -RT \ln(K_{eq})$$

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40

The Cell

• The fundamental unit for living systems is the cell.

- There are two basic cell types, **prokaryotic** and **eukaryotic**.

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41

The Cell

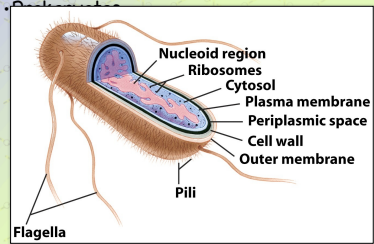
• Prokaryotes

- These were the first to evolve some 3.6 billion years ago.
- They have simpler cell structure.
- These organisms are always unicellular
- They have an cell or plasma membrane, but no internal membrane structures
- They typically have a single, circular chromosome
- They have pili for attaching to surfaces and flagella for motility

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42-1

The Cell



Chem 352, Lecture 1 - Introduction to Biochemistry 42

42-2

The Cell

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42-3

The Cell

• Eukaryotes have a much more complex cell.

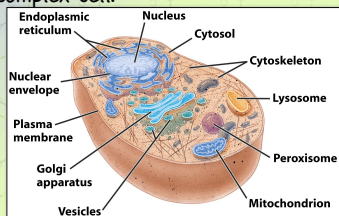
- The evolved around 2 billion years ago.
- These organisms can be multicellular, starting 1 billion years ago.
- These cells have volumes that are about 1000 times larger than a prokaryotic cell.
- In addition to a plasma membrane, they have membrane enclosed structures called **organelles** within the cell, which have dedicated functions

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43-1

The Cell

• Eukaryotes have a much more complex cell.

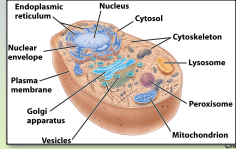


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43-2

The Cell

- Some of the organelles include
 - The **endoplasmic reticulum (ER)**
 - The **golgi apparatus**
 - The **mitochondria**
 - The **chloroplasts**

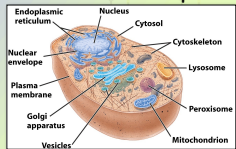
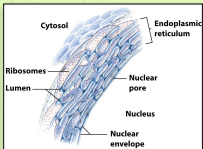


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44-1

The Cell

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 - The **endoplasmic reticulum (ER)**
 - The **golgi apparatus**
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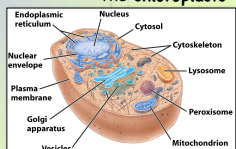



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44-2

The Cell

- Some of the organelles include
 - The **endoplasmic reticulum (ER)**
 - The **golgi apparatus**
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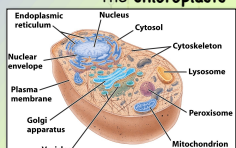
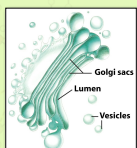


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44-3

The Cell

- Some of the organelles include
 - The **endoplasmic reticulum (ER)**
 - The **golgi apparatus**
 - The **mitochondria**
 - The **chloroplasts**

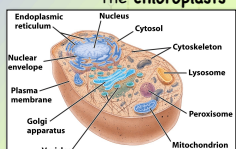



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44-4

The Cell

- Some of the organelles include
 - The **endoplasmic reticulum (ER)**
 - The **golgi apparatus**
 - The **mitochondria**
 - The **chloroplasts**



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44-5

The Cell

- Some of the organelles include
 - The **endoplasmic reticulum (ER)**
 - The **golgi apparatus**
 - The **mitochondria**
 - The **chloroplasts**

44-6

The Cell

- Some of the organelles include
 - The **endoplasmic reticulum (ER)**
 - The **golgi apparatus**
 - The **mitochondria**
 - The **chloroplasts**

44-7

The Cell

- Some of the organelles include
 - The **endoplasmic reticulum (ER)**
 - The **golgi apparatus**
 - The **mitochondria**
 - The **chloroplasts**

44-8

The Cell

- Some of the organelles include
 - The **endoplasmic reticulum (ER)**
 - The **golgi apparatus**
 - The **mitochondria**
 - The **chloroplasts**

44-9

Science Podcast on Cyanobacteria

- Science Magazine website (www.sciencemag.org)
- Podcast on Cyanobacteria
- Provides an introduction to many of the terms we will be using this semester.

45

Prokaryotes and Eukaryotes

Body's Hardworking Microbes Get Some Overdue Respect

HUMANS HAVE BEEN DOING BATTLE WITH bacteria since the 1600s, throwing disease with antibiotics, vaccines, and good hygiene will never cease. But in 2005, Nobel laureate Joshua Lederberg called for an end to the "the good, the bad, and the ugly" that has fueled our war against microbes. "We should think of each other and its partner as a superorganism with the respective genomes and a common destiny," he wrote in *Science* in 2000.

His comments were prescient. This past decade has seen a shift in how we see the microbes and viruses in and on our bodies. There is increasing acceptance that they are us, and for good reason. Nine in 10 of the cells in the body are microbial. In the gut alone, as many as 1000 species living in the body 100 times as many genes as our own DNA genome. A few microbes make us sick, but most are commensal and just call the human body home. Collectively, they are

sequenced 500 relevant microbial genomes out of a planned 1000.

Some of these microbes may play important roles in metabolic processes. In 2004, a team led by Jeffrey Gordon of Washington University School of Medicine in St. Louis, Missouri, found that germ-free mice gained weight after they were repopulated with gut bacteria—evidence that these bacteria helped the body harvest more energy from digested foods. Later studies showed that both obese mice and obese people have had more *obesigenic* bacteria than their normal-weight counterparts.

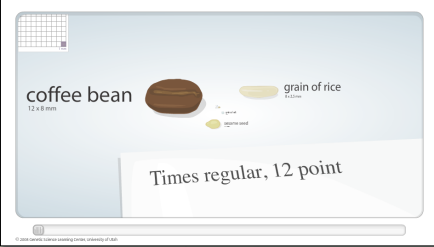
The immune system is also growing critical in many aspects of health. The immune system teaches to develop properly. What's more, to protect themselves inside the body, commensal bacteria can interact with immune cell receptors or even induce the production of certain immune system cells. One abundant gut bacterium, *Lactobacillus reuteri*, is known to have anti-inflammatory properties, and its abundance seems to help protect against the recurrence of Crohn's disease. Likewise, Sandy Muehlenkamp of the California Institute of Technology in Pasadena

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46

Putting Things in Perspective

CELL SIZE AND SCALE



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47

The Cell

Miniseries: Illustrating the Machinery of Life Escherichia coli*

David S. Goodsell

From the Department of Molecular Biology, The Scripps Research Institute, La Jolla, California

Diverse biological data may be used to create illustrations of molecules in their cellular context. I describe the scientific results that support a recent textbook illustration of an *Escherichia coli* cell. The image highlights a portion of the bacterium at one million times, showing the location and form of individual macromolecules. Results from biochemistry, electron microscopy, and X-ray crystallography were used to create the image.

Keywords: Cellular biology, molecular biology, molecular visualization, textbook, diagrams.

*A clear picture of the interior of a living cell that shows the average distribution of molecules of the cell. I relied on a hybrid approach. I took the concentration of macromolecules from the same sources that I used in the 1991 article. This includes the overall value of 20% water for the cell, as well as the number of proteins, RNA, lipids, and other molecules. I also used the same values for the concentrations for the major players in metabolism, nucleic acids, and other macromolecules.

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48

Molecular Resources

- **Marvin**
 - A tool for drawing and analyzing small molecules
- **The Protein Data Bank (PDB)**
 - A database where you can find and observe the structures of biological macromolecules and aggregates of these molecules.
 - Not limited to proteins

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49

Next up

- **Lecture 2 - Water**
 - Water's physical properties
 - Boiling point and Melting point
 - Intermolecular interactions
 - Water's chemical properties
 - pH and acids & bases
- **Reading**
 - Chapter 2 of Moran et al.

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50