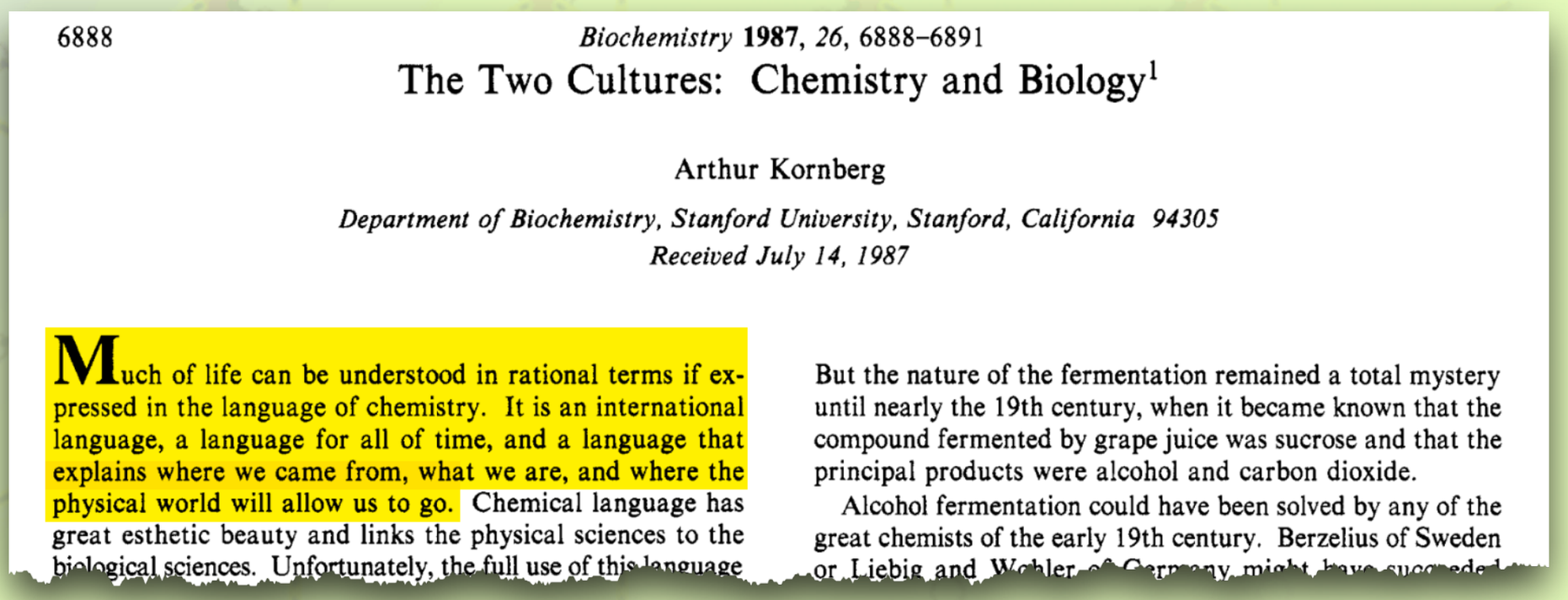
Chem 352 - Lecture 1
Introduction to Biochemistry

Question for the Day: *What characteristics distinguishes a living systems, such as yourself, from a non-living system?*

Introduction

"*Much of life [bio] can be understood in rational terms if expressed in the language of chemistry. It is an international language, a language for all time, and a language that explains where we came from, what we are, and where the physical world will allow us to go.*" Arthur Kornberg, 1987.



6888 *Biochemistry* **1987**, *26*, 6888–6891

The Two Cultures: Chemistry and Biology[1]

Arthur Kornberg

Department of Biochemistry, Stanford University, Stanford, California 94305

Received July 14, 1987

Much of life can be understood in rational terms if expressed in the language of chemistry. It is an international language, a language for all of time, and a language that explains where we came from, what we are, and where the physical world will allow us to go. Chemical language has great esthetic beauty and links the physical sciences to the biological sciences. Unfortunately, the full use of this language

But the nature of the fermentation remained a total mystery until nearly the 19th century, when it became known that the compound fermented by grape juice was sucrose and that the principal products were alcohol and carbon dioxide.

Alcohol fermentation could have been solved by any of the great chemists of the early 19th century. Berzelius of Sweden or Liebig and Wöhler of Germany might have succeeded

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- Kornberg shared the 1959 Nobel Prize with Severo Ochoa "*for their discovery of the mechanisms in biological synthesis of ribonucleic acid and deoxyribonucleic acid.*"

Introduction

The language of biochemistry

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The language of biochemistry

- ***Words***: Chemical names and structures
- ***Sentences***: Chemical reactions
  - ***Subjects***: Reactants
  - ***Predicate***: Products
    - ***Verbs***: Enzymes (the biological catalysts)
- ***Paragraphs***: Metabolic Pathways

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- ***Paragraphs***: Metabolic Pathways

Interactive Metabolic Map

- http://www.metabolic-pathway.com/fullMap.html

The Origins of Biochemistry

The Science of Biochemistry

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- For over 8,000 years humans have made use of fermentation as a way of preserving dietary calories.

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The Science of Biochemistry

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- For over 8,000 years humans have made use of fermentation as a way of preserving dietary calories.
  - When fermentation is carried out by the fungus yeast, sugar is converted to CO_2 and ethanol (bread, beer, wine)
  - When fermentation is carried out by certain bacteria, sugar is converted to lactic acid (yogurt), or acetic acid (vinegar).

The Science of Biochemistry

The Origins of Biochemistry

- ***Concept:*** *Early biochemists had to confront the doctrine of* ***vitalism****, which claimed that living matter and nonliving matter were fundamentally different.*

The Science of Biochemistry

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  - It argued the living organisms were able to do this because they possessed a special "life force".
- It was Friedrich Wöhler who demonstrated that a special "life force" was not necessary to the organic molecule urea.

The Science of Biochemistry

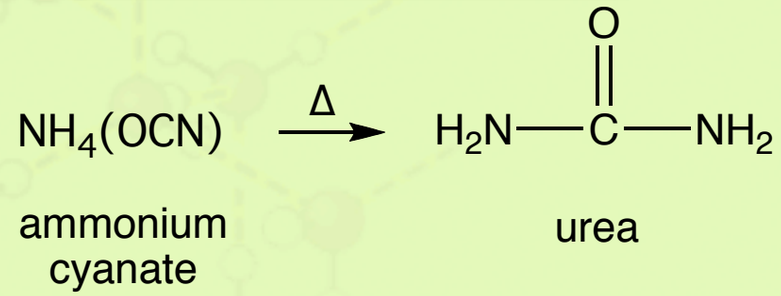
The Origins of Biochemistry

The Science of Biochemistry

The Origins of Biochemistry

- Friedrich Wöhler (1800-1882) is credited with challenging this doctrine in 1828 when he carried out a simple experiment showing that the *organic* molecule, **urea**, could be synthesized from an *inorganic* salt, **ammonium cyanate**



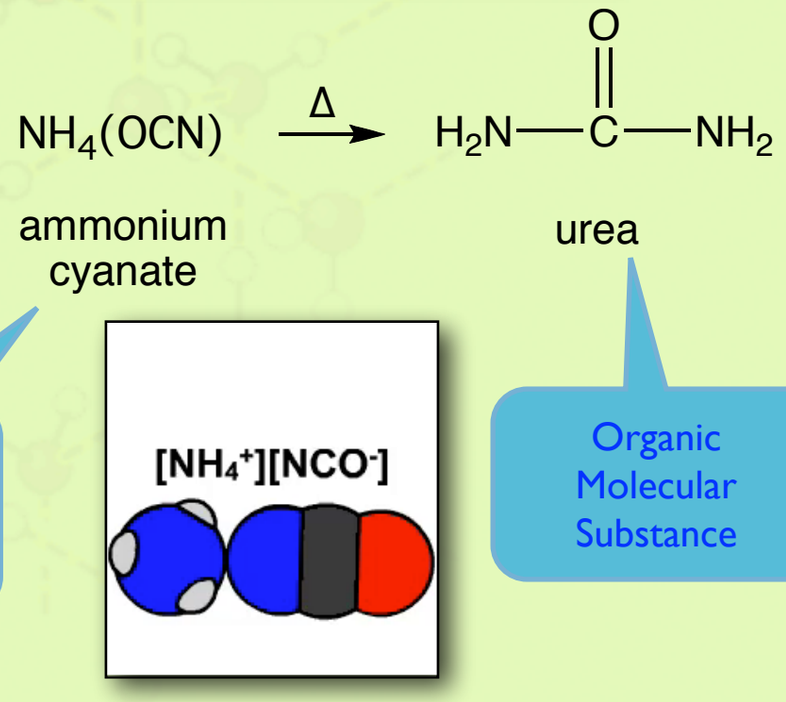


The Science of Biochemistry

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The Science of Biochemistry

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The Science of Biochemistry

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- They studied yeasts ability to ferment sugar into CO_2 and ethanol.
- Eduard (1860-1917) and Hans (1850-1902) Buchner were able to show that living yeast cells were not required for alcohol fermentation.
- Extracts from dead yeast cells could also carry out fermentation of sugars.



Nobel Prize 1907



The Science of Biochemistry

The Origins of Biochemistry

- In the late 1800's it was recognized that catalysts were responsible for fermentation.
  - These catalysts were named ***enzymes***

The Science of Biochemistry

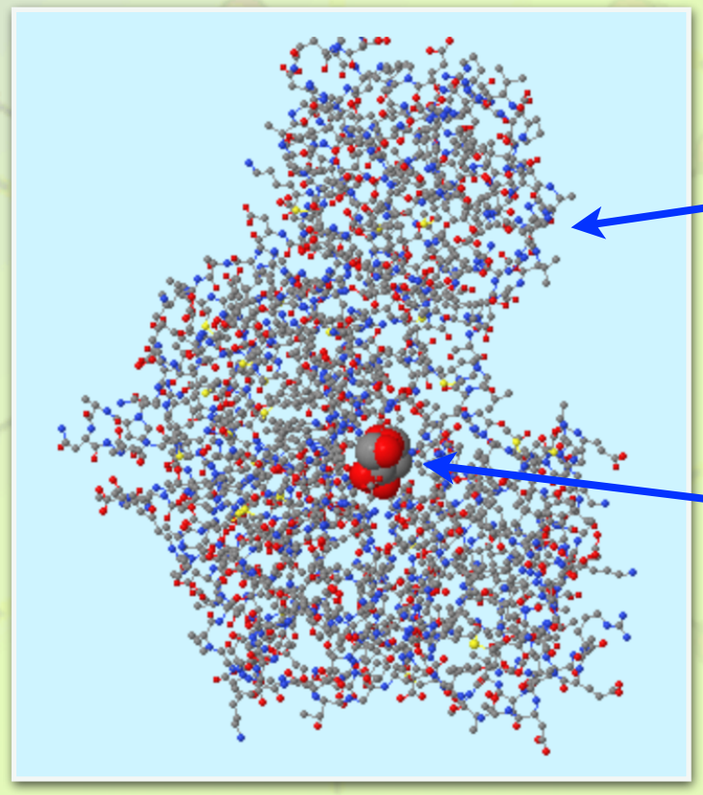
The Origins of Biochemistry

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Hexokinase
the enzyme that catalyzes the first reaction in glycolysis and fermentation pathways.
Molecular weight = 49,600 g/mol

Glucose
a sugar that is the reactant for the reaction catalyzed by hexokinase
Molecular weight = 180 g/mol

The Science of Biochemistry

The Origins of Biochemistry

The Science of Biochemistry

The Origins of Biochemistry

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  - These elements became known as ***genes***

The Science of Biochemistry

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  - These elements became known as ***genes***
- In the early 1900's, genes were discover to be associated with cellular structures called ***chromosomes***, which are composed of both proteins and nucleic acids.
  - At first it was believed that the genetic information of genes was stored in the protein portion of the chromosome.

The Science of Biochemistry

The Origins of Biochemistry

The Science of Biochemistry

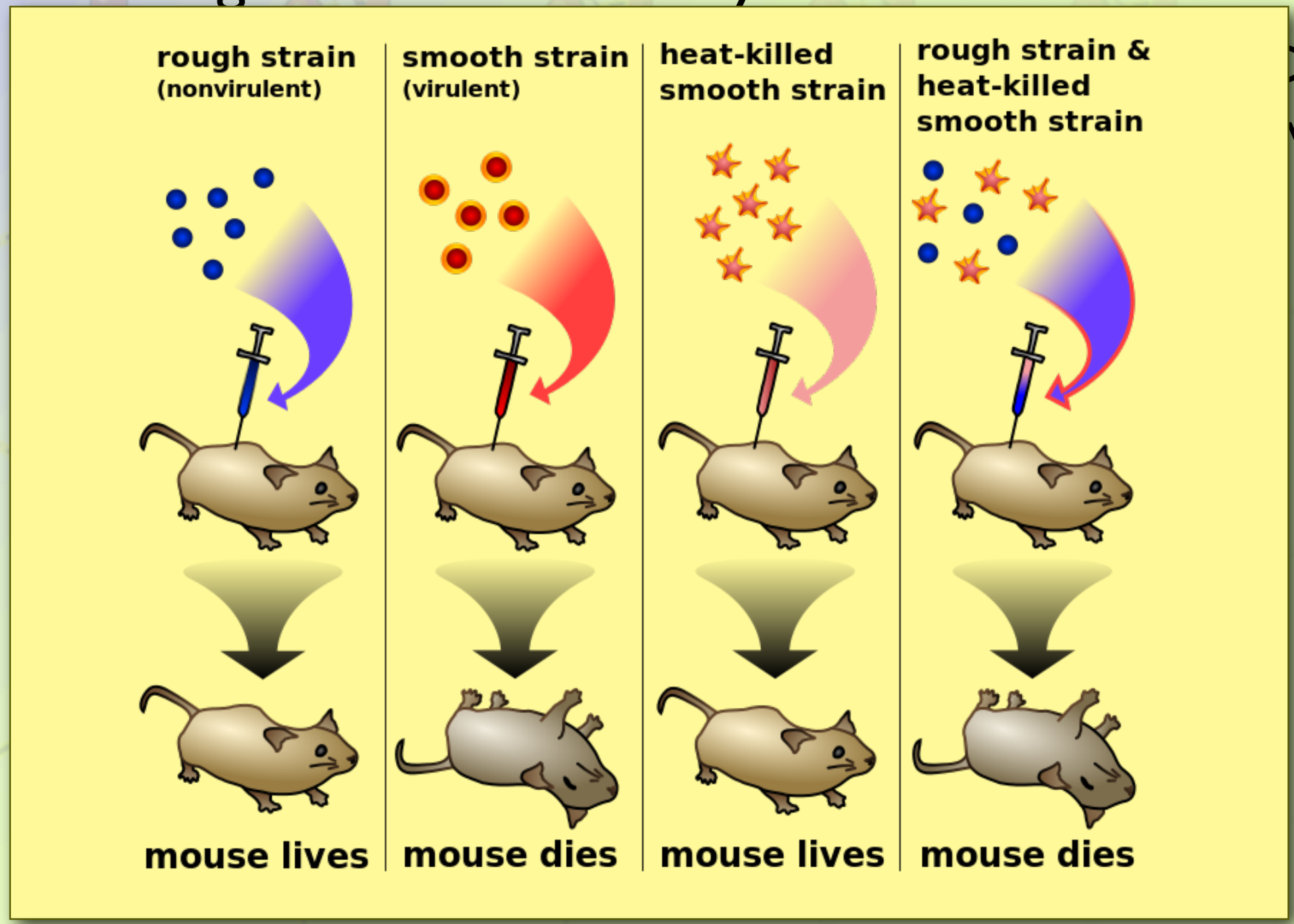
The Origins of Biochemistry

- However, experiments in the 1940's Oswald Avery, Colin MacLeod and Maclyn McCarty demonstrated that it was a form of nucleic acid called ***DNA***, which actually contained the genetic information.
  - ***DNA*** stands for ***deoxyribonucleic acid***.

The Science of Biochemistry

The Origins of Biochemistry

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The Science of Biochemistry

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  - ***DNA*** stands for ***deoxyribonucleic acid***.
- This spurred great interest learning more about the nucleic acids, both ribonucleic acid (RNA) and deoxyribonucleic acid (DNA).

The Science of Biochemistry

The Origins of Biochemistry

- ***Concept:*** *Biology was transformed in 1953, when James Watson and Francis Crick proposed the double-helical model for DNA structure.*

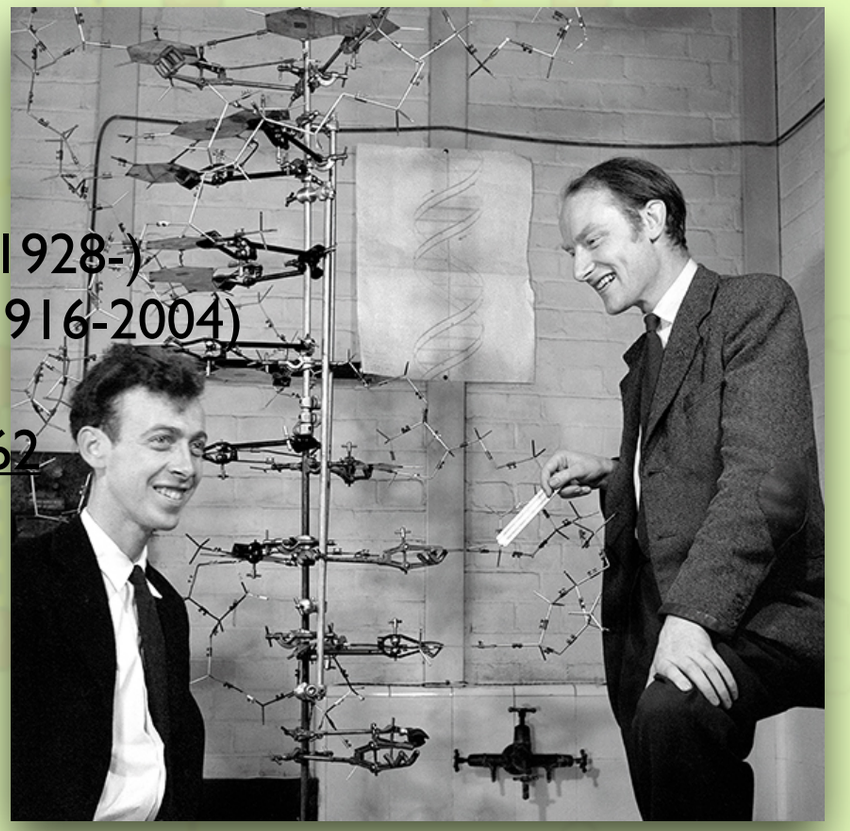
The Science of Biochemistry

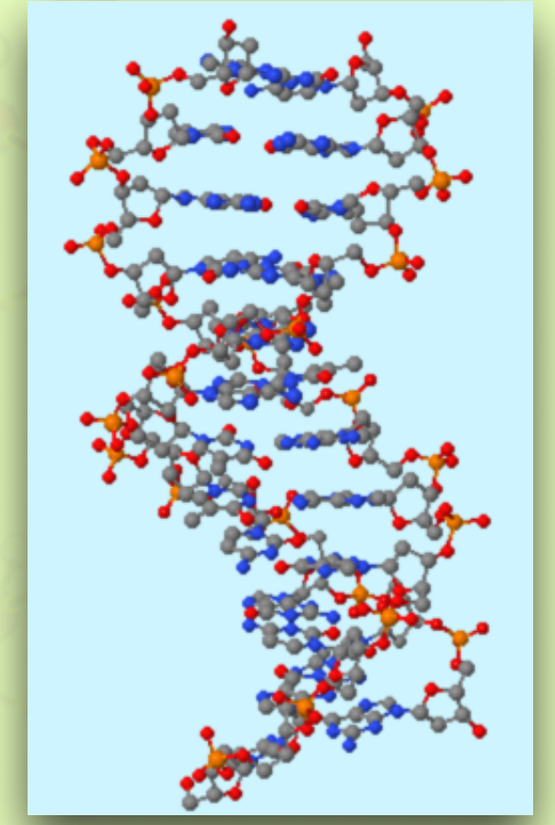
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James Watson (1928-)
Francis Crick (1916-2004)

Nobel Prize 1962

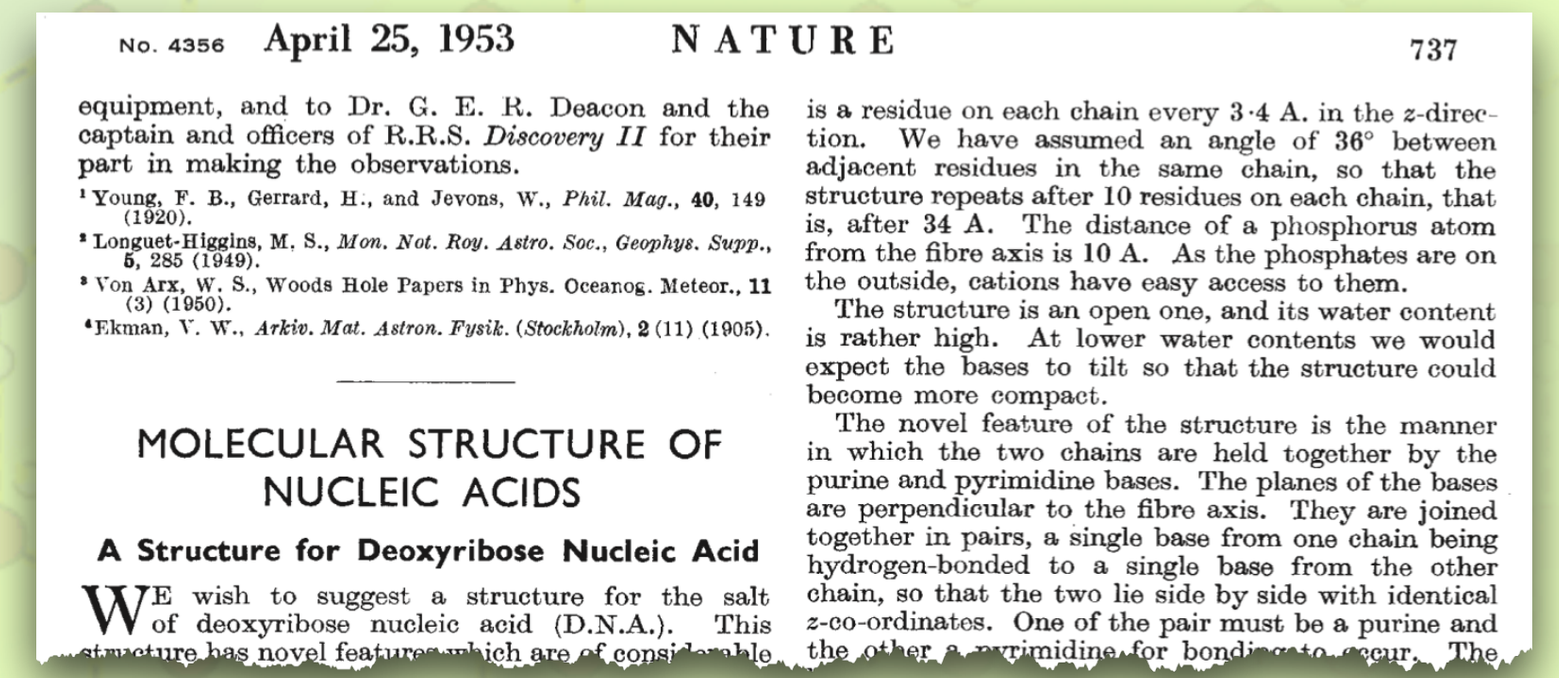




The Science of Biochemistry

The Origins of Biochemistry

- Watson and Crick's model gained almost immediate acceptance because of its ability to explain how genetics information could be replicated and passed down to the next generation.



No. 4356 April 25, 1953 NATURE 737

equipment, and to Dr. G. E. R. Deacon and the captain and officers of R.R.S. *Discovery II* for their part in making the observations.

[1] Young, F. B., Gerrard, H., and Jevons, W., *Phil. Mag.*, **40**, 149 (1920).
[2] Longuet-Higgins, M. S., *Mon. Not. Roy. Astro. Soc., Geophys. Supp.*, **5**, 285 (1949).
[3] Von Arx, W. S., Woods Hole Papers in Phys. Oceanog. Meteor., **11** (3) (1950).
[4] Ekman, V. W., *Arkiv. Mat. Astron. Fysik.* (*Stockholm*), **2** (11) (1905).

MOLECULAR STRUCTURE OF NUCLEIC ACIDS

A Structure for Deoxyribose Nucleic Acid

WE wish to suggest a structure for the salt of deoxyribose nucleic acid (D.N.A.). This structure has novel features which are of considerable

is a residue on each chain every 3·4 A. in the *z*-direction. We have assumed an angle of 36° between adjacent residues in the same chain, so that the structure repeats after 10 residues on each chain, that is, after 34 A. The distance of a phosphorus atom from the fibre axis is 10 A. As the phosphates are on the outside, cations have easy access to them.

The structure is an open one, and its water content is rather high. At lower water contents we would expect the bases to tilt so that the structure could become more compact.

The novel feature of the structure is the manner in which the two chains are held together by the purine and pyrimidine bases. The planes of the bases are perpendicular to the fibre axis. They are joined together in pairs, a single base from one chain being hydrogen-bonded to a single base from the other chain, so that the two lie side by side with identical *z*-co-ordinates. One of the pair must be a purine and the other a pyrimidine for bonding to occur. The

The Science of Biochemistry

The Origins of Biochemistry

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The Origins of Biochemistry

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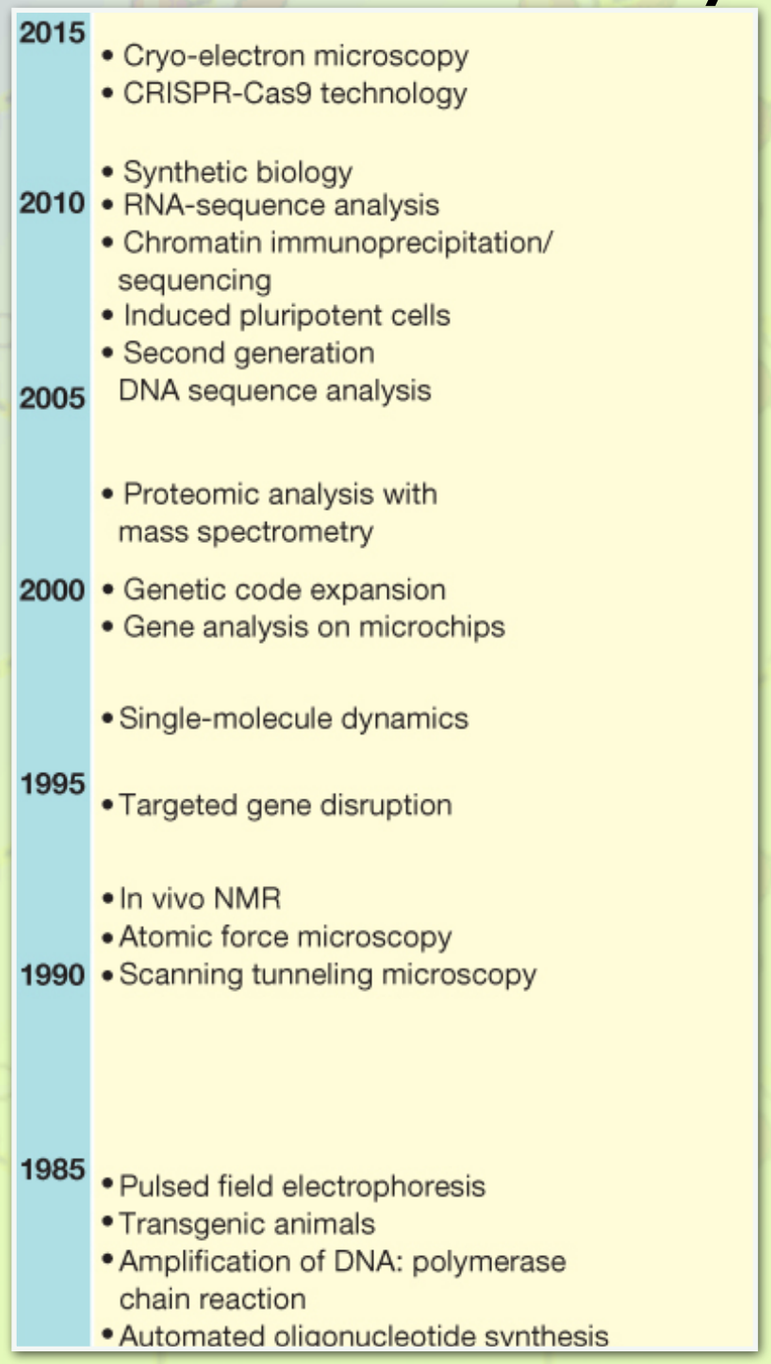
The Science of Biochemistry

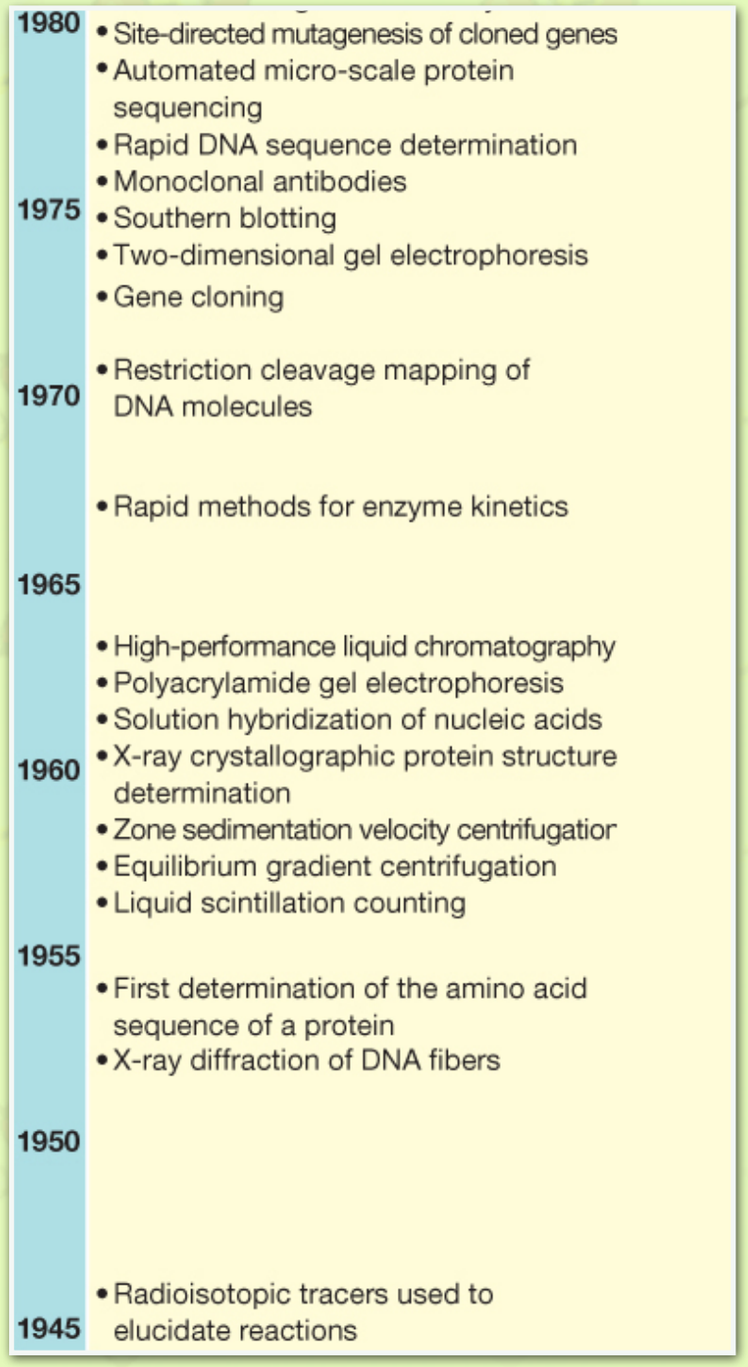
The Science of Biochemistry

The Tools of Biochemistry

The Science of Biochemistry

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Concept: *Powerful new chemical and physical techniques have accelerated the pace at which biological processes have become understood in molecular terms.*

The Science of Biochemistry

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- Many of the chapters in *Appling et al.* have end-of-chapter sections called *Tools of Biochemistry*

The Science of Biochemistry

The Tools of Biochemistry

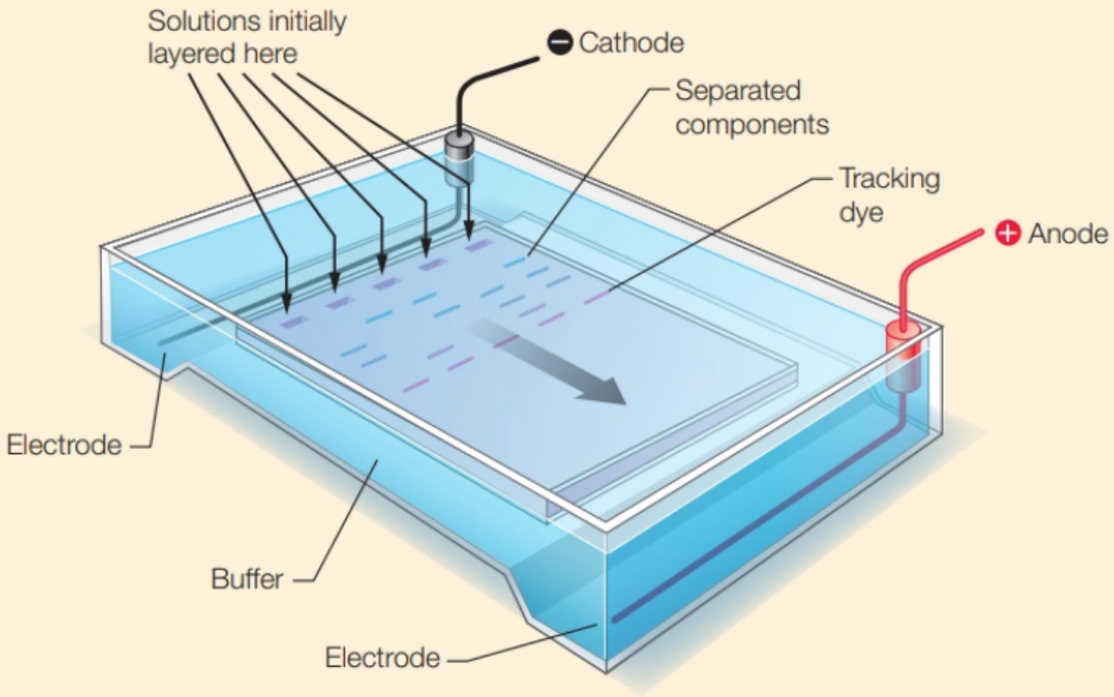
TOOLS OF BIOCHEMISTRY | 2A Electrophoresis and Isoelectric Focusing

When an electric field is applied to a solution, solute molecules with a net positive charge migrate toward the cathode, and molecules with a net negative charge move toward the anode. This migration is called **electrophoresis.** Although electrophoresis can be carried out free in solution, it is more convenient to use some kind of *supporting medium* through which the charged molecules move. The supporting medium could be paper or, most typically, a gel composed of the polysaccharide agarose (commonly used to separate nucleic acids; see FIGURE 2A.1) or crosslinked polyacrylamide (commonly used to separate proteins).

The velocity, or **electrophoretic mobility (μ),** of the molecule in the field is defined as the ratio between two opposing factors: the force exerted by the electric field on the charged particle, and the frictional force exerted on the particle by the medium:

$$\mu = \frac{Ze}{f} \qquad (2A.1)^3$$

The numerator equals the product of the negative (or positive) charge (e) times the number of unit charges, Z (a positive or negative integer). The greater the overall charge on the molecule, the greater the force it experiences in the electric field. The denominator f is the **frictional coefficient,** which depends on the size and shape of the molecule. Large or asymmetric molecules encounter more frictional resistance than small or compact ones and consequently have larger frictional coefficients. Equation 2A.1 tells us that the mobility of a molecule depends on its charge, its molecular



▲ FIGURE 2A.1 **Electrophoresis.** A molecule with a net positive charge will migrate toward the cathode, whereas a molecule with a net negative charge will migrate toward the anode.

or nucleic acid mixture was applied as a narrow band in the well of the gel, components migrating with different electrophoretic mobilities appear as separated bands on the gel. FIGURE 2A.3 shows an example of separation of DNA fragments by this method using an agarose gel

The Science of Biochemistry

The Tools of Biochemistry

Concept: *Powerful new chemical and physical techniques have accelerated the pace at which biological processes have become understood in molecular terms.*

- Many of the chapters in *Appling et al.* have end-of-chapter sections called *Tools of Biochemistry*
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- Many of the chapters in *Appling et al.* have end-of-chapter sections called *Tools of Biochemistry*
  - These provide insight into the the tools that have greatly expanded our understanding of biochemistry during the past century.
- In this course we will not be focusing on these tools, but rather the information they provide.
  - For example, in Lecture 2 we will be considering the charge on a biomolecule; electrophoresis is a tool that can be used to separate biomolecules based on their charge.

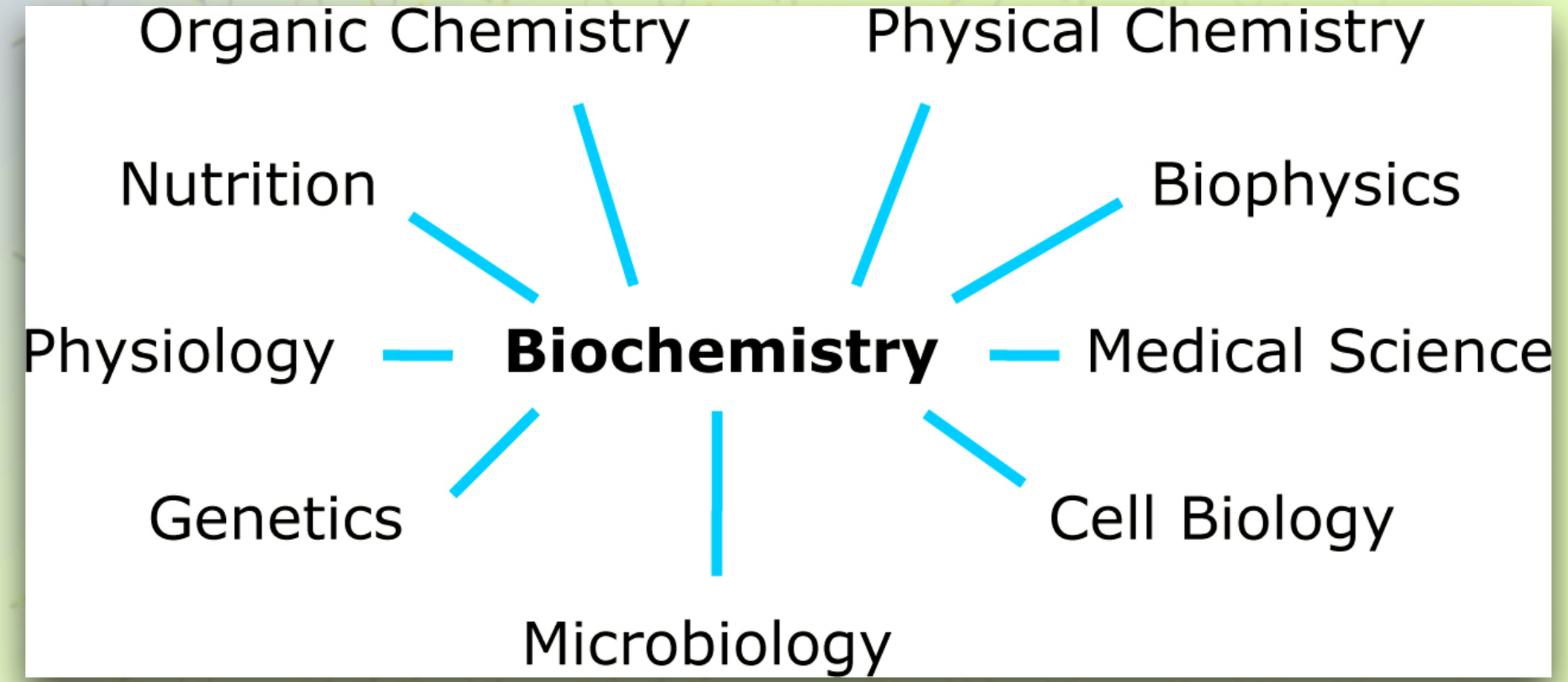
The Science of Biochemistry

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The Elements and Molecules of Living Systems

Elements and Molecules of Living Systems

The Chemical Elements of Cells and Organisms

Elements and Molecules of Living Systems

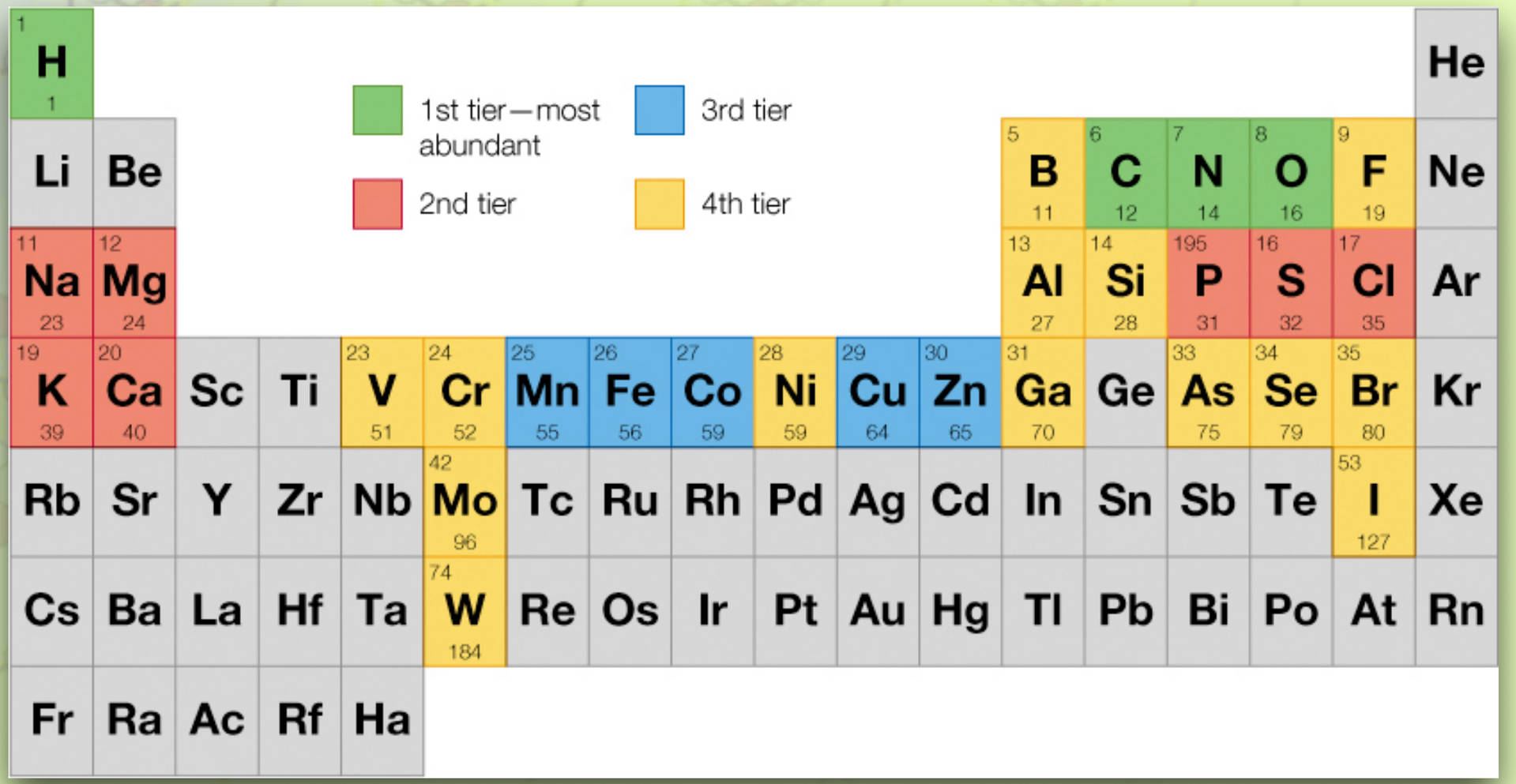
The Chemical Elements of Cells and Organisms

- ***Concept:*** *Life depends primarily on a few elements (C, H, O, N, S and P), although many others have essential functions as well.*

Elements and Molecules of Living Systems

The Chemical Elements of Cells and Organisms

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Elements and Molecules of Living Systems

The Origin of Biomolecules and Cells

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Elements and Molecules of Living Systems

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Video:
- The Miller-Urey Experiment Explained

Elements and Molecules of Living Systems

The Origin of Biomolecules and Cells

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- Even though the theory of evolution can explain how more complex life forms evolved from simpler ones, it does not explain how cells, as the basic unit of living systems, first formed.

Elements and Molecules of Living Systems

The Origin of Biomolecules and Cells

- Even though the theory of evolution can explain how more complex life forms evolved from simpler ones, it does not explain how cells, as the basic unit of living systems, first formed.
- Many biochemists, however, believe that ancient cells used ribonucleic acid (RNA) to carry out the roles that both DNA and proteins now play in living cells.
- That time in our history is often referred to as the"RNA World"

Elements and Molecules of Living Systems

The Origin of Biomolecules and Cells

Elements and Molecules of Living Systems

The Origin of Biomolecules and Cells

- Timeline
  - The Earth is around 4.6 billion years old

Elements and Molecules of Living Systems

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Elements and Molecules of Living Systems

The Origin of Biomolecules and Cells

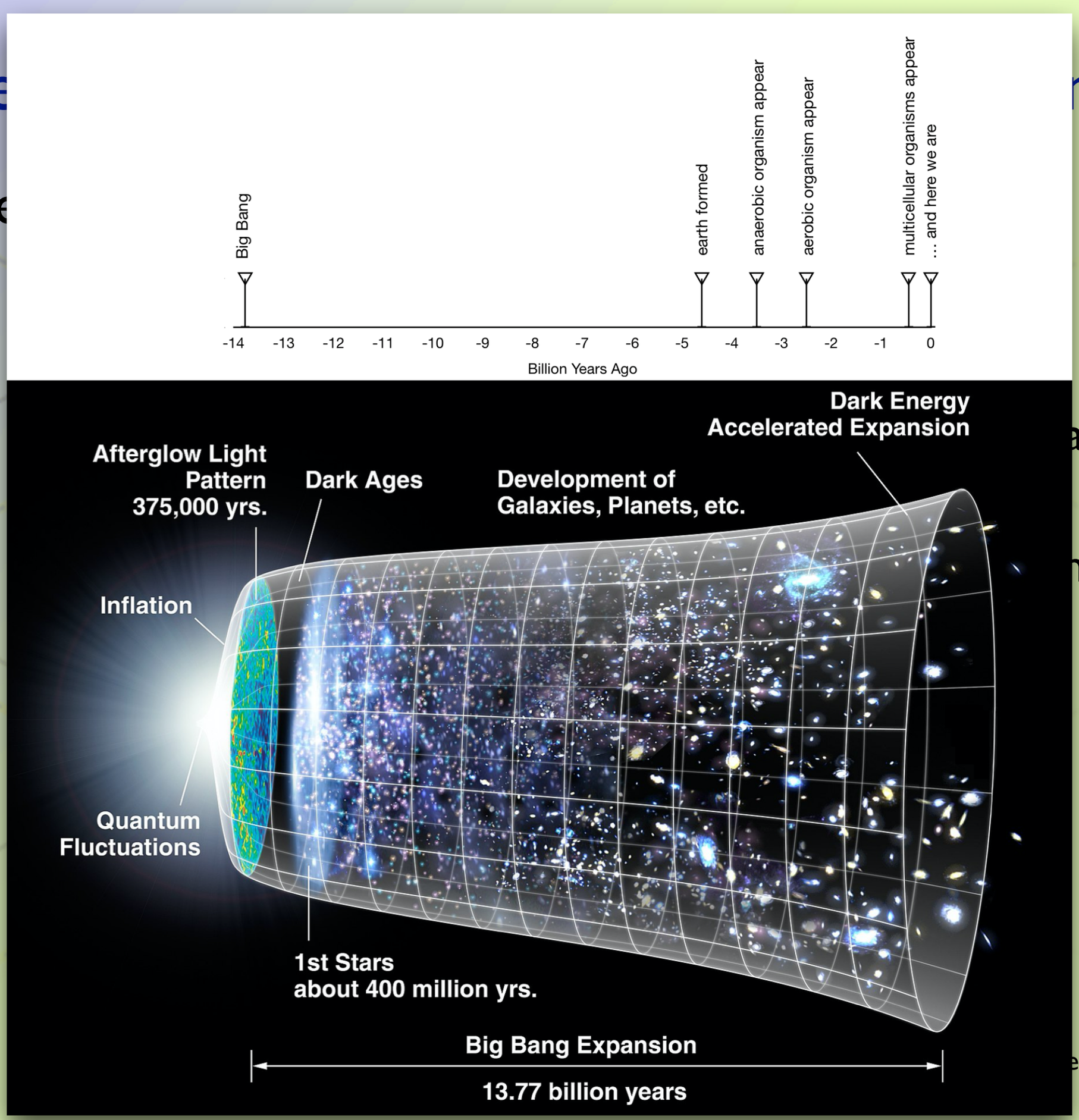
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Elements and Molecules of Living Systems

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The Complexity and Size of Biological Molecules

- The complexity and size of biological molecules is very wide-ranging.

Elements and Molecules of Living Systems

The Complexity and Size of Biological Molecules

- The complexity and size of biological molecules is very wide-ranging.
- When referencing the size of a single biological molecule we will use the unit of mass called a Dalton (Da)
  - If a mole (6.02×10^{23}) of carbon-12 atoms weighs 12 g, then one carbon atom weighs 12 Da.
  - If a mole of a particular protein weighs 49,212 g, then one molecule of that protein weighs 49,212 Da

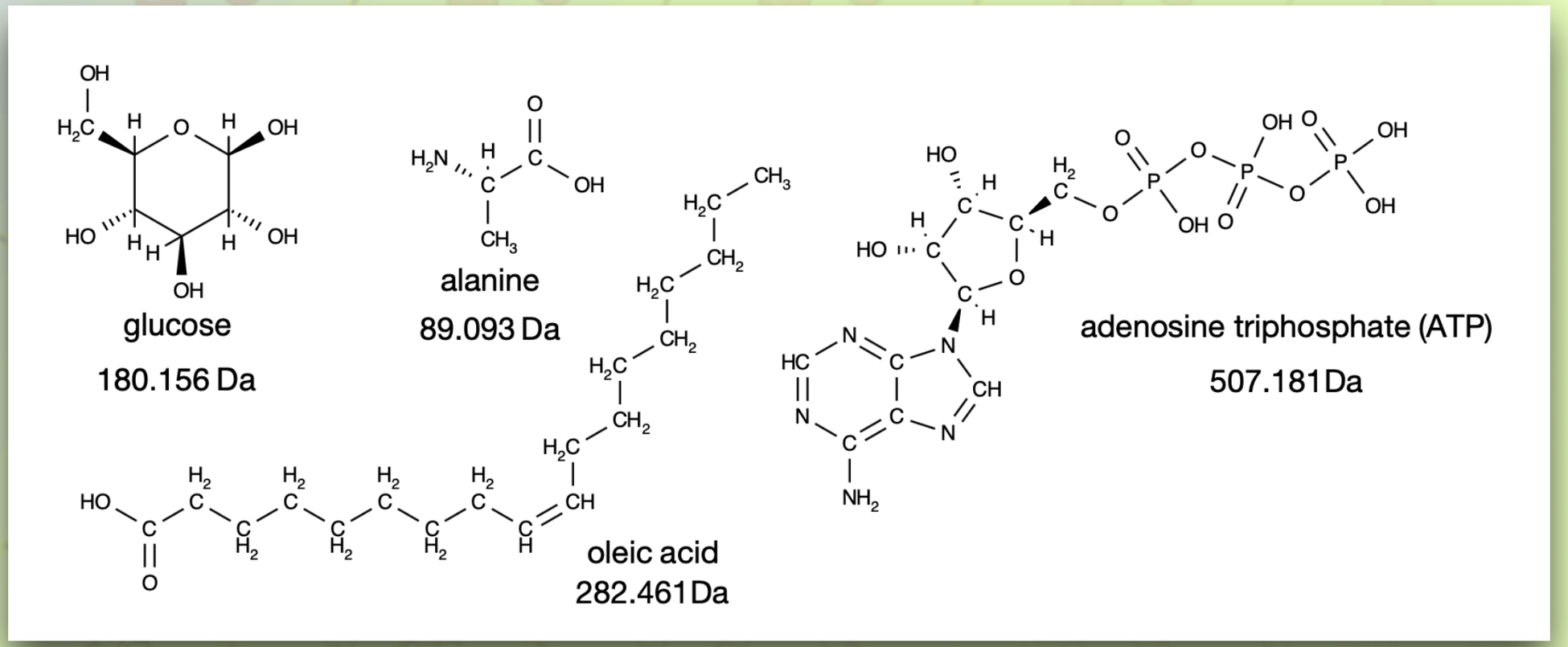
Elements and Molecules of Living Systems

The Complexity and Size of Biological Molecules

Elements and Molecules of Living Systems

The Complexity and Size of Biological Molecules

- The smaller sized molecules, often referred to as ***metabolites***, include sugars, amino acids, fatty acids and nucleotides.



Elements and Molecules of Living Systems

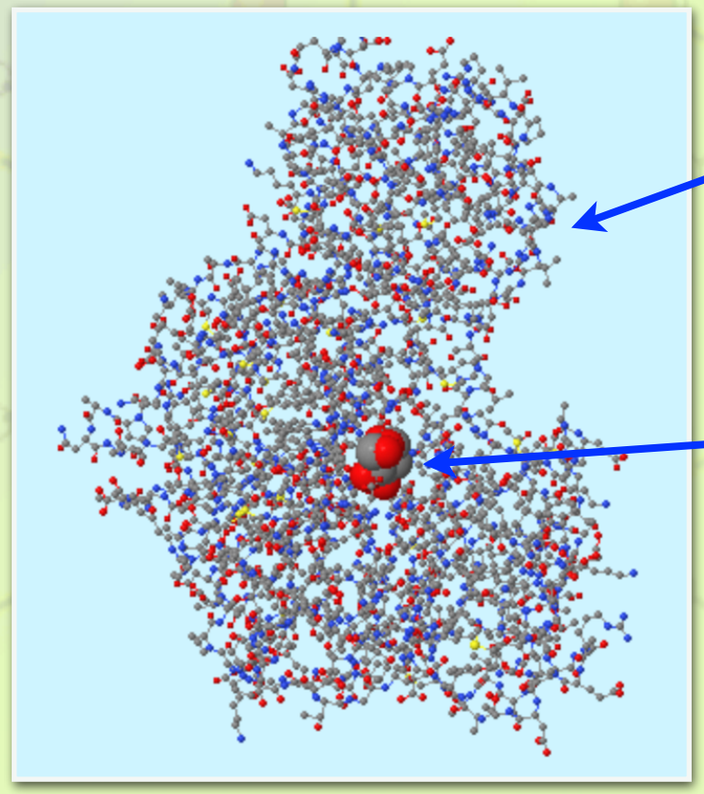
The Complexity and Size of Biological Molecules

- At the other end of the spectrum are the biological ***macromolecules***.

Elements and Molecules of Living Systems

The Complexity and Size of Biological Molecules

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  - Proteins (7,000 Da → 1million Da)



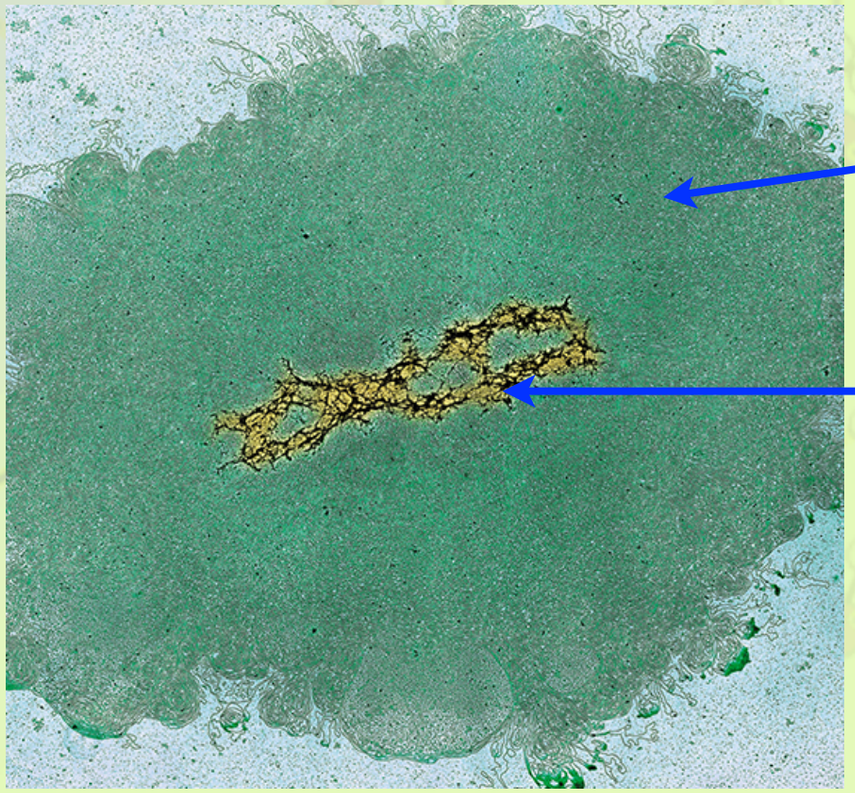
Hexokinase
the enzyme that catalyzes the first reaction in glycolysis and fermentation pathways.
49,600 Da

Glucose
a sugar that is the reactant for the reaction catalyzed by hexokinase
180 Da

Elements and Molecules of Living Systems

The Complexity and Size of Biological Molecules

- At the other end of the spectrum are the biological ***macromolecules***.
  - Proteins (7,000 Da → 1million Da)
  - Nucleic acids (→ 20 billion Da)



DNA
loops out from the protein skeleton
of a human chromosome
~ 20,000,000,000 Da

Protein
protein skeleton of this chromosome

Elements and Molecules of Living Systems

The Biopolymers: Proteins, Nucleic Acids, and Carbohydrates

Elements and Molecules of Living Systems

The Biopolymers: Proteins, Nucleic Acids, and Carbohydrates

- ***Concept:*** *Cells use a modular approach for constructing large molecules*

Elements and Molecules of Living Systems

The Biopolymers: Proteins, Nucleic Acids, and Carbohydrates

- ***Concept:*** *Cells use a modular approach for constructing large molecules*
- The good news is that the biological macromolecules are ***polymers***.
  - This means that they are made by joining small molecules called ***monomers*** together, much like beads on a string.
  - When all of the monomers are the same, the result is called a ***homopolymers***.
  - When different monomers are used, the result is called a ***heteropolymer***.
  - Polymers can be either ***linear*** or ***branched***.

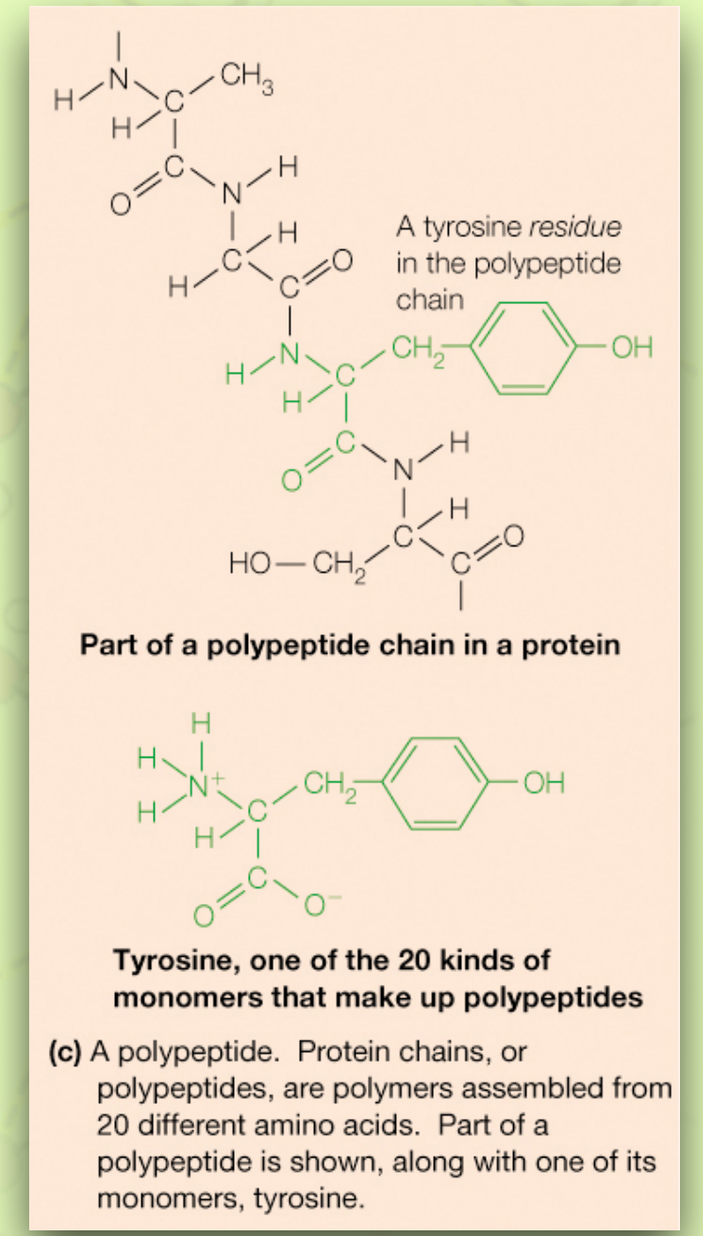
Elements and Molecules of Living

The Biopolymers: Proteins, Nucleic Acids, and Carbohydrates

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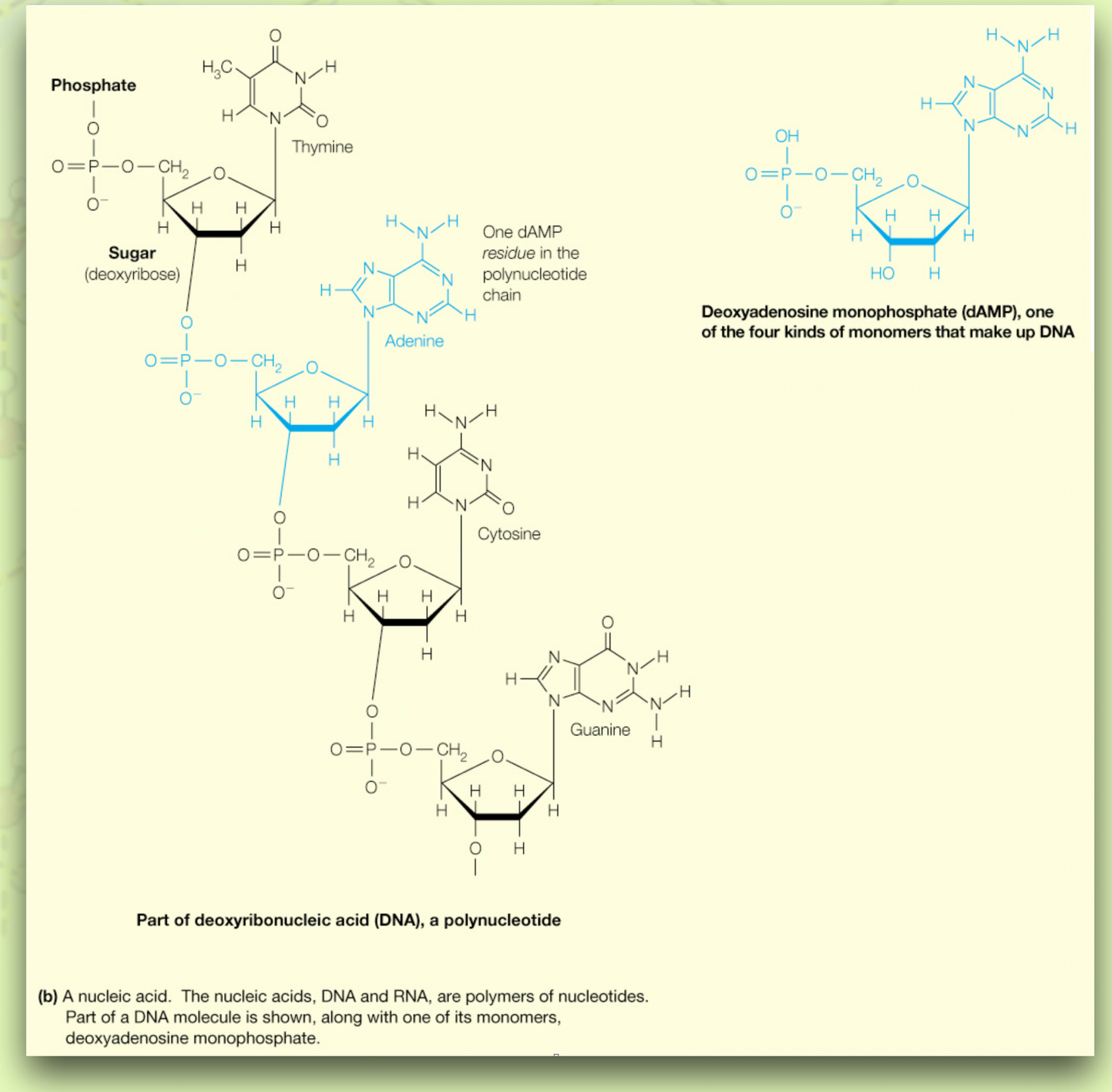
- **Proteins** are ***linear heteropolymers*** of amino acid monomers.



Elements and Molecules of Living

The Biopolymers: Proteins, Nucleic Acids, and Carbohydrates

- **Nucleic** acids are ***linear heteropolymers*** of nucleotide monomers.



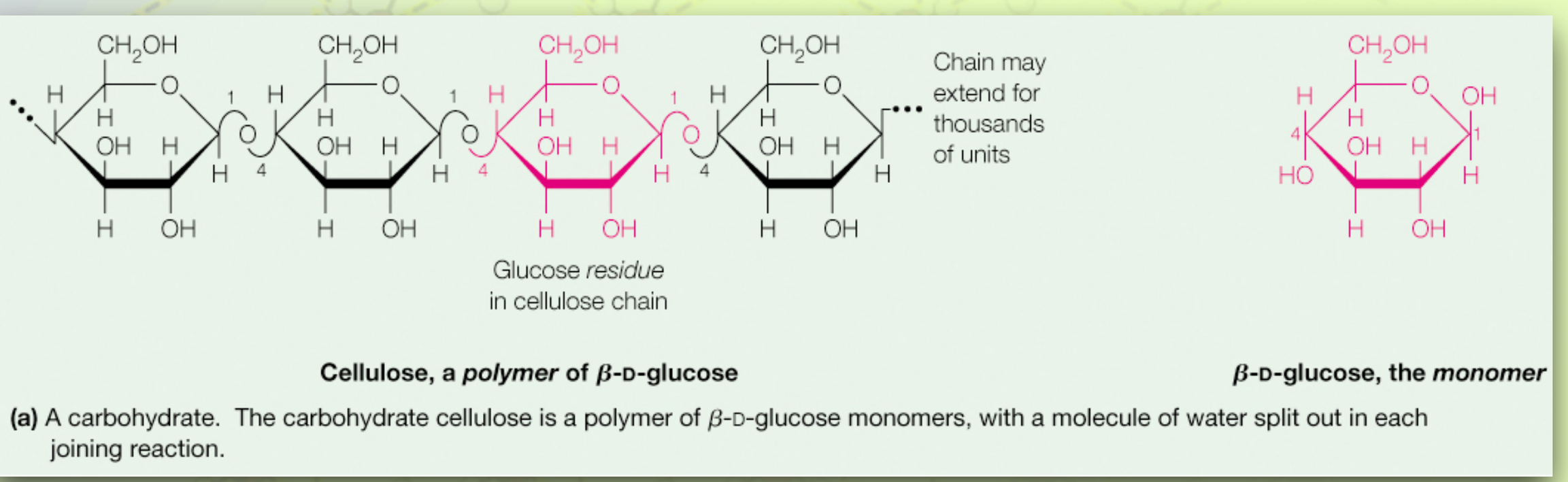
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- **Polysaccharides**, which are a form of carbohydrate, and they can be either *linear* or ***branched homopolymers*** or ***heteropolymers*** of monosaccharide monomers



(a) A carbohydrate. The carbohydrate cellulose is a polymer of β-D-glucose monomers, with a molecule of water split out in each joining reaction.

Cellulose is a linear homopolymer of glucose monomers

Elements and Molecules of Living Systems

Lipids

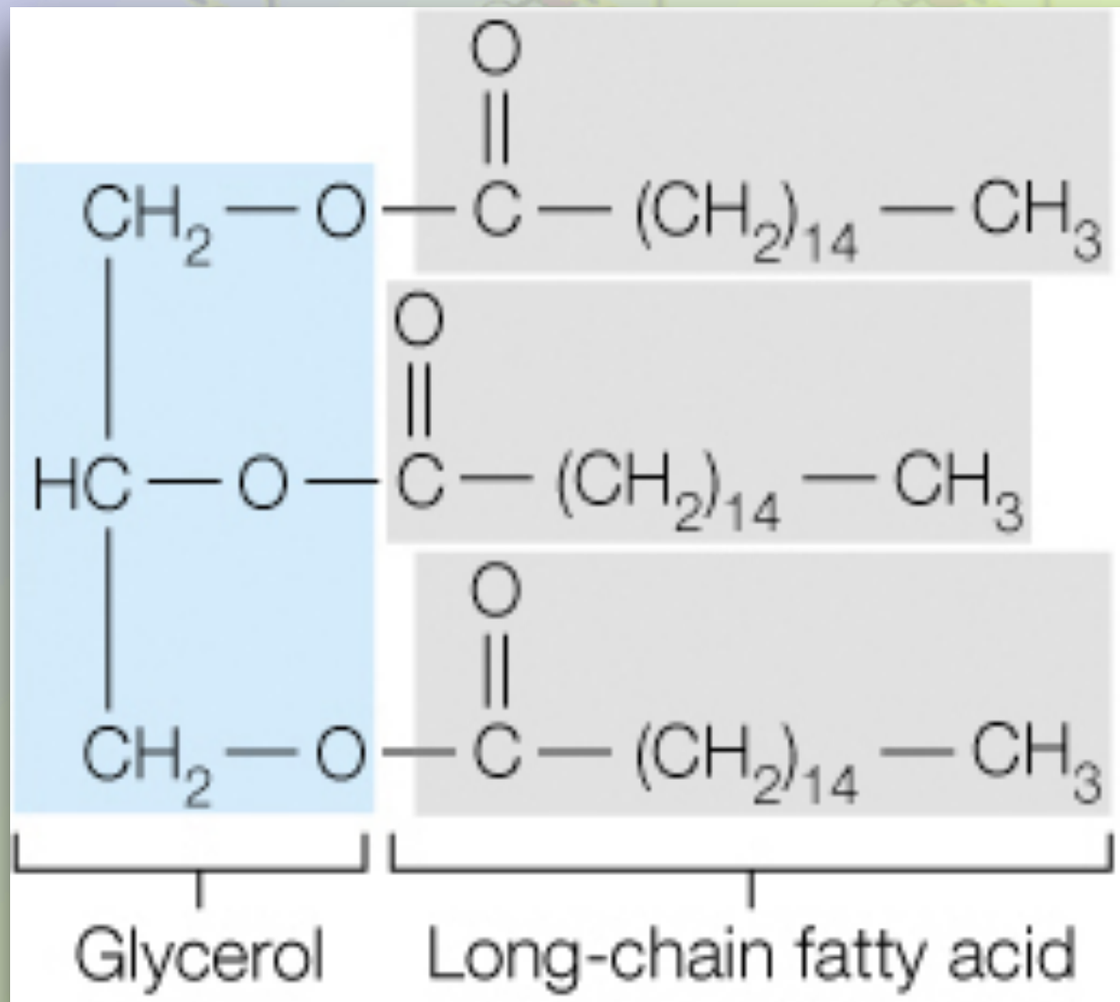
Elements and Molecules of Living Systems

Lipids

- In addition to proteins, nucleic acids, and carbohydrates, ***lipids*** are also one of the major classes of biomolecules.
  - However, lipids are not polymers though some are modular in the way they are constructed.
  - The one defining characteristic of lipids is their low solubility in water.

Elements and Molecules of Living Systems

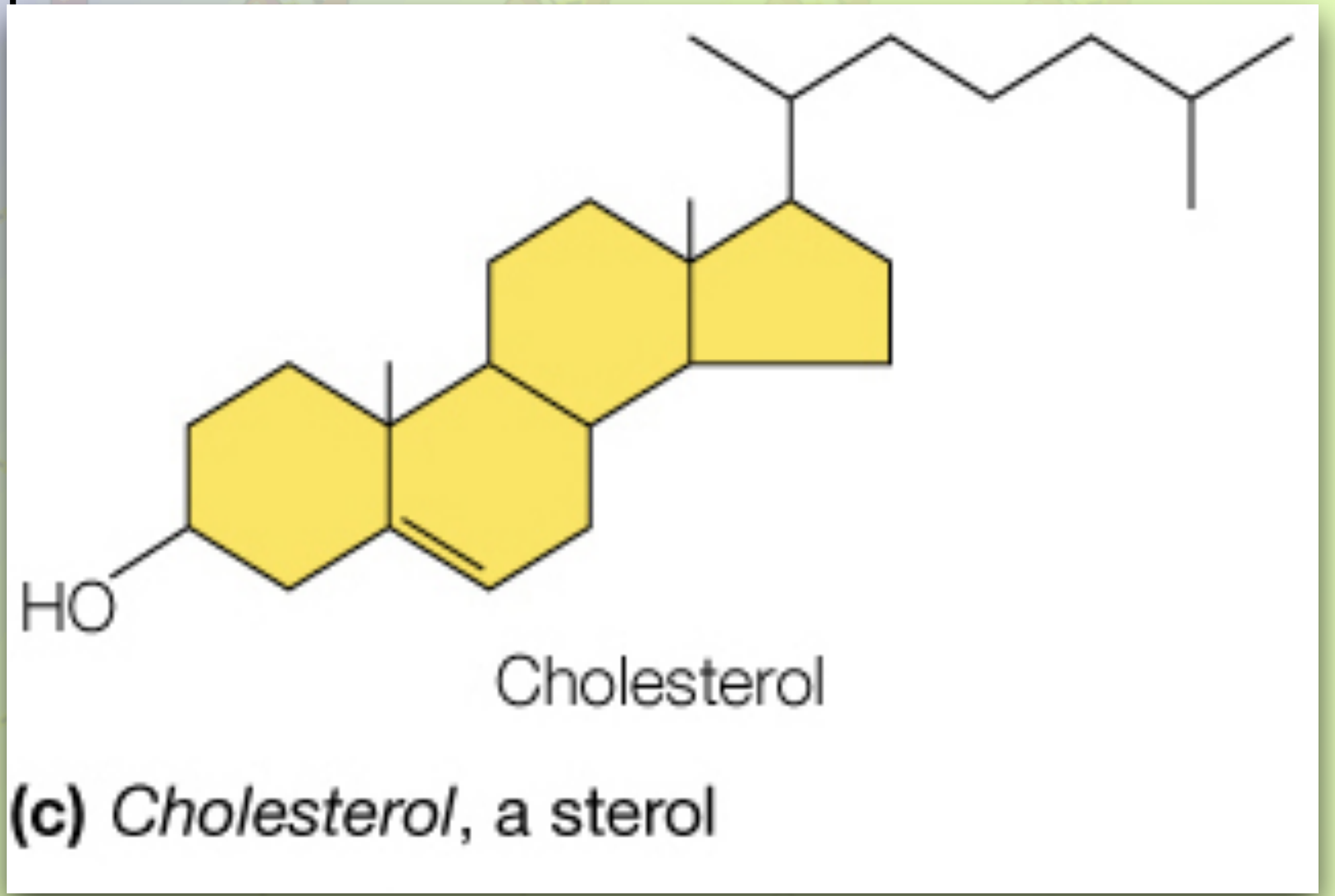
Lipids



(a) A triacylglycerol. In this example, three molecules of a C_{16} saturated fatty acid, *palmitic acid*, are esterified with glycerol.

Elements and Molecules of Living Systems

Lipids



(c) *Cholesterol*, a sterol

Elements and Molecules of Living Systems

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Elements and Molecules of Living Systems

Lipids and Membranes

Elements and Molecules of Living Systems

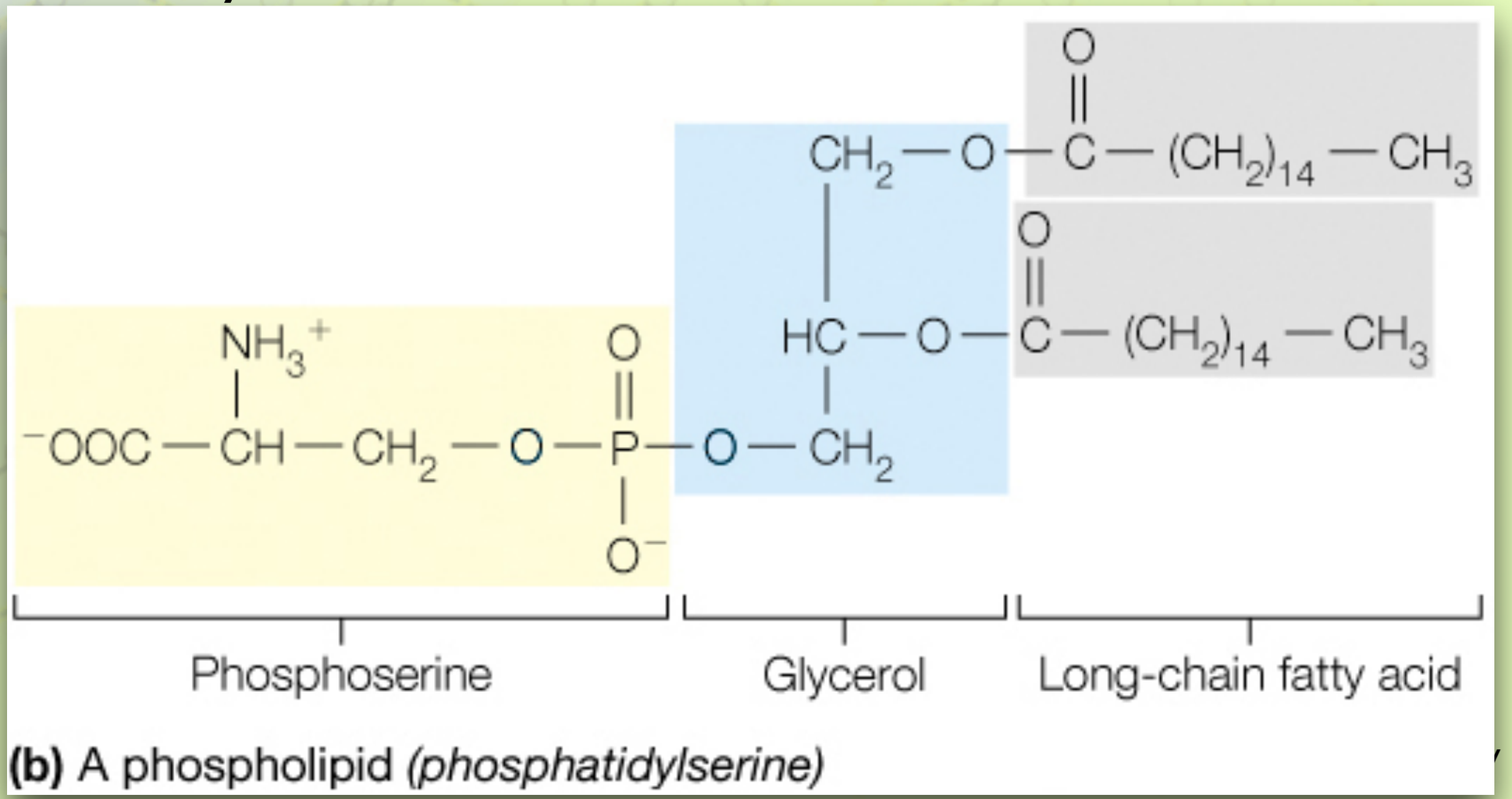
Lipids and Membranes

- An important class of lipids are the ***phospholipids***.
  - In addition to their characteristic ***hydrophobic*** moiety, they also contain a very polar ***hydrophilic*** moiety.

Elements and Molecules of Living Systems

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(b) A phospholipid *(phosphatidylserine)*

Elements and Molecules of Living Systems

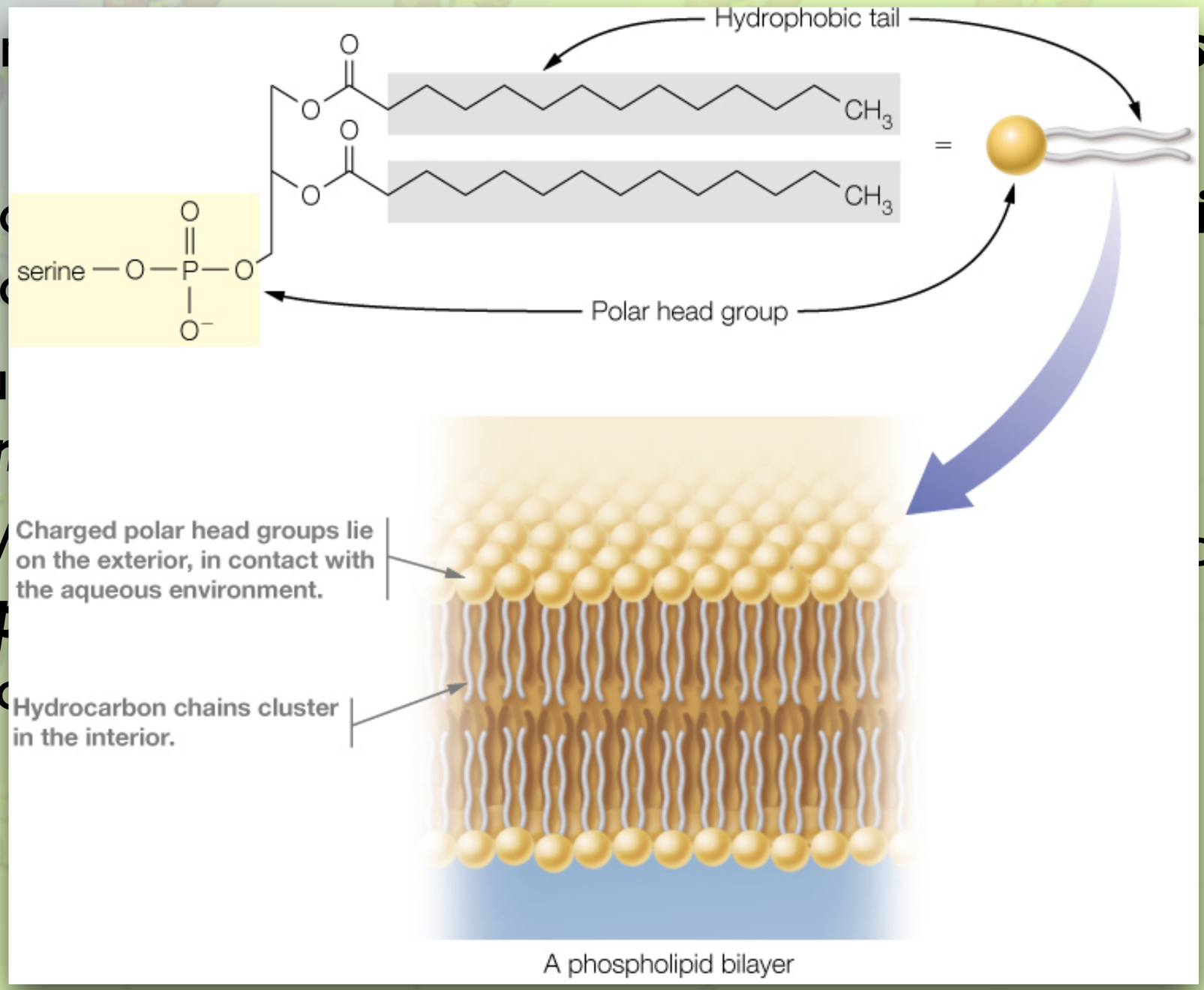
Lipids and Membranes

- An important class of lipids are the ***phospholipids***.
  - In addition to their characteristic ***hydrophobic*** moiety, they also contain a very polar ***hydrophilic*** moiety.
  - Such conflicted molecules are said to be ***amphipathic***.
  - When exposed to water, phospholipids spontaneously ***lipid bilayer***, which form the framework of biological membranes

Elements and Molecules of Living Systems

Lipids and Membranes

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A phospholipid bilayer

Elements and Molecules of Living Systems

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Distinguishing Characteristics of Living System

Characteristics of Living Systems

Concept: *Life depends on creating and duplicating order in a chaotic environment. This ordering requires energy.*

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- In 2002, the American biochemist Daniel Koshland summarized the essential attributes that distinguish living systems from nonliving things.



SCIENCE'S COMPASS • ESSAY

SPECIAL ESSAY

The Seven Pillars of Life

Daniel E. Koshland Jr.

What is the definition of life? I remember a conference of the scientific elite that sought to answer that question. Is an enzyme alive? Is a virus alive? Is a cell alive? After many hours of launching promising balloons that defined life in a sentence, followed by equally conclusive punctures of these bal-

ment the principles. If I were in ancient Greece, I would create a goddess of life whom I would call PICERAS, for reasons that will become clear.

The first pillar of life is a **Program**. By program I mean an organized plan that describes both the ingredients themselves and the kinetics of the interactions among

mental challenges that are to be faced.

The third of the pillars of life is **Compartmentalization**. All the organisms that we consider living are confined to a limited volume, surrounded by a surface that we call a membrane or skin that keeps the ingredients in a defined volume and keeps deleterious chemicals—toxic or diluting—on the outside. Moreover, as organisms become large, they are divided into smaller compartments, which we call cells (or organs, that is, groups of cells), in order to centralize and specialize certain functions within the larger organism. The reason for compartmentalization is that life depends on the reaction kinetics of its ingredients,

(Koshland, D.E. **2002**, "The Seven Pillars of Life", Science 295, 2215-2216)

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7. ***Seclusion*** (operation of processes and pathways in isolation)

The Cell

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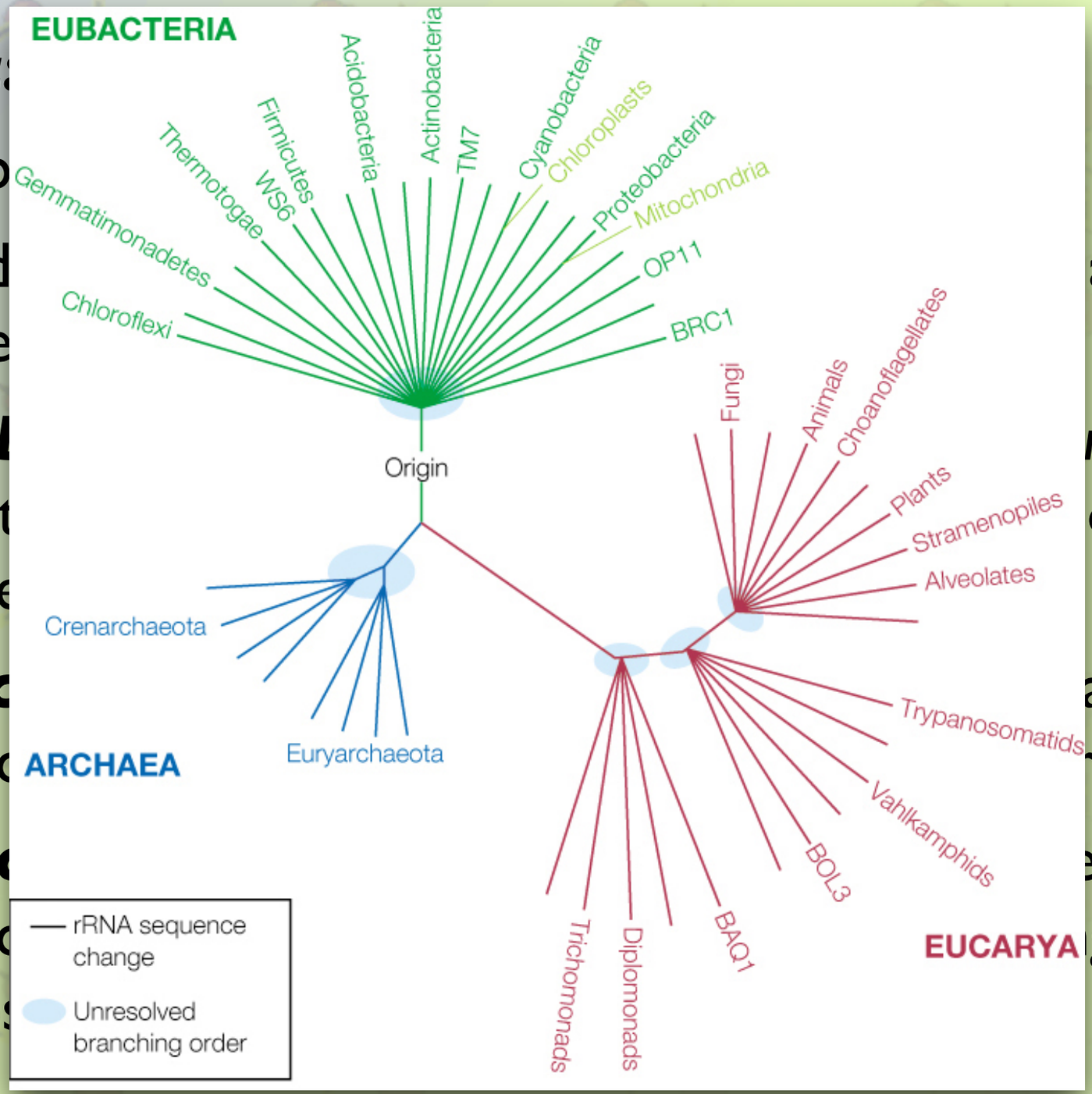
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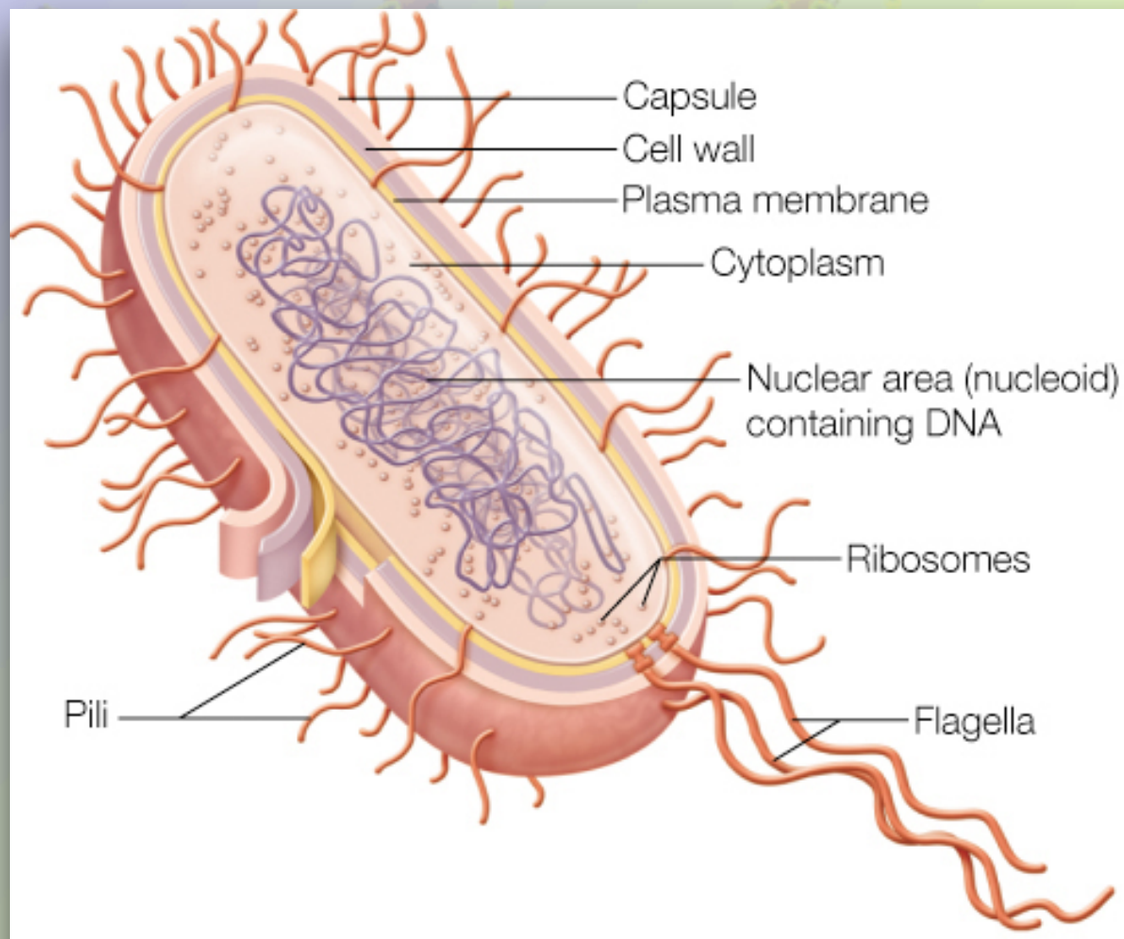
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- ***Prokaryotes*** *(Eubacteria and Archea) have cells that are uncompartmentlized;*
- ***Eukaryotes*** *have cells containing membrane-bound compartments called organelles.*

The Cell

Prokaryote



(a) Schematic view of a representative bacterial cell. The DNA molecule that constitutes most of the genetic material is coiled up in a region called the nucleoid, which shares the fluid interior of the cell (the cytoplasm) with ribosomes (which synthesize proteins), other particles, and a large variety of dissolved molecules. The cell is bounded by a plasma membrane, outside of which is usually a fairly rigid cell wall. Many bacteria also have a gelatinous outer capsule. Projecting from the surface may be pili, which attach the cell to other cells or surfaces, and one or more flagellae, which enable the cell to swim through a liquid environment.

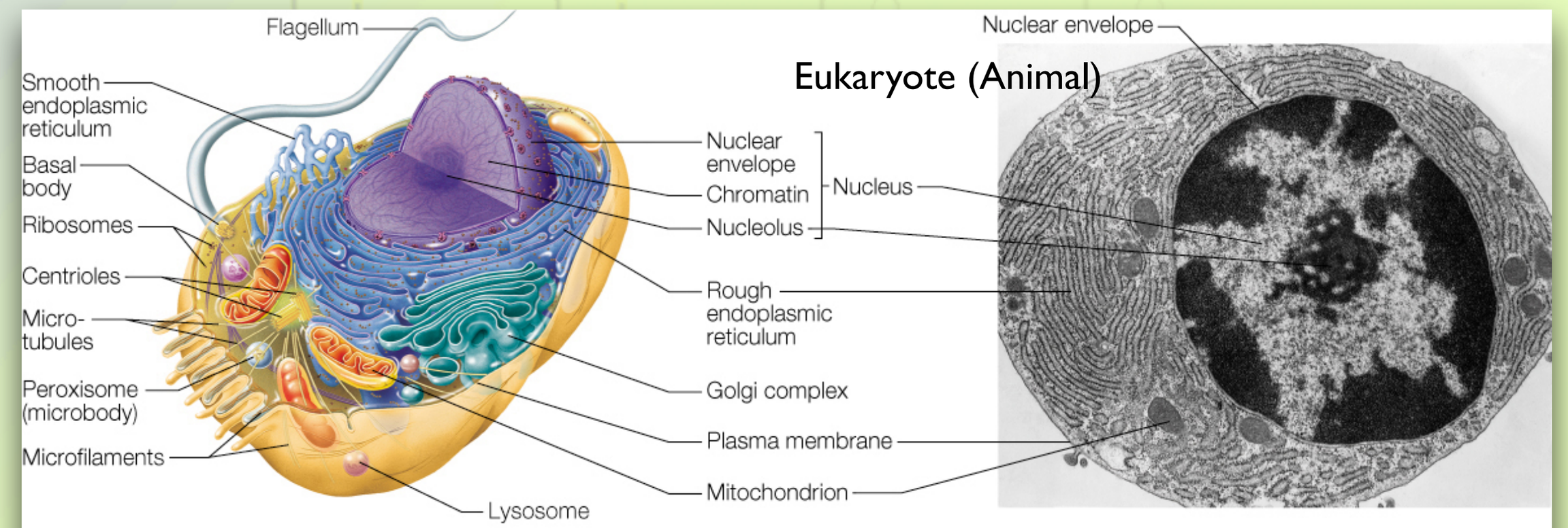


(b) Scanning electron micrograph of *Salmonella*: rod-shaped Gram-negative enterobacteria that causes typhoid fever, paratyphoid fever, and food-borne illness.

The Cell

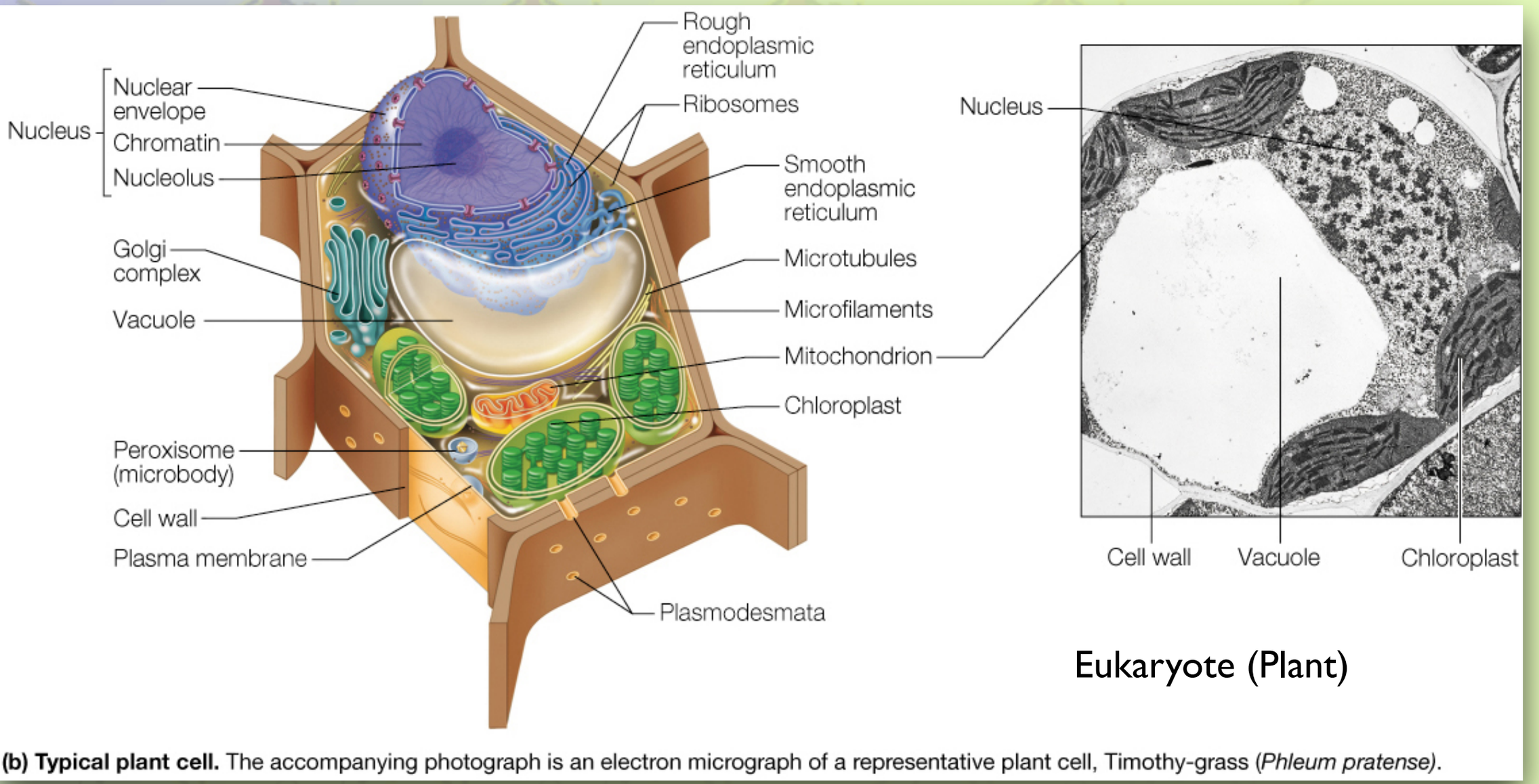
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(a) Typical animal cell. The accompanying photograph is an electron micrograph of a representative animal cell, a white blood cell.

The Cell



Eukaryote (Plant)

(b) Typical plant cell. The accompanying photograph is an electron micrograph of a representative plant cell, Timothy-grass (*Phleum pratense*).

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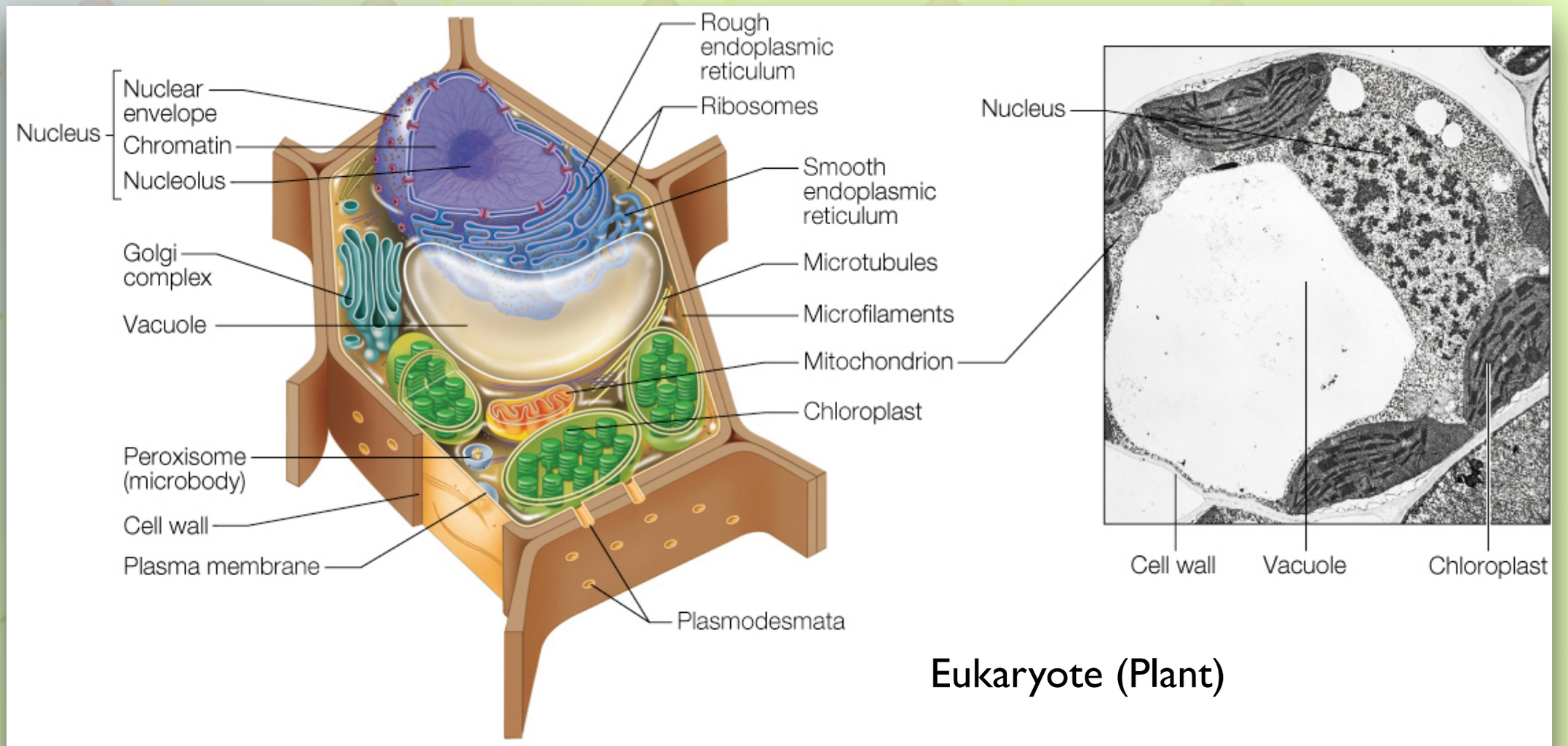
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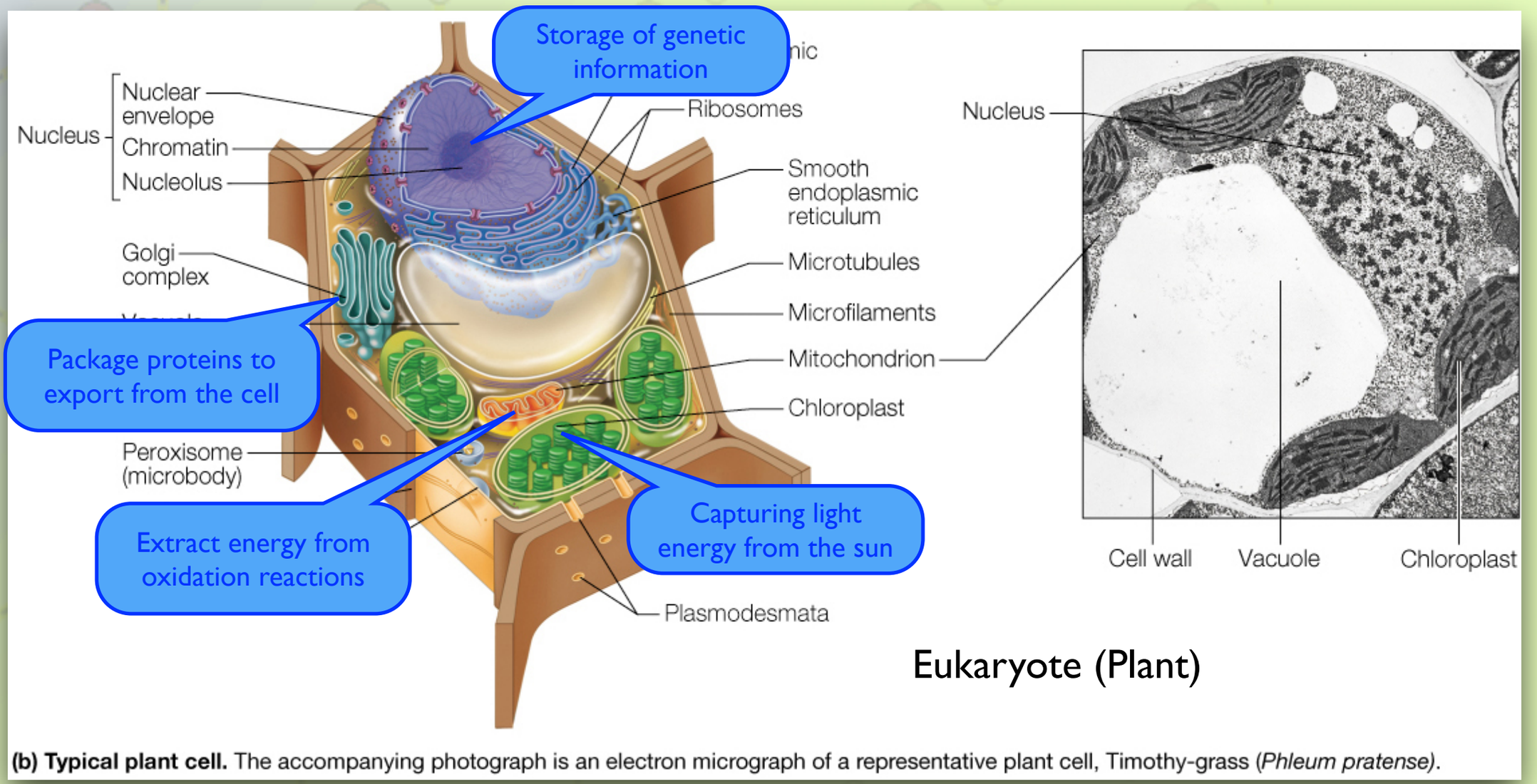


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(b) Typical plant cell. The accompanying photograph is an electron micrograph of a representative plant cell, Timothy-grass (*Phleum pratense*).

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The Cell

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Biochemistry and Molecular Biology Education
Vol. 37, No. 6, pp. 325–332, 2009

Miniseries: Illustrating the Machinery of Life

Escherichia coli*

Received for publication, August 21, 2009, and in revised form, September 15, 2009

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 magnifies 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 at the proper scale, the proper concentration and with no missing parts, seems to me to be central to the understanding of the workings of life." This is how I began my 1991 article that presented several illustrations of *Escherichia coli* [1]. At the time, there was just enough information to create a convincing picture of the environment inside living cells. Since then, the amount of information has increased dramatically, and the task of illustrating cells has become more challenging. Many of the molecules that I described in 1991 have had their structures determined, and we have learned much more about the molecules that I did not include. Moreover, we have learned that the cell is highly dependent on the environmental conditions of the cell. I settled on a hybrid approach. I took the concentrations of macromolecules from the same sources that I used in the 1991 article. This includes the overall value of 70% 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 protein synthesis, transport, and energy production. I

The Information Explosion

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Concept: *Much of today's biochemistry looks at the cell globally, attempting to understand its functions in terms of the cooperative expression of genes.*

- New scientific tools and techniques are being developed and used to generate and analyze increasing amount of biochemical and molecular biological information.

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  - Structure-based drug design through the structural analysis of potential drug targets (enzymes or receptors)

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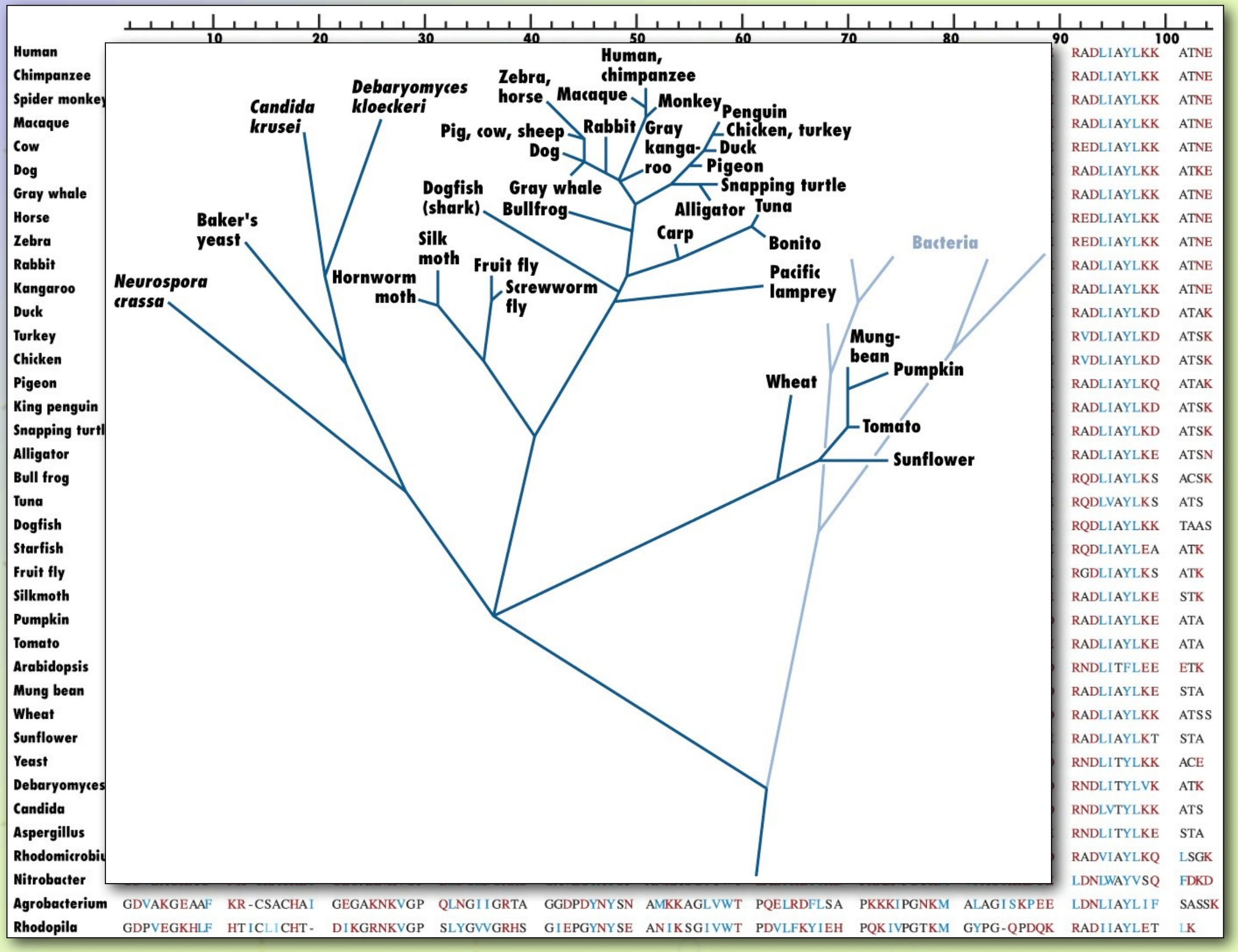
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  - Assessing the expression and function of each gene in a genome
  - Understanding the evolutionary relationships among genes within the same genome and within genomes of different organisms

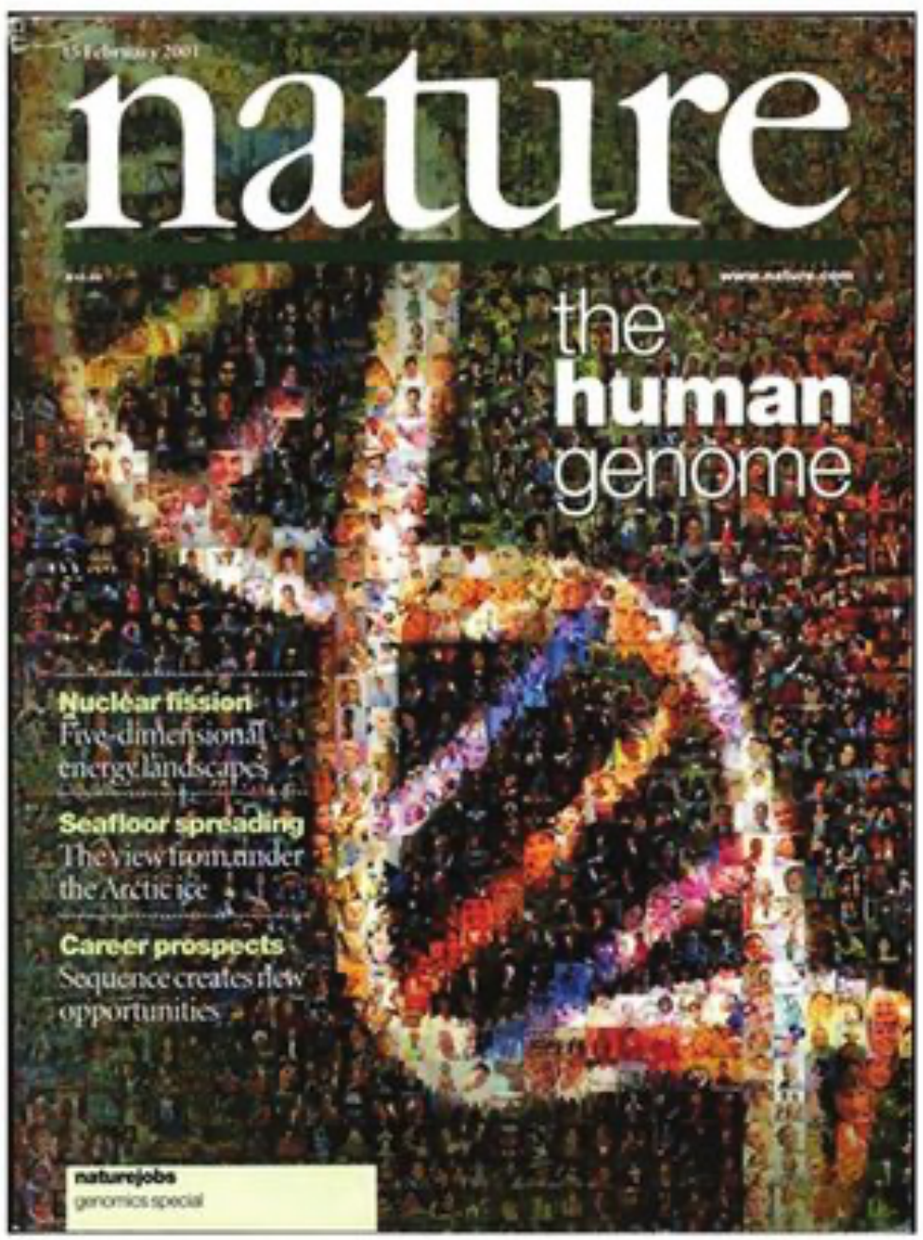
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Macaque	GDVEKGKKIF	IMKCSQCHTV	EKGGKHKTGP	NLHGLFGRKT	GQAPGYSYTA	ANKNKGITWG	EDTLMEYLEN	PKKYIPGTKM	IFVGIKKKEE	RADLIAYLKK	ATNE
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Horse	GDVEKGKKIF	VQKCAQCHTV	EKGGKHKTGP	NLHGLFGRKT	GQAPGFTYTD	ANKNKGITWK	EETLMEYLEN	PKKYIPGTKM	IFAGIKKKTE	REDLIAYLKK	ATNE
Zebra	GDVEKGKKIF	VQKCAQCHTV	EKGGKHKTGP	NLHGLFGRKT	GQAPGFSYTD	ANKNKGITWK	EETLMEYLEN	PKKYIPGTKM	IFAGIKKKTE	REDLIAYLKK	ATNE
Rabbit	GDVEKGKKIF	VQKCAQCHTV	EKGGKHKTGP	NLHGLFGRKT	GQAVGFSYTD	ANKNKGITWG	EDTLMEYLEN	PKKYIPGTKM	IFAGIKKKDE	RADLIAYLKK	ATNE
Kangaroo	GDVEKGKKIF	VQKCAQCHTV	EKGGKHKTGP	NLHGIFGRKT	GQAPGFTYTD	ANKNKGIIWG	EDTLMEYLEN	PKKYIPGTKM	IFAGIKKKGE	RADLIAYLKK	ATNE
Duck	GDVEKGKKIF	VQKCSQCHTV	EKGGKHKTGP	NLHGLFGRKT	GQAEGFSYTD	ANKNKGITWG	EDTLMEYLEN	PKKYIPGTKM	IFAGIKKKSE	RADLIAYLKD	ATAK
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Chicken	GDIEKGKKIF	VQKCSQCHTV	EKGGKHKTGP	NLHGLFGRKT	GQAEGFSYTD	ANKNKGITWG	EDTLMEYLEN	PKKYIPGTKM	IFAGIKKKSE	RVDLIAYLKD	ATSK
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Alligator	GDVEKGKKIF	VQKCAQCHTV	EKGGKHKTGP	NLHGLIGRKT	GQAPGFSYTE	ANKNKGITWG	EETLMEYLEN	PKKYIPGTKM	IFAGIKKKPE	RADLIAYLKE	ATSN
Bull frog	GDVEKGKKIF	VQKCAQCHTV	EKGGKHKVGP	NLYGLIGRKT	GQAAGFSYTD	ANKNKGITWG	EDTLMEYLEN	PKKYIPGTKM	IFAGIKKKGE	RQDLIAYLKS	ACSK
Tuna	GDVAKGKKTF	VQKCAQCHTV	ENGGKHKVGP	NLWGLFGRKT	GQAEGYSYTD	ANKSKGIVWN	ENTLMEYLEN	PKKYIPGTKM	IFAGIKKKGE	RQDLVAYLKS	ATS
Dogfish	GDVEKGKKVF	VQKCAQCHTV	ENGGKHKTGP	NLSGLFGRKT	GQAQGFSYTD	ANKSKGITWQ	QETLRIYLEN	PKKYIPGTKM	IFAGIKKKSE	RQDLIAYLKK	TAAS
Starfish	GQVEKGKKIF	VQRCAQCHTV	EKAGKHKTGP	NLNGILGRKT	GQAAGFSYTD	ANRNKGITWK	NETLFEYLEN	PKKYIPGTKM	VFAGLKKQKE	RQDLIAYLEA	ATK
Fruit fly	GDVEKGKKLF	VQRCAQCHTV	EAGGKHKVGP	NLHGLIGRKT	GQAAGFAYTD	ANKAKGITWN	EDTLFEYLEN	PKKYIPGTKM	IFAGLKKPNE	RGDLIAYLKS	ATK
Silkmoth	GNAENGKKIF	VQRCAQCHTV	EAGGKHKVGP	NLHGFYGRKT	GQAPGFSYSN	ANKAKGITWG	DDTLFEYLEN	PKKYIPGTKM	VFAGLKKANE	RADLIAYLKE	STK
Pumpkin	GNSKAGEKIF	KTKCAQCHTV	DKGAGHKQGP	NLNGLFGRQS	GTTPGYSYSA	ANKNRAVIWE	EKTLYDYLLN	PKKYIPGTKM	VFPGLKKPQD	RADLIAYLKE	ATA
Tomato	GNPKAGEKIF	KTKCAQCHTV	EKGAGHKEGP	NLNGLFGRQS	GTTAGYSYSA	ANKNMAVNWG	ENTLYDYLLN	PKKYIPGTKM	VFPGLKKPQE	RADLIAYLKE	ATA
Arabidopsis	GDAKKGANLF	KTRCAQCHTL	KAGEGNKIGP	ELHGLFGRKT	GSVAGYSYTD	ANKQKGIEWK	DDTLFEYLEN	PKKYIPGTKM	AFGGLKKPKD	RNDLITFLEE	ETK
Mung bean	GNSKSGEKIF	KTKCAQCHTV	DKGAGHKQGP	NLNGLIGRQS	GTTAGYSYST	ANKNMAVIWE	EKTLYDYLLN	PKKYIPGTKM	VFPGLKKPQD	RADLIAYLKE	STA
Wheat	GNPDAGAKIF	KTKCAQCHTV	DAGAGHKQGP	NLHGLFGRQS	GTTAGYSYSA	ANKNKAVEWE	ENTLYDYLLN	PKKYIPGTKM	VFPGLKKPQD	RADLIAYLKK	ATSS
Sunflower	GNPTTGEKIF	KTKCAQCHTV	EKGAGHKQGP	NLNGLFGRQS	GTTAGYSYSA	GNKNKAVIWE	ENTLYDYLLN	PKKYIPGTKM	VFPGLKKPQE	RADLIAYLKT	STA
Yeast	GSAKKGATLF	KTRCLQCHTV	EKGGPHKVGP	NLHGIFGRHS	GQAEGYSYTD	ANIKKNVLWD	ENNMSEYLTN	PKKYIPGTKM	AFGGLKKEKD	RNDLITYLKK	ACE
Debaryomyces	GSEKKGANLF	KTRCLQCHTV	EKGGPHKVGP	NLHGVVGRTS	GQAQGFSYTD	ANKKKGVEWT	EQDLSDYLEN	PKKYIPGTKM	AFGGLKKAKD	RNDLITYLVK	ATK
Candida	GSEKKGATLF	KTRCLQCHTV	EKGGPHKVGP	NLHGVFGRKS	GLAEGYSYTD	ANKKKGVEWT	EQTMSDYLEN	PKKYIPGTKM	AFGGLKKPKD	RNDLVTYLKK	ATS
Aspergillus	GDAK-GAKLF	QTRCAQCHTV	EAGGPHKVGP	NLHGLFGRKT	GQSEGYAYTD	ANKQAGVTWD	ENTLFSYLEN	PKKFIPGTKM	AFGGLKKGKE	RNDLITYLKE	STA
Rhodomicrobium	GDPVKGEQVF	KQ-CKICHQV	GPTAKNGVGP	EQNDVFGQKA	GARPGFNYSD	AMKNSGLTWD	EATLDKYLEN	PKAVVPGTKM	VFVGLKNPQD	RADVIAYLKQ	LSGK
Nitrobacter	GDVEAGKAAF	NK-CKACHEI	GESAKNKVGP	ELDGLDGRHS	GAVEGYAYSP	ANKASGITWT	EAEFKEYIKD	PKAKVPGTKM	VFAGIKKDSE	LDNLWAYVSQ	FDKD
Agrobacterium	GDVAKGEAAF	KR-CSACHAI	GEGAKNKVGP	QLNGIIGRTA	GGDPDYNYSN	AMKKAGLVWT	PQELRDFLSA	PKKKIPGNKM	ALAGISKPEE	LDNLIAYLIF	SASSK
Rhodopila	GDPVEGKHLF	HTICLICHT-	DIKGRNKVGP	SLYGVVGRHS	GIEPGYNYSE	ANIKSGIVWT	PDVLFKYIEH	PQKIVPGTKM	GYPG-QPDQK	RADIIAYLET	LK

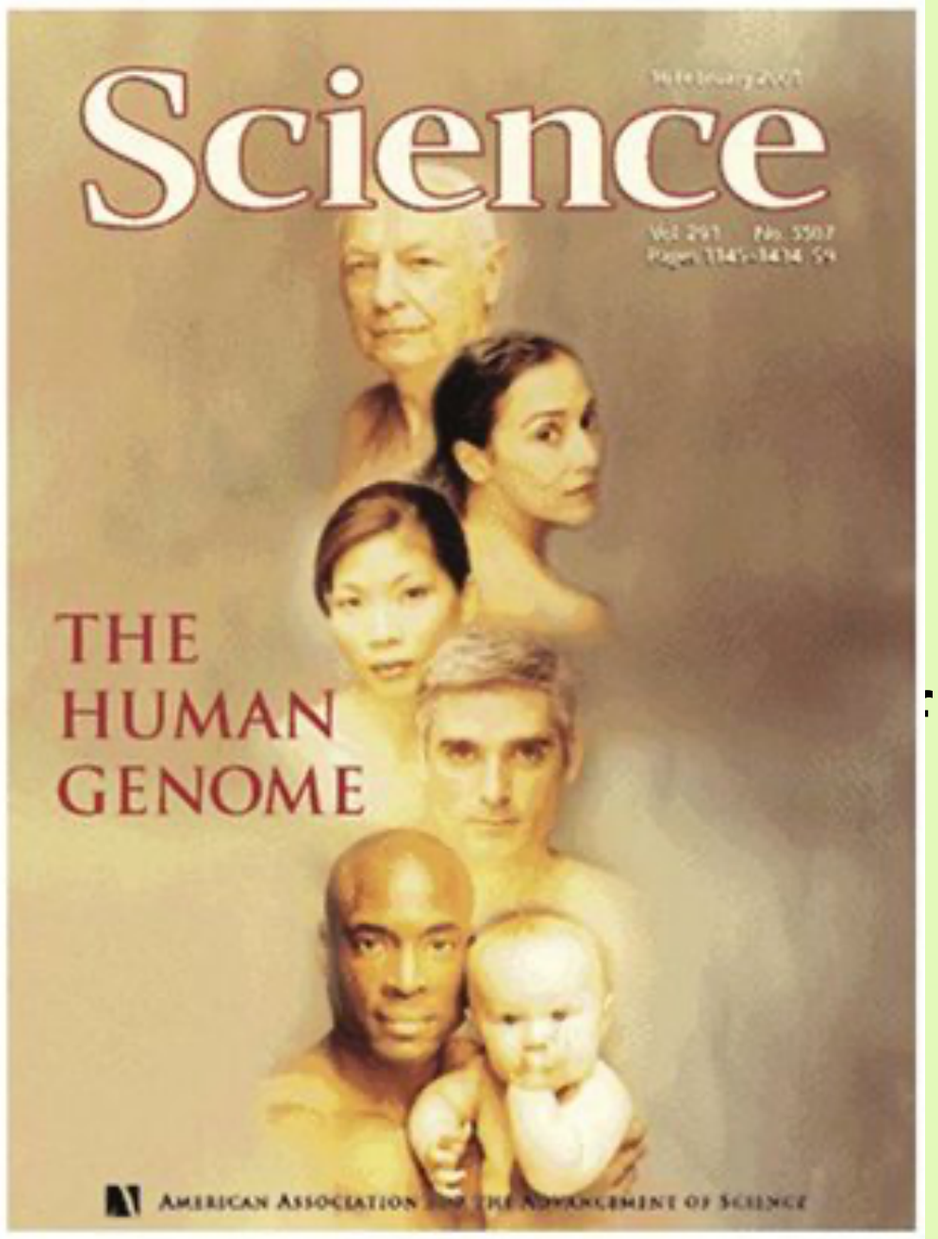

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Human
Chimpanzee
Spider monkey
Macaque
Cow
Dog
Gray whale
Horse
Zebra
Rabbit
Kangaroo
Duck
Turkey
Chicken
Pigeon
King penguin
Snapping turtl
Alligator
Bull frog
Tuna
Dogfish
Starfish
Fruit fly
Silkmoth
Pumpkin
Tomato
Arabidopsis
Mung bean
Wheat
Sunflower
Yeast
Debaryomyces
Candida
Aspergillus
Rhodomicrobiu
Nitrobacter
Agrobacterium
Rhodopila
Human, chimpanzee
Zebra, horse
Macaque
Monkey
Penguin
Chicken, turkey
Duck
Pigeon
Snapping turtle
Tuna
Bonito
Pacific lamprey
Carp
Alligator
Gray kanga-roo
Rabbit
Pig, cow, sheep
Dog
Gray whale
Bullfrog
Dogfish (shark)
Debaryomyces kloeckeri
Candida krusei
Baker's yeast
Neurospora crassa
Silk moth
Hornworm moth
Fruit fly
Screwworm fly
Bacteria
Mung-bean
Pumpkin
Tomato
Sunflower
Wheat
RADLIAYLKK ATNE
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RADVIAYLKQ LSGK
LDNLWAYVSQ FDKD
GDVAKGEAAF KR-CSACHAI GEGAKNKVGP QLNGIIGRTA GGDPDYNYSN AMKKAGLVWT PQELRDFLSA PKKKIPGNKM ALAGISKPEE LDNLIAYLIF SASSK
GDPVEGKHLF HTICLICHT- DIKGRNKVGP SLYGVVGRHS GIEPGYNYSE ANIKSGIVWT PDVLFKYIEH PQKIVPGTKM GYPG-QPDQK RADIIAYLET LK

The Information Explosion

- Some broader goals of genomics include,
  - Determining the nucleotide sequences of entire genome of different organisms
  - Assessing the expression and function of each gene in a genome
  - Understanding the evolutionary relationships among genes within the same genome and within genomes of different organisms

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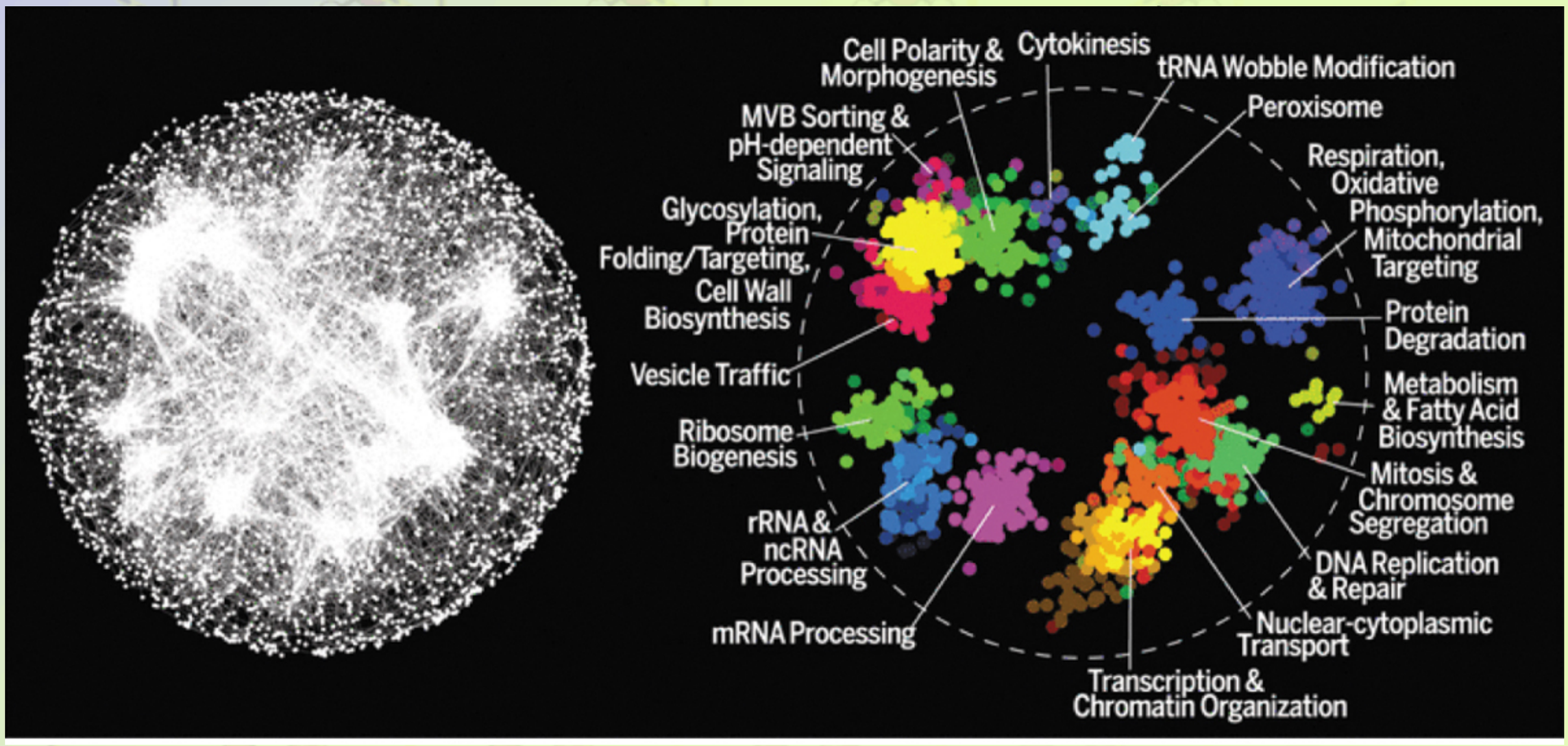


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Science, Vol 291, 16. February, 2001

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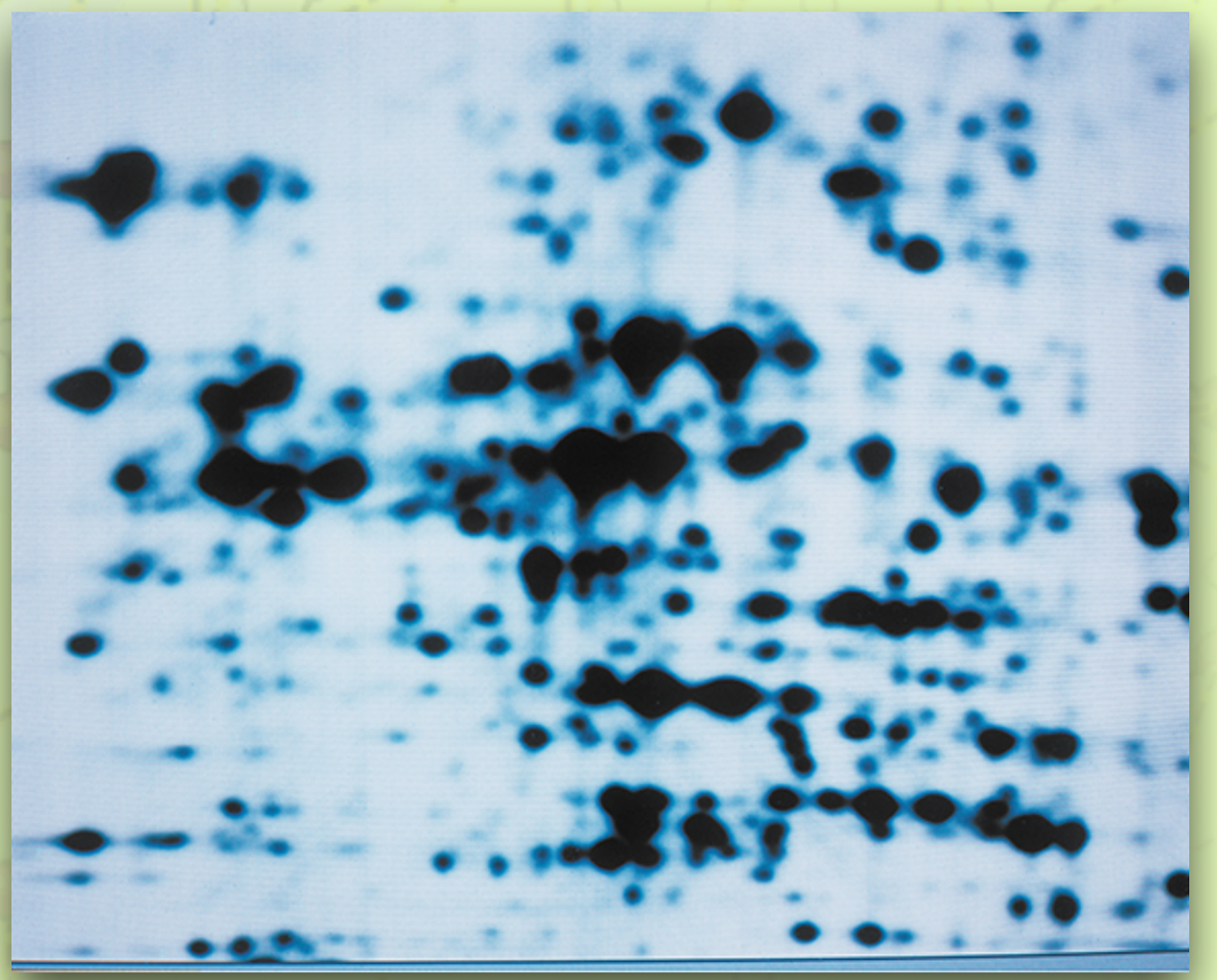
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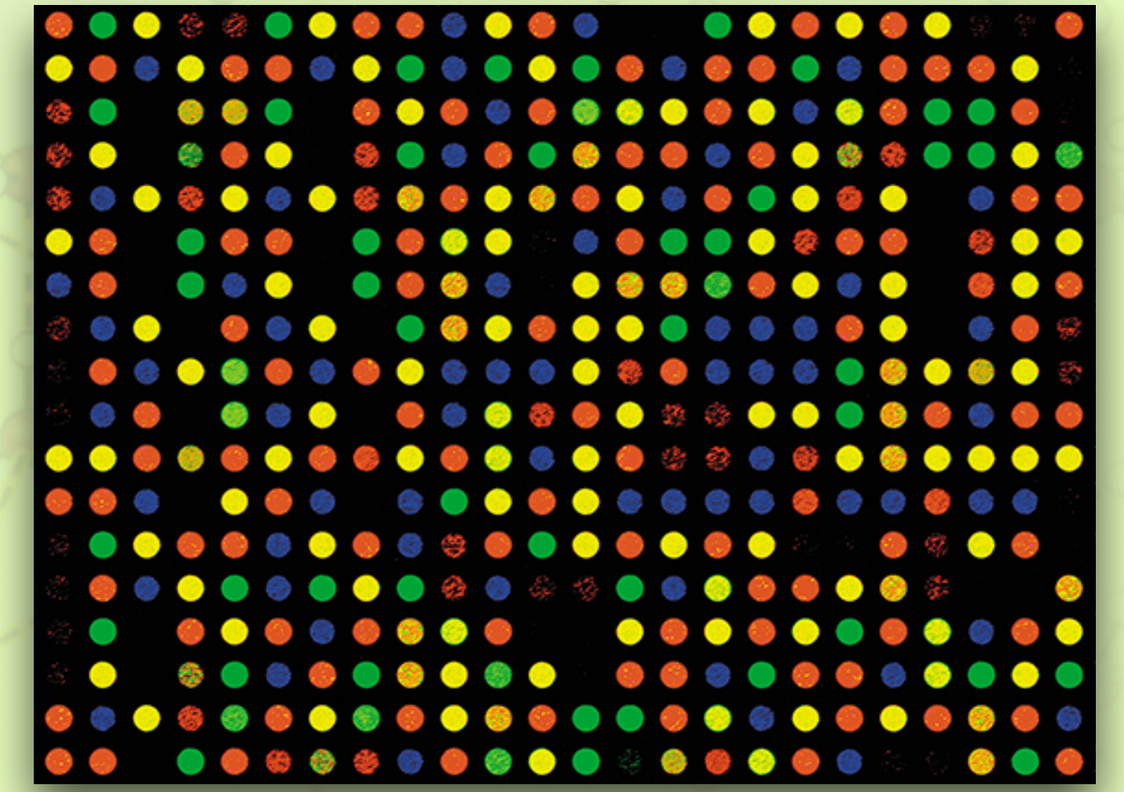
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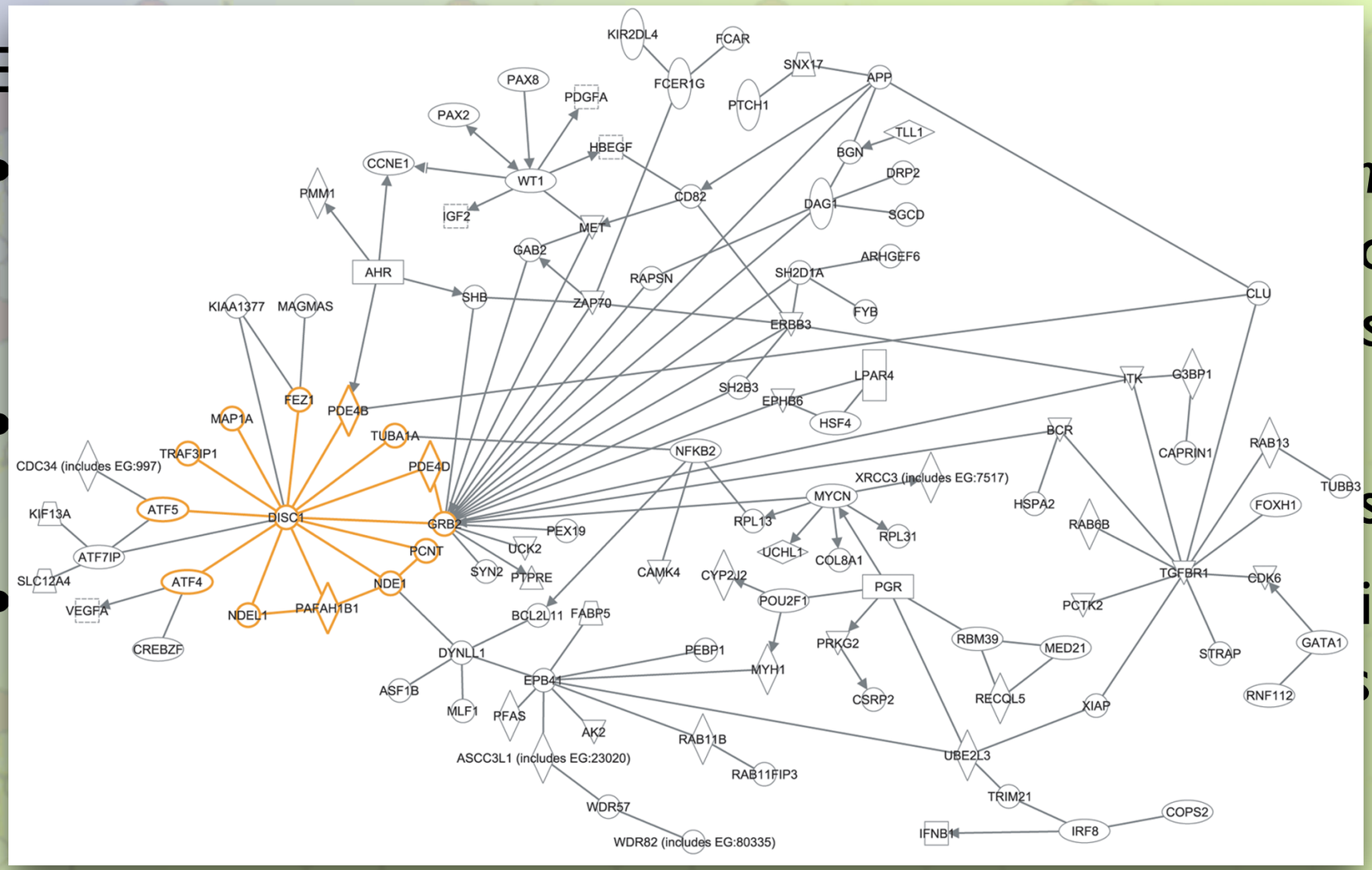


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The Information Explosion

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- Biochemistry bridges biological and chemical sciences by focusing at the molecular level on what happens in living systems.
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- Biochemistry is an experimental science and uses a variety of different tools and techniques, some of which generate large amount of information.

Up Next

Lecture 2 - Weak interactions in an aqueous environment

- Noncovalent interactions
- Role of water in biological processes
- Acid-Base Equilibrium
- Interactions between macro-ions in solution

Reading

- Chapter 2 of Appling *et al.*