The nature of life on Earth

Defining Life

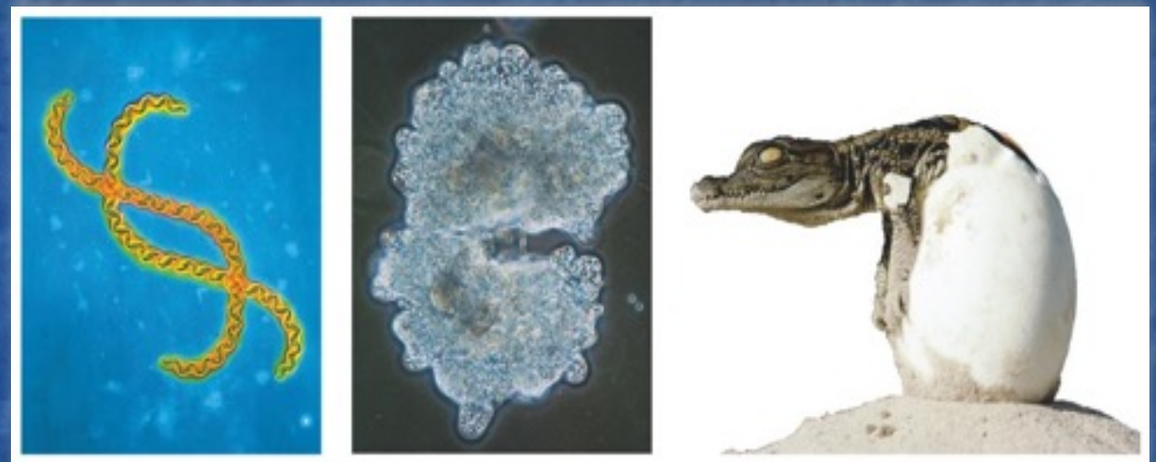
- Our common sense serves us quite well in discerning between things that are living versus non-living
- However, the dividing line between the two is not as well-defined as you might think!
  - e.g., it is debatable if viruses are living or not
- Fortunately, most life forms on Earth have many properties in common with one another
- Life elsewhere in the universe may be quite different, but we will start by trying to better understand life on Earth, and the conditions it needs to survive

What is life (on Earth)?

- A diverse array of living organisms (life forms) can be found in the biosphere on Earth. Properties common to these organisms are a carbon- and water-based cellular form with complex organization and heritable genetic information. Living organisms undergo metabolism, maintain homeostasis, possess a capacity to grow, respond to stimuli, reproduce and, through natural selection, adapt to their environment in successive generations. More complex living organisms can communicate through various means.

Six Key Properties of Life

- Most living organisms on Earth share the following properties:
  - Order
  - Reproduction
  - Growth and development
  - Energy utilization
  - Response to the environment
  - Evolutionary adaptation



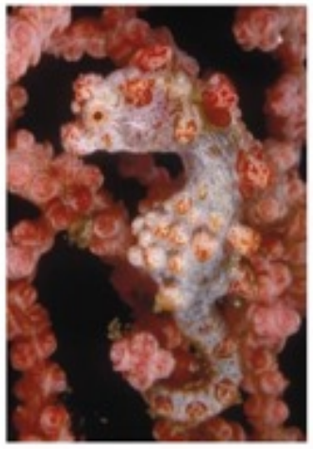
a Order: Living organisms exhibit order in their internal structure, as is apparent in this microscopic view of spiral patterns in two single-celled organisms.

b Reproduction: Organisms reproduce their own kind. Here, a single-celled organism (an amoeba) has already copied its genetic material (DNA) and is now dividing into two cells.

c Growth and development: Living organisms grow and develop in patterns determined at least in part by heredity. Here, we see a Nile crocodile emerging from its shell.

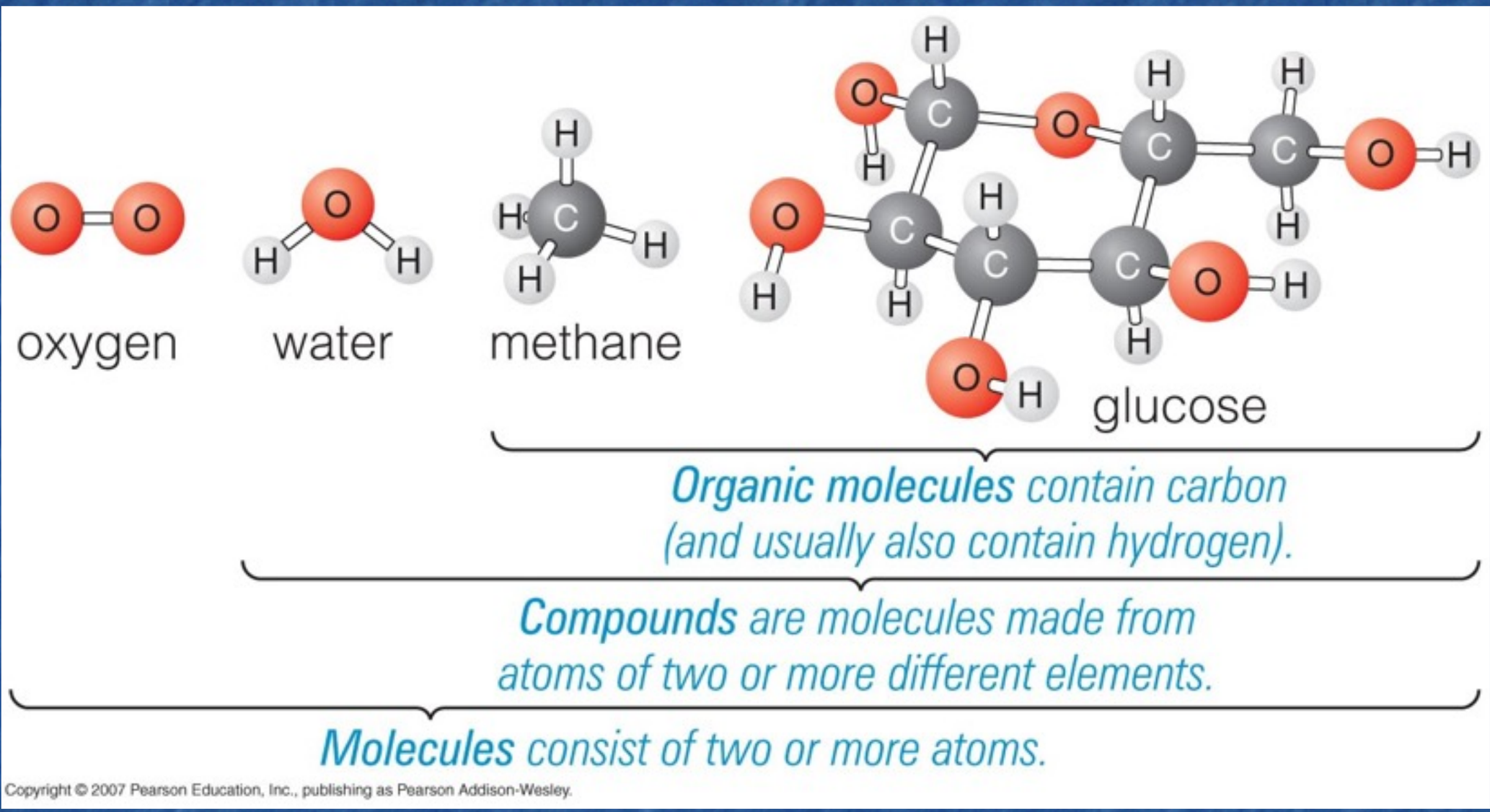
d Energy utilization: Living organisms use energy to fuel their many activities. These tube worms which live near a deep-sea volcanic vent, obtain energy from chemical reactions made possible in part by the heat released from the volcanic vent.

e Response to the enviornment: Life actively responds to changes in its surroundings. Here, we see a jackrabbit's ears flush with blood; the blood flow adjusts automatically to help the animal maintain a constant internal temperature by adjusting the heat loss from the ears.

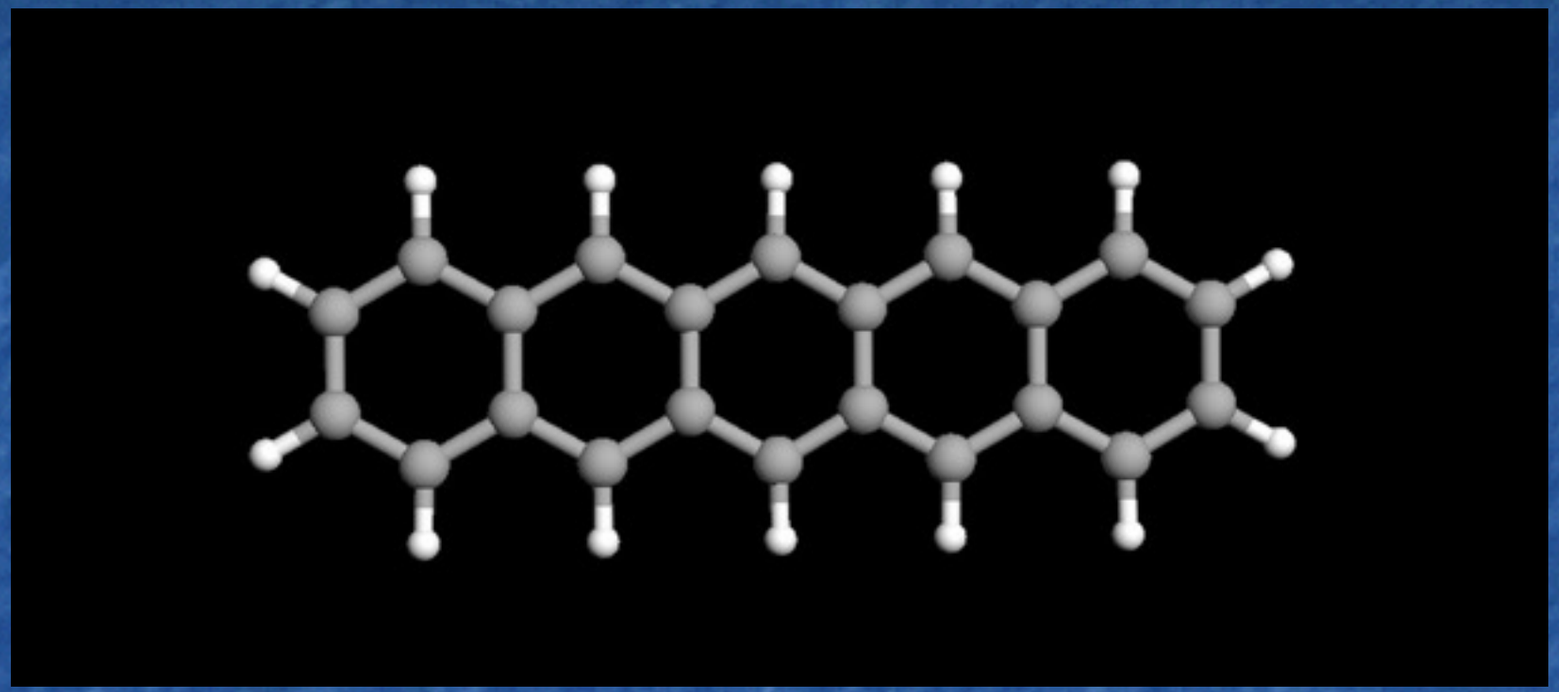


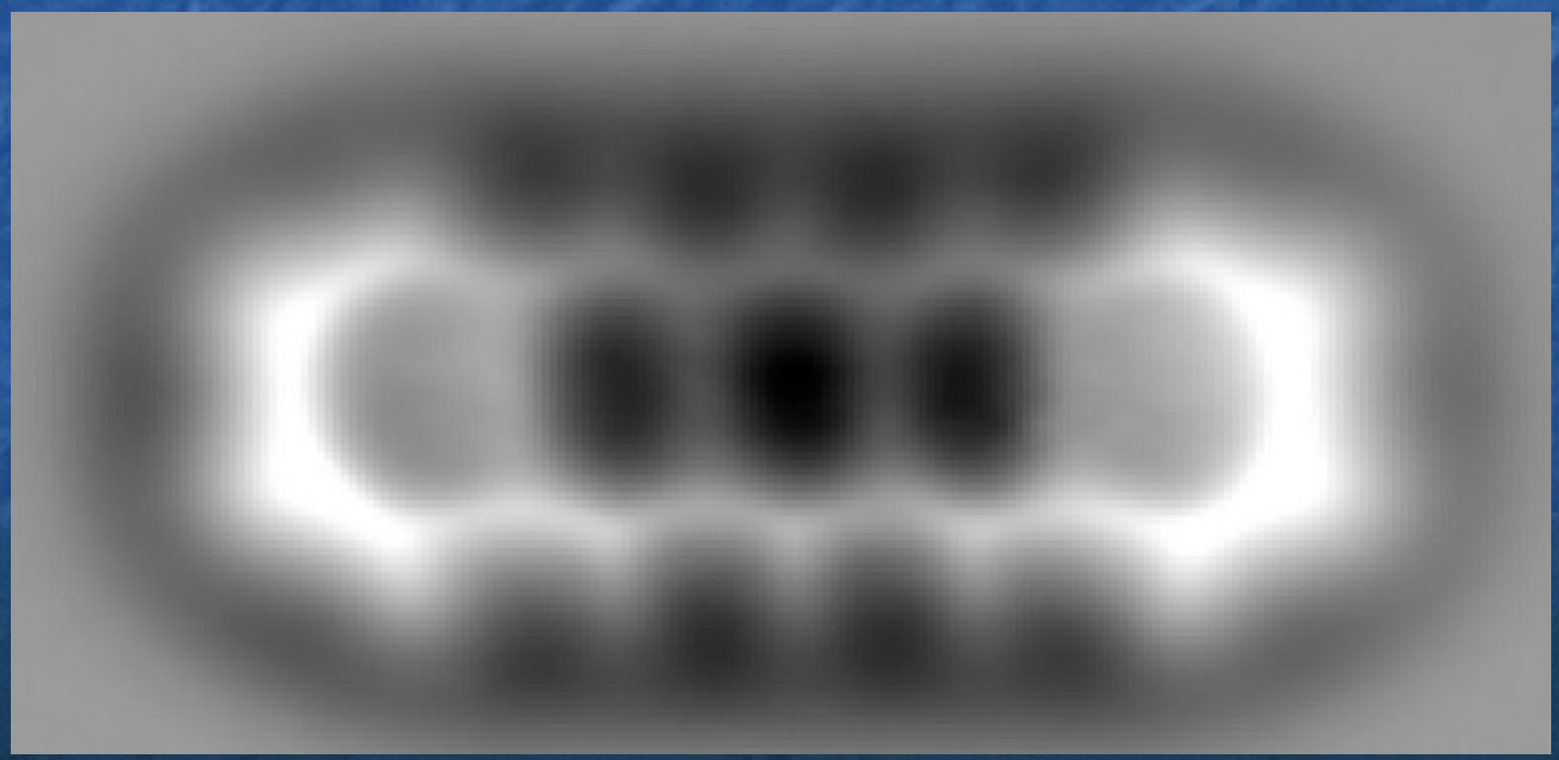
f Evolutionary adaptation: Life evolves in a way that leads to organisms that are adapted to their enviornments. Here, a pygmy seahorse is camouflaged in its coral surroundings.

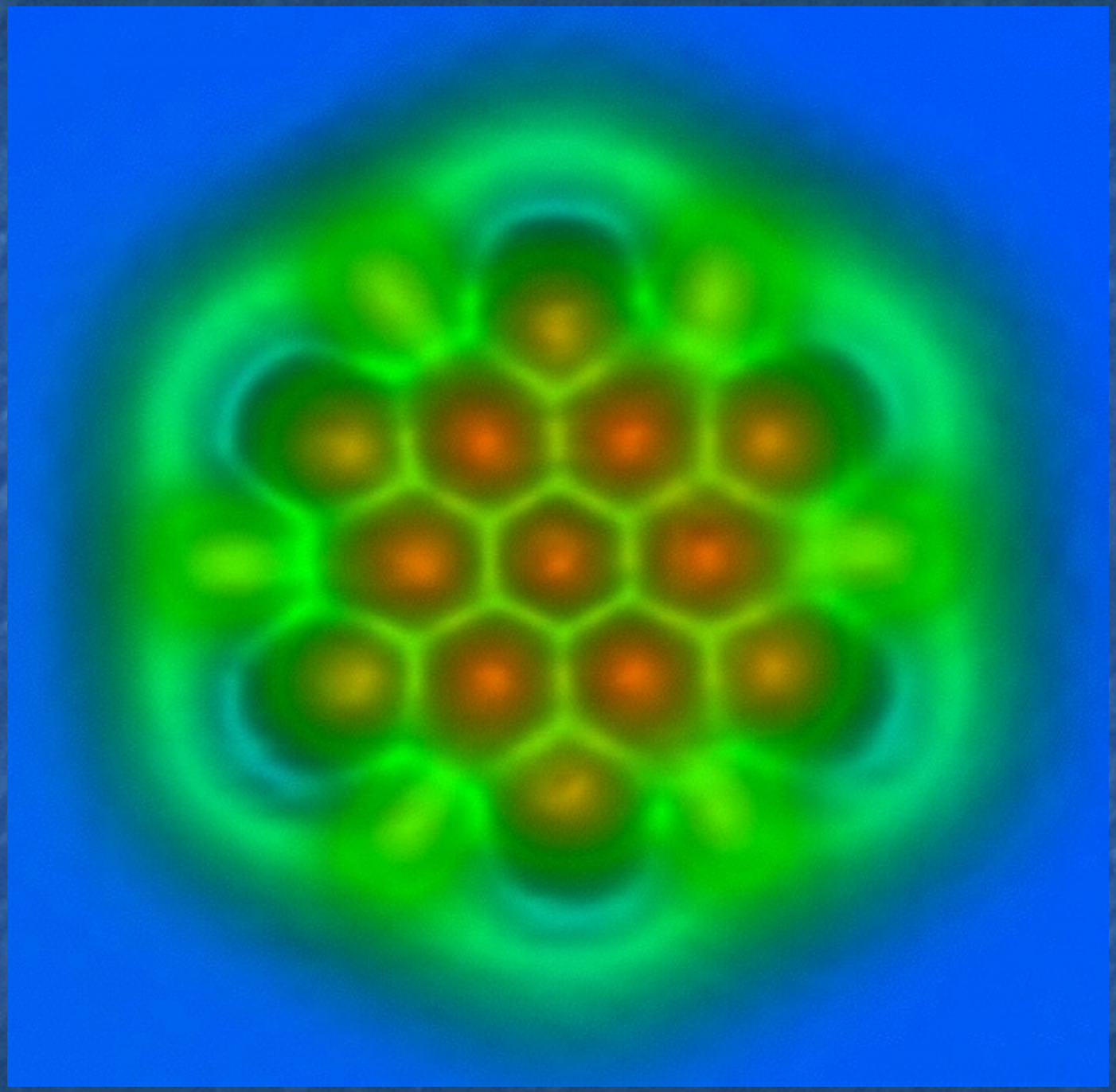
Atoms to molecules



Seeing is believing

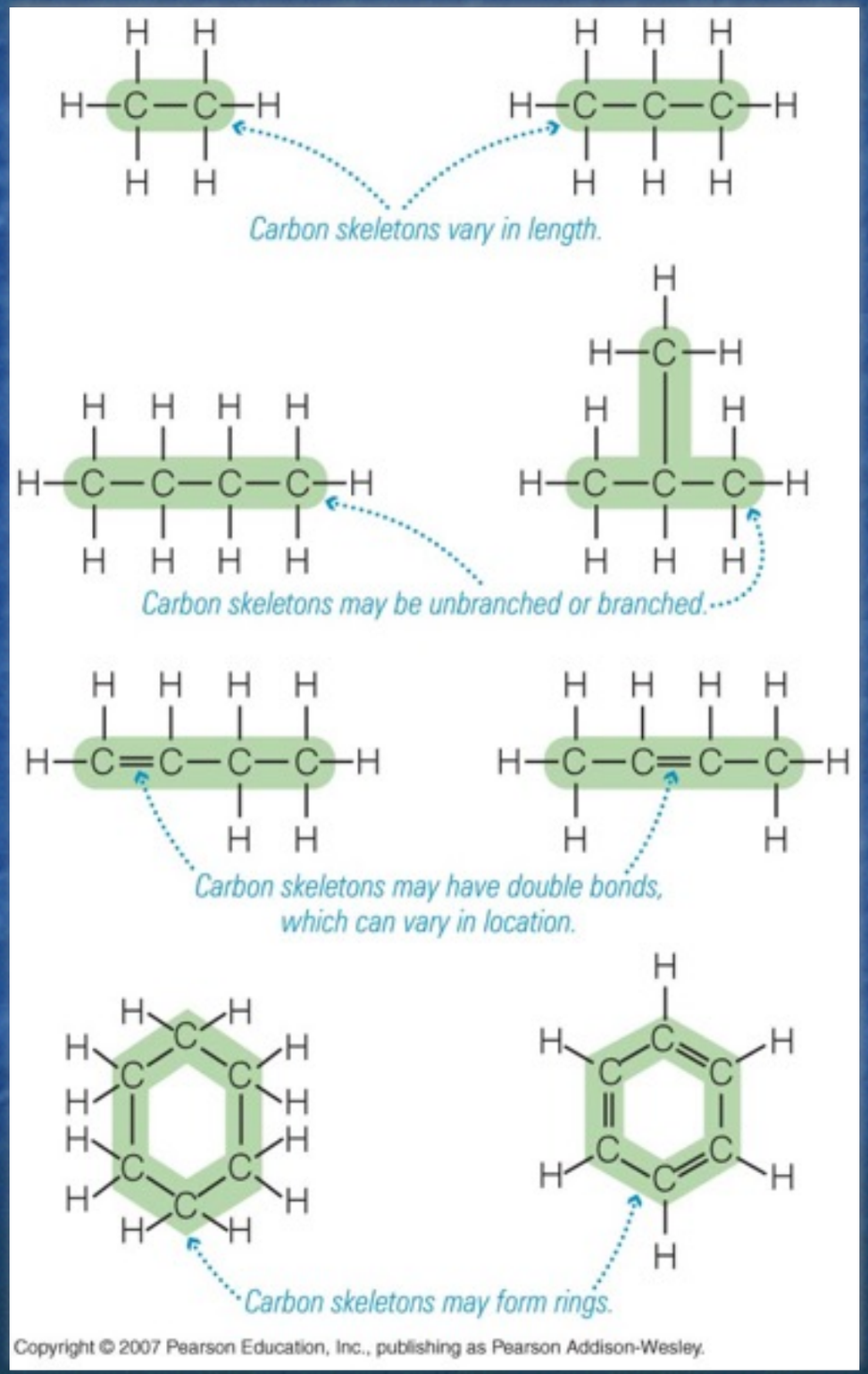






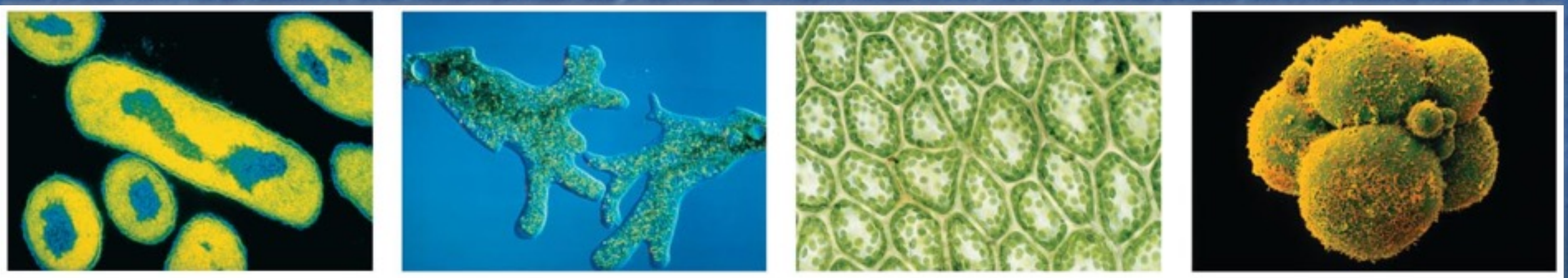
Carbon-based Life

- All life on Earth is carbon-based.
  - carbon plays a key role in the structure of cells.
- Carbon is advantageous because it has four valence electrons available to form bonds with other atoms.
- Other forms of life, such as silicon-based life, are theoretically possible, but have not yet been found.
  - however, since silicon and other similar atoms are not as well suited for life, it is conceivable that all life in the universe may be carbon-based.



Cells

- All life forms on Earth are made of cells
  - some organisms are single-celled, while others contain trillions of cells
- A cell contains living matter, and is separated from its surroundings by a cell membrane
- At a basic level, all living cells are similar to one another
- In complex organisms (like us), different cells perform different functions



a Bacteria **b** Amoebas **c** Plant cells **d** Animal cells

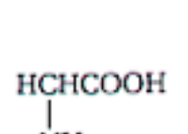
Four Key Components of Cells

- Carbohydrates
  - provide energy for cells
  - major component of cell structures
- Lipids
  - store energy for cells
  - the major ingredient of cell membranes
- Proteins
  - perform many of the cell's functions
  - enzymes facilitate chemical reactions
- Nucleic acids
  - DNA stores genetic instructions
  - RNA carries out these instructions

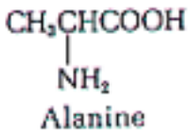
The building blocks of life (part 1)

The Primordial Biomolecules

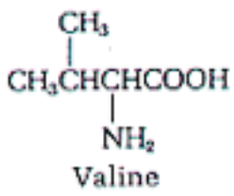
The amino acids (in un-ionized form)



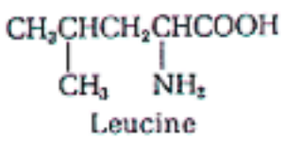
Glycine



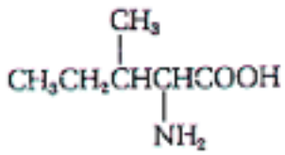
Alanine



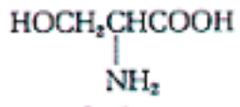
Valine



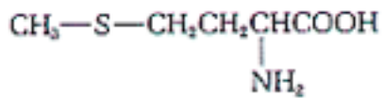
Leucine



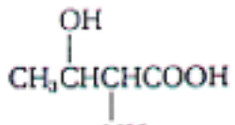
Isoleucine



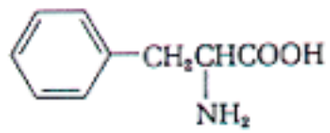
Serine



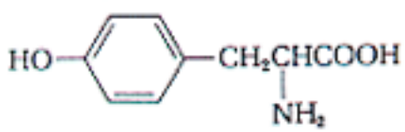
Methionine



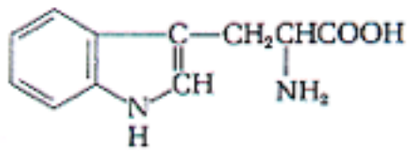
Threonine



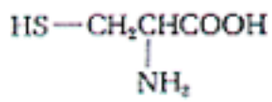
Phenylalanine



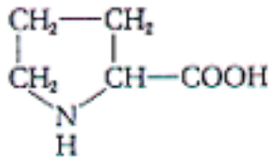
Tyrosine



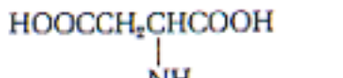
Tryptophan



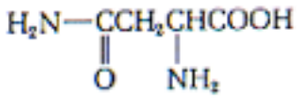
Cysteine



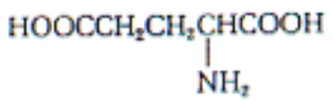
Proline



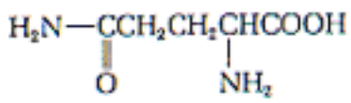
Aspartic acid



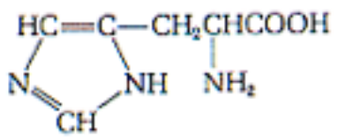
Asparagine



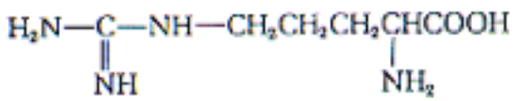
Glutamic acid



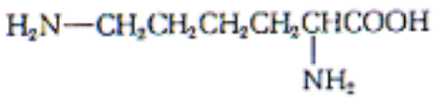
Glutamine



Histidine



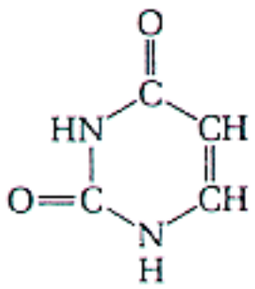
Arginine



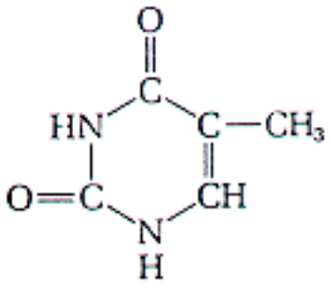
Lysine

The building blocks of life (part 2)

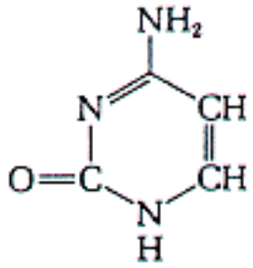
The pyrimidines



Uracil

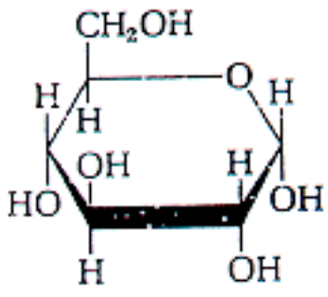


Thymine

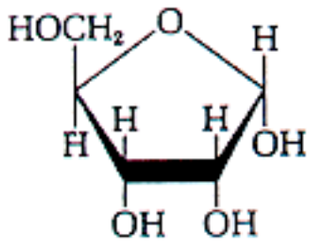


Cytosine

The sugars

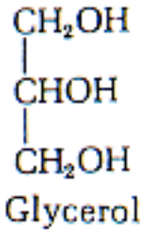


α-D-Glucose



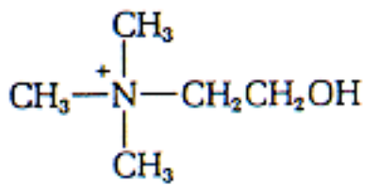
α-D-Ribose

A sugar alcohol



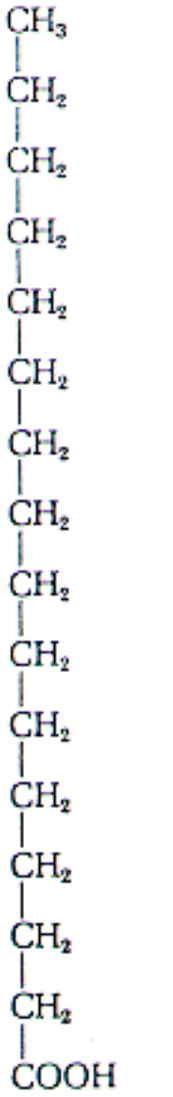
Glycerol

A nitrogenous alcohol



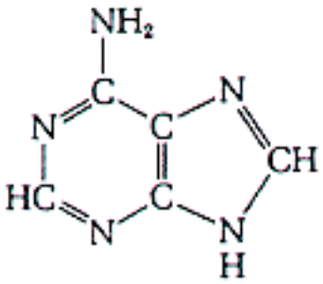
Choline

A fatty acid

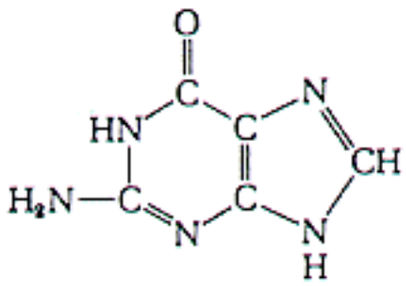


Palmitic acid

The purines

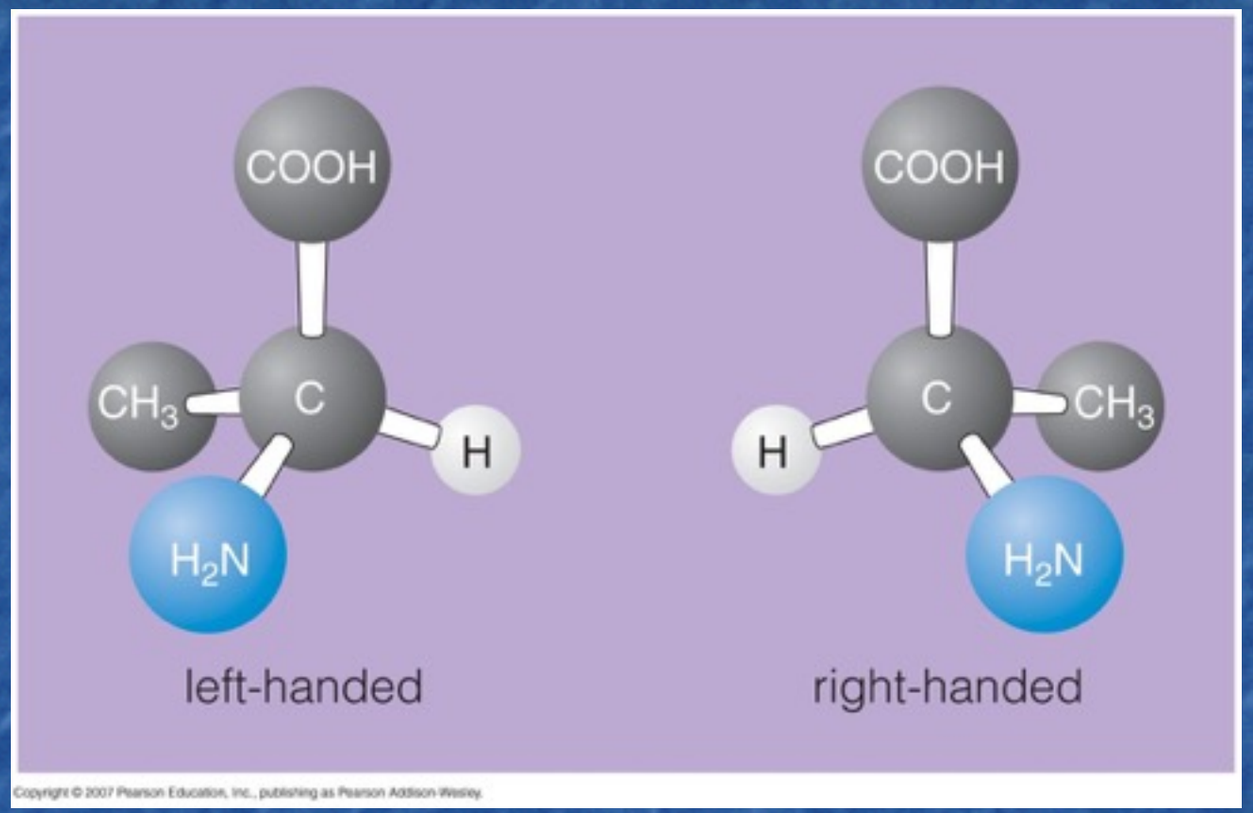


Adenine



Guanine

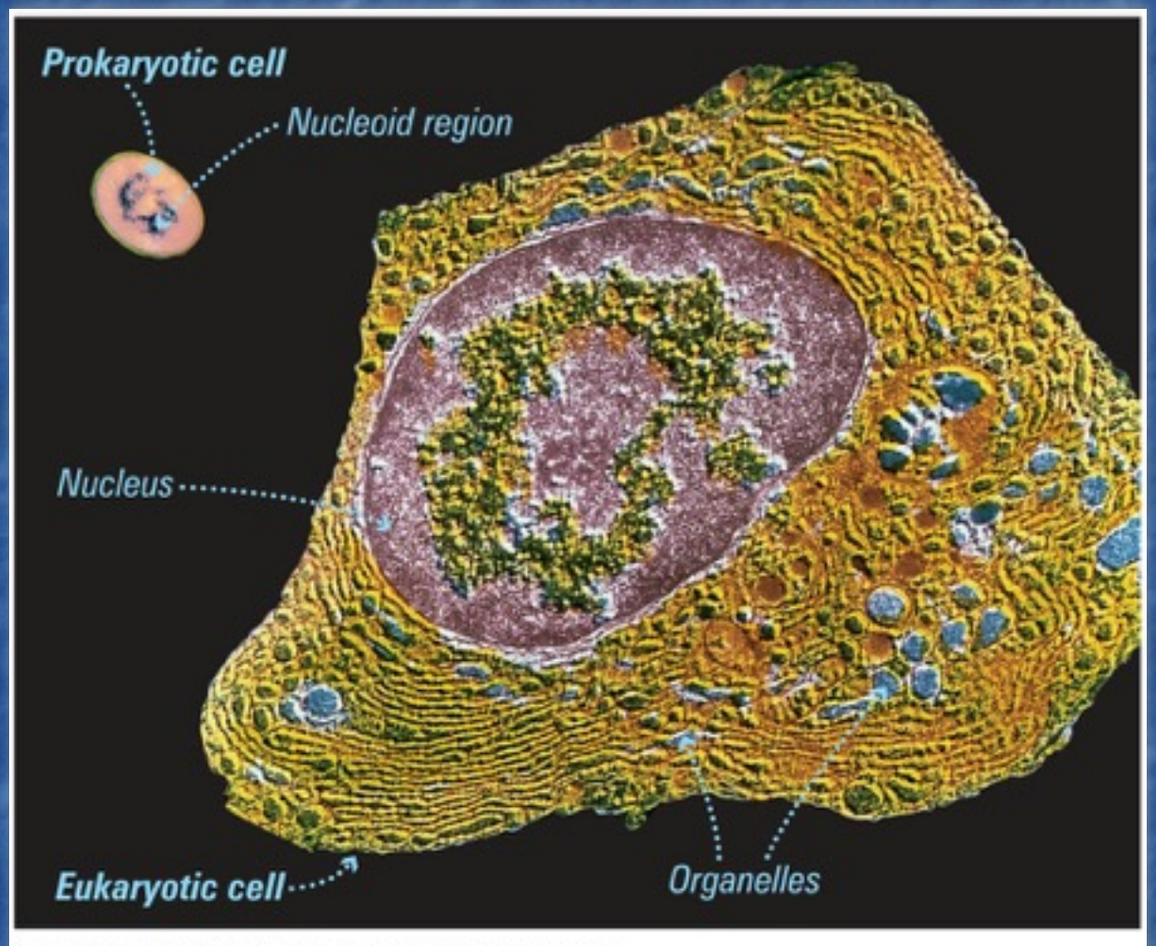
Chirality



- Chiral molecules are those that can arrange themselves in one of two configurations - each being the mirror image of the other.
- Living cells only use left handed amino acid molecules to build proteins.
- The natural mix of chiral molecules is 50/50. Life introduces an imbalance of one over the other.

Two Types of Organisms

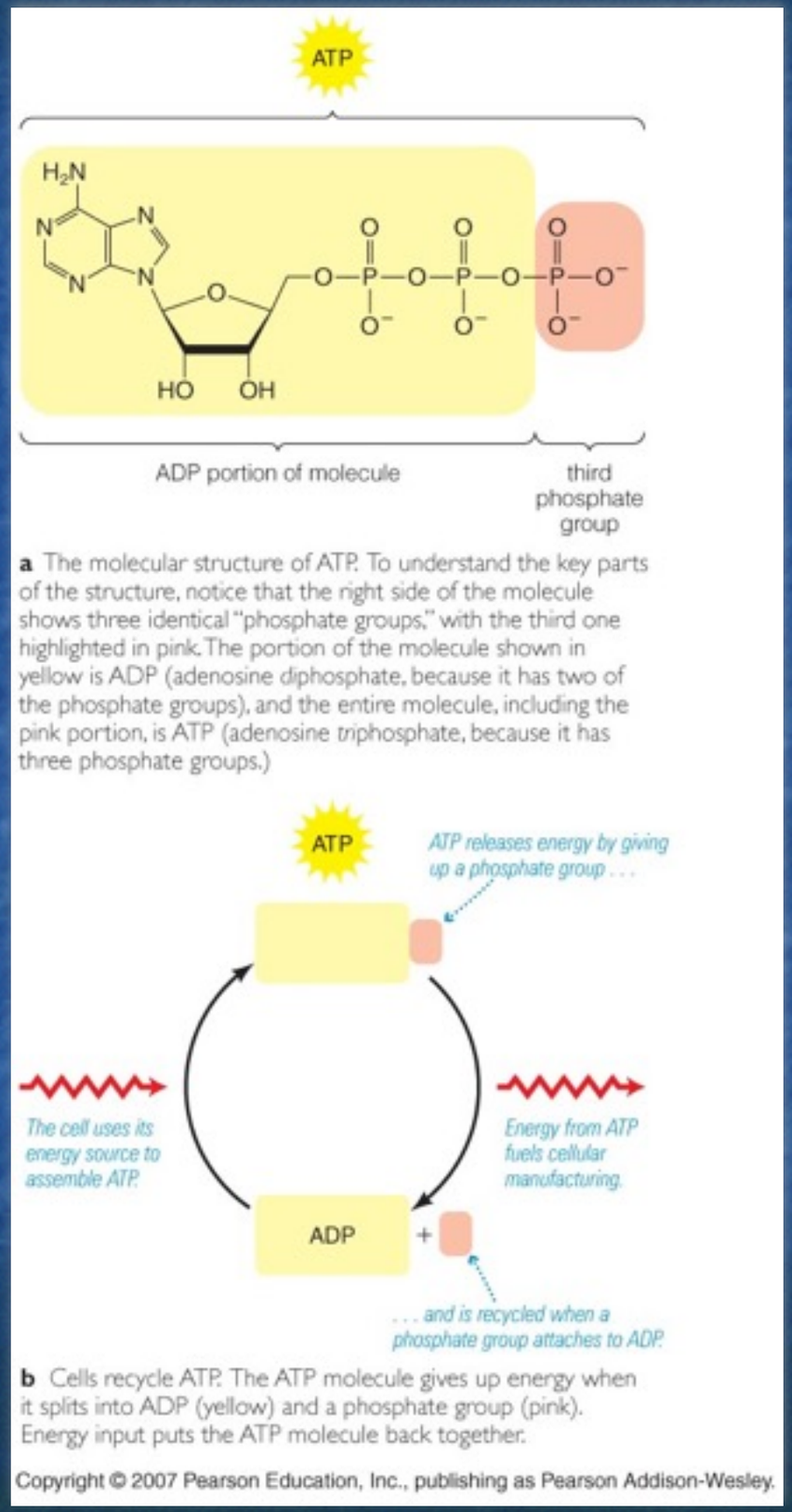
- Prokaryotes
  - No cell nucleus
  - Single-celled organisms
- Eukaryotes
  - Cell nucleus present
  - Single-celled or multicellular



A cell's nucleus keeps the genetic material (DNA) separate from the rest of the cell.

Cell Metabolism

- Almost all cells use ATP to store and release energy
  - when ATP releases its energy, it turns into ADP
- ATP can be used to power the many chemical reactions that take place within cells
- Cells need a steady source of energy and carbon in order to function



a The molecular structure of ATP. To understand the key parts of the structure, notice that the right side of the molecule shows three identical "phosphate groups," with the third one highlighted in pink. The portion of the molecule shown in yellow is ADP (adenosine *di*phosphate, because it has two of the phosphate groups), and the entire molecule, including the pink portion, is ATP (adenosine *tri*phosphate, because it has three phosphate groups.)

b Cells recycle ATP. The ATP molecule gives up energy when it splits into ADP (yellow) and a phosphate group (pink). Energy input puts the ATP molecule back together.

Sources of Carbon and Energy

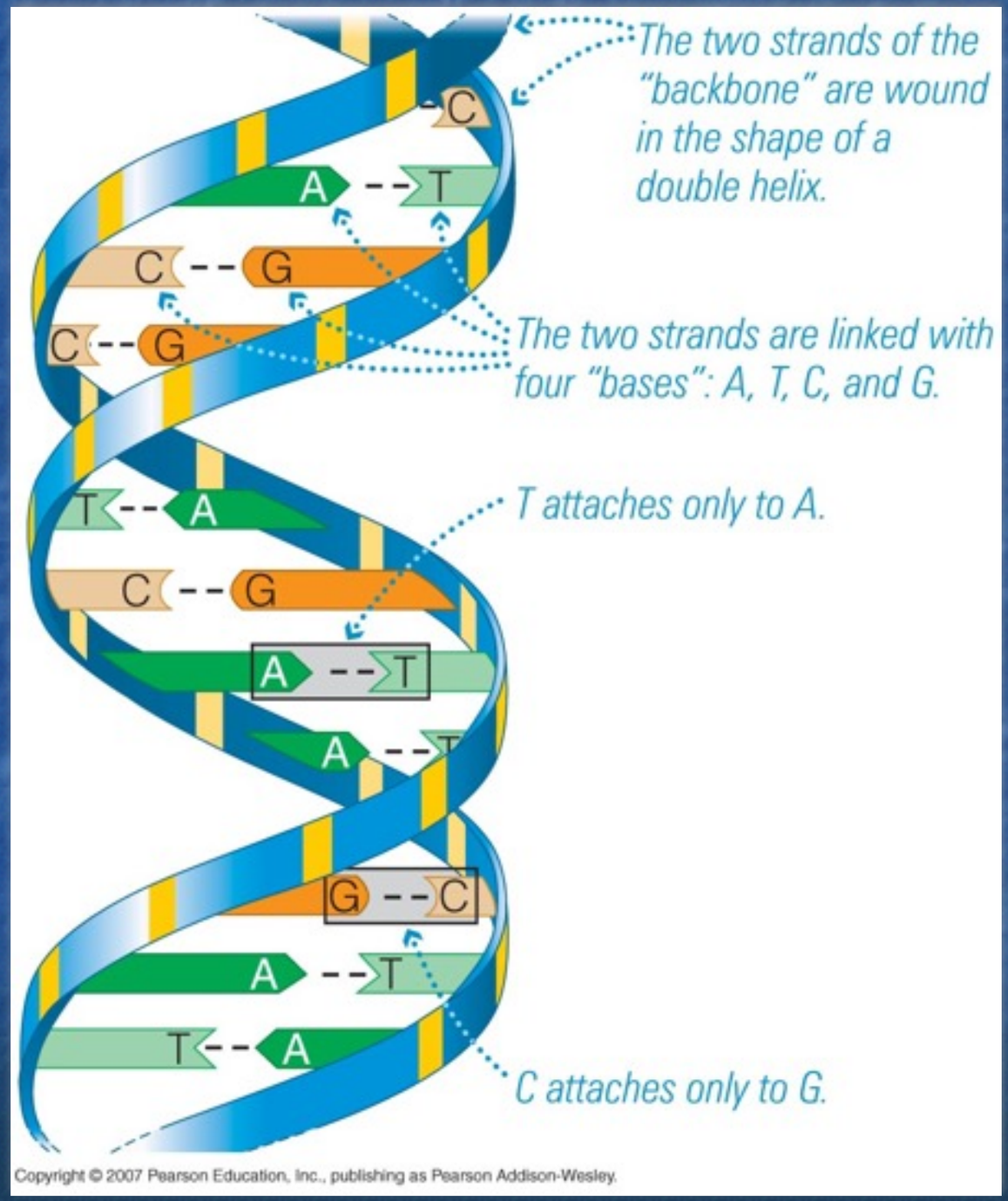
- Sources of carbon
  - organic material (obtained by eating food)
    - heterotrophs
  - carbon dioxide (from the atmosphere or water)
    - autotrophs
- Sources of energy
  - sunlight (via photosynthesis)
  - chemical energy from
    - organic material (contains carbon)
    - inorganic material (no carbon)

TABLE 5.1 *Metabolic Classifications of Living Organisms*

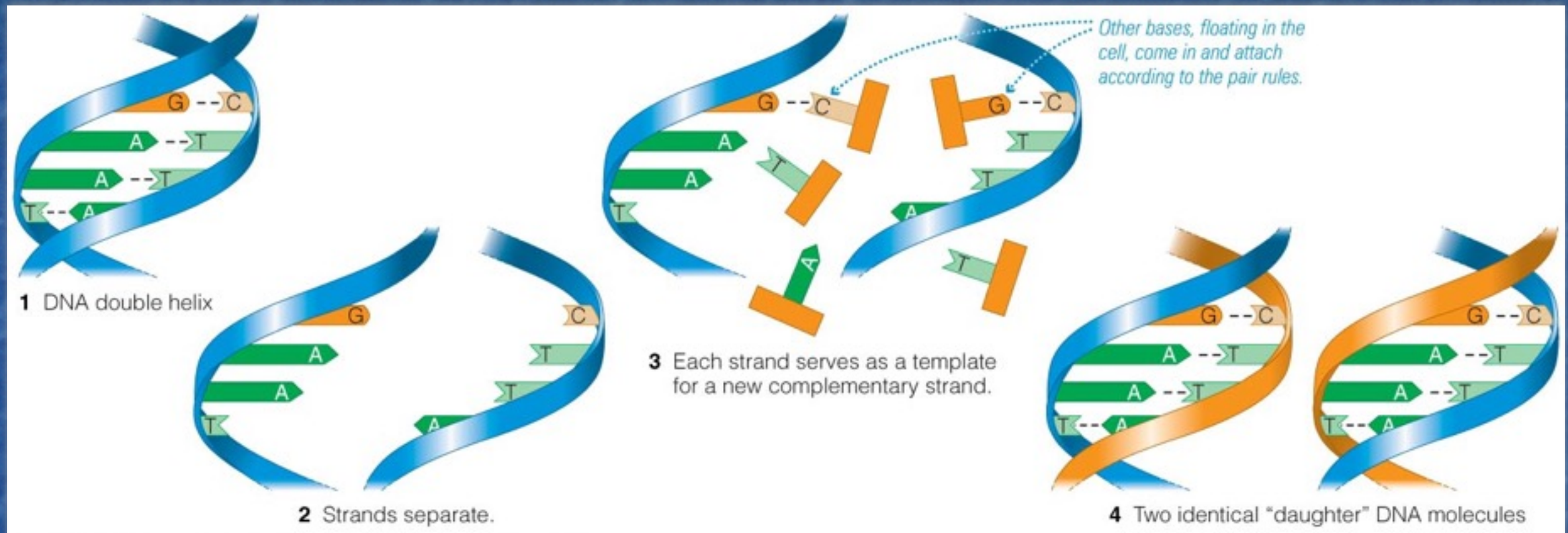
Metabolic Classification	*Carbon Source*	*Energy Source*	*Examples*
photoautotroph	carbon dioxide	sunlight	plants, photosynthetic bacteria
chemoautotroph	carbon dioxide	inorganic chemicals (e.g., iron, sulfur, ammonia)	some bacteria and archaea, especially in extreme environments
photoheterotroph	organic compounds	sunlight	some bacteria and archaea
chemoheterotroph	organic compounds	organic compounds	animals, many microbes

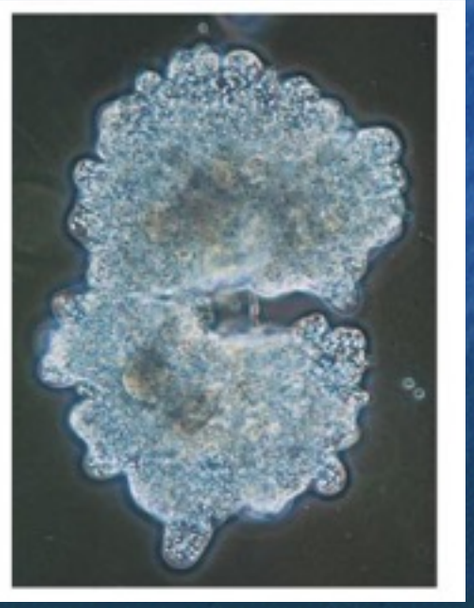
The Structure of DNA

- The "rungs" in the DNA ladder are made of four DNA bases
  - Adenine (A)
  - Cytosine (C)
  - Guanine (G)
  - Thymine (T)
- The sequence of these bases encodes genetic information



Replication of DNA





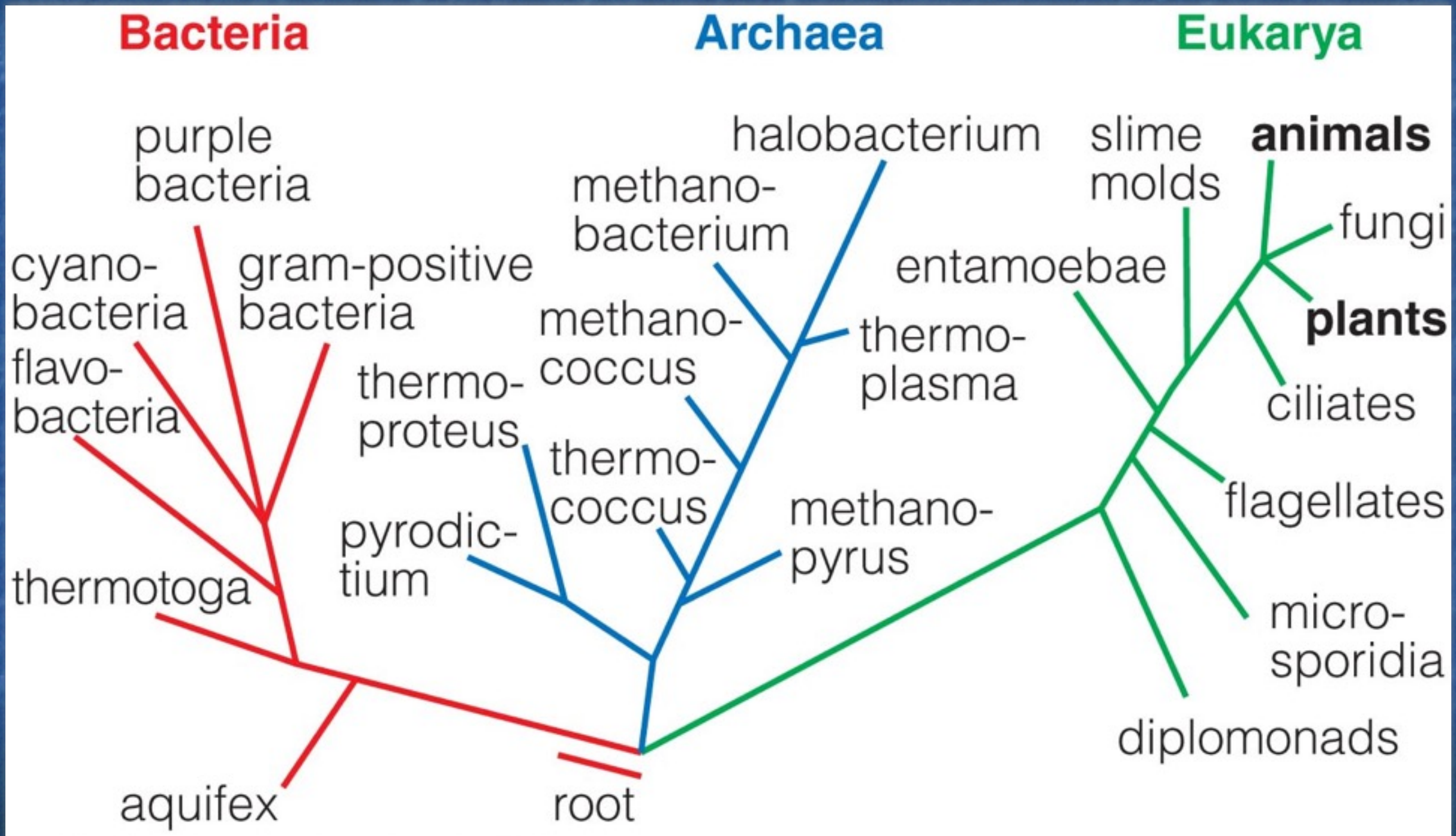
How evolution works

- In general, there are not enough resources (e.g. food) for all organisms to survive and thrive.
- Within a given population, individuals display variations in their physical characteristics.
- Some traits will increase chances of survival and subsequent reproduction, while others may decrease them or make no difference.
- "Successful" or naturally selected characteristics are preferentially passed on to the next generation. Unsuccessful characteristics are preferentially eliminated.
- Genetic information carried in DNA is the means by which characteristics are inherited from one generation to the next.

How to understand evolution...

- Step 1: read "The Blind Watchmaker" by Richard Dawkins
- Step 2: repeat step 1 until understanding is achieved...

Three Domains and the Tree of Life



The single common ancestor

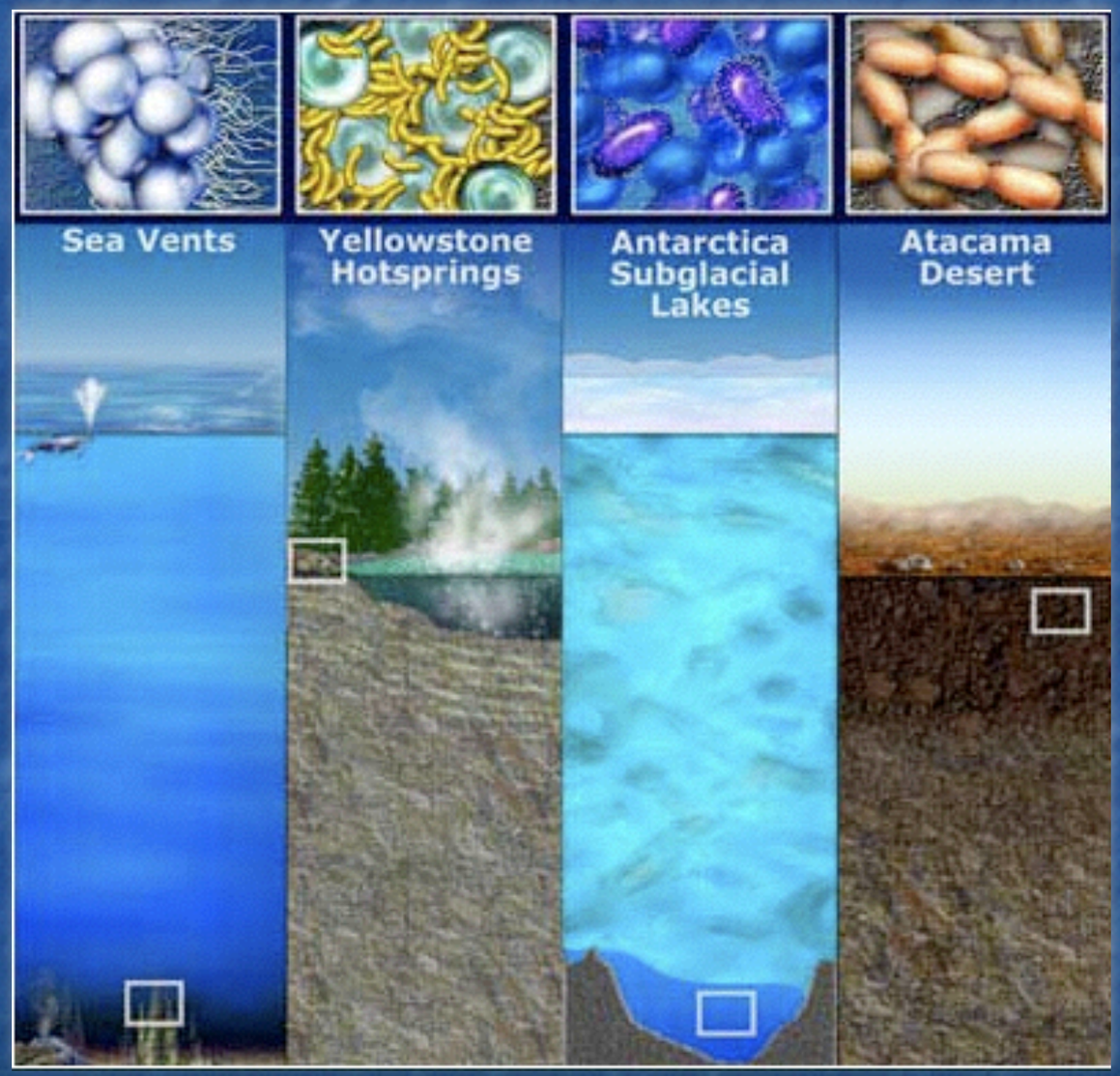
- All life on Earth appears to have followed the same biochemical recipe:
  - Carbon based chemistry
  - DNA based heredity
  - ATP (or similar) driven cell metabolism
  - Cell based structures
  - 20 (22) amino acids forming the protein chemistry
  - Uniform chirality of chemistry
- If one accepts that despite the tremendous similarity of (almost) all life on Earth arose from divergent evolution then the above similarities imply the existence of some early, common ancestor to all life on Earth.

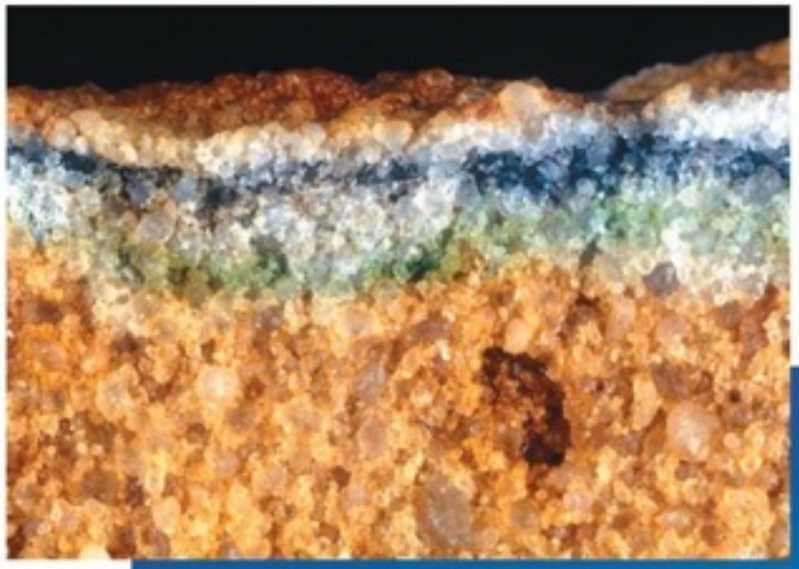
Alien life in Mono lake?

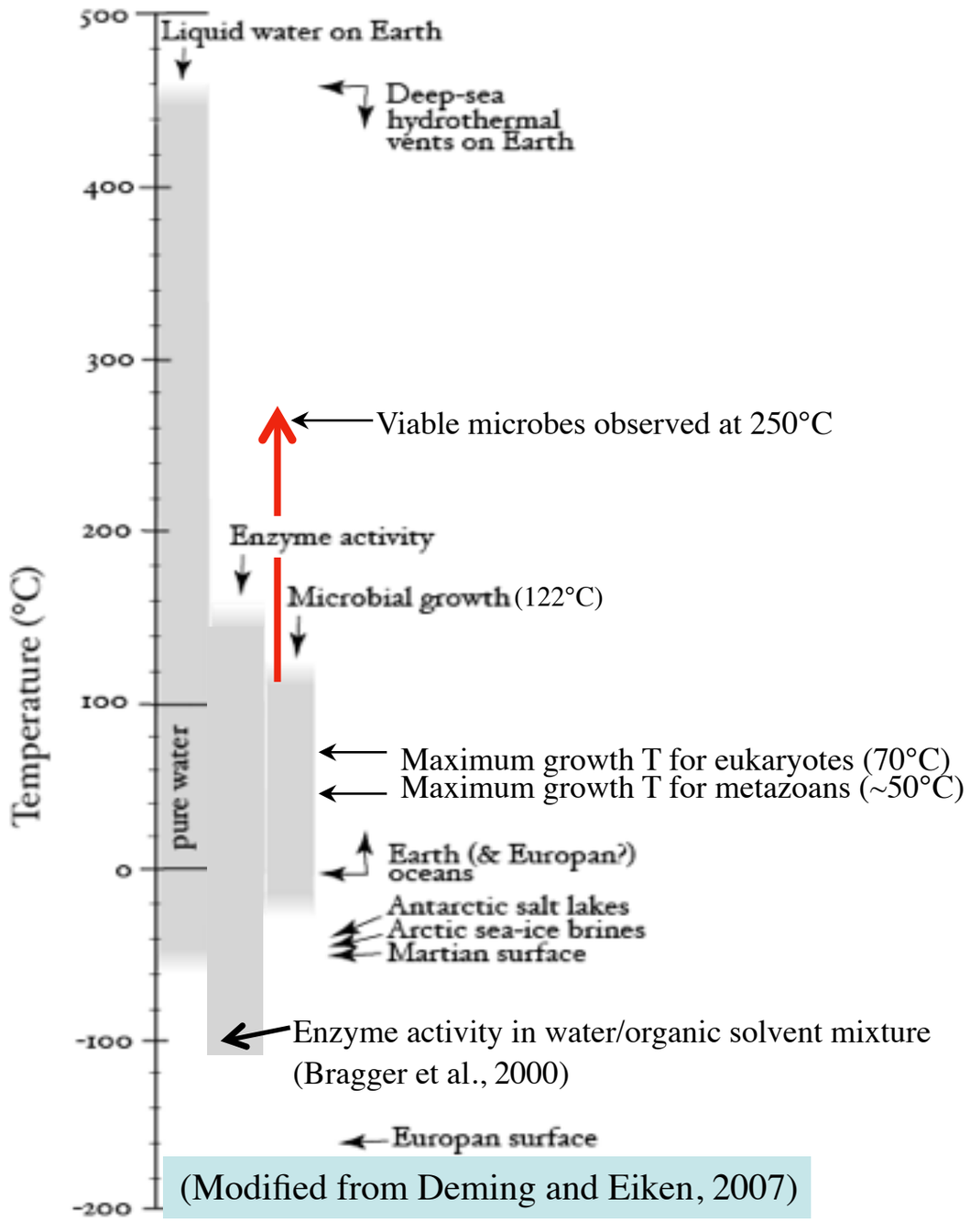
- Just to be clear: finding an organism that didn't need phosphorus, that used arsenic instead, would be one of the most significant scientific discoveries of all time. It would mean that Mono Lake was home to a form of life biologically distinct from all other known life on Earth. It would strongly suggest that life got started on our planet not once, but at least twice, that the origin of life on Earth was not a freak accident requiring highly specialized circumstances, but a relatively commonplace event. And that in turn would strengthen the argument that life is likely to be present on other worlds as well. Not too shabby a result for an afternoon stroll by a mountain lake.

Extremophiles

- Some life forms on Earth have been found in extreme environments
  - in boiling hot water close to deep sea volcanic vents
  - in hot acidic water near hot springs
  - within rocks in cold dry desert regions
  - deep underground in rocks or subglacial lakes
  - etc.!
- These discoveries increase our chances of finding extra-terrestrial life, perhaps even in our solar system







(Modified from Deming and Eiken, 2007)

The Role of Water

- Despite the variety of life forms present on Earth, all these life forms need liquid water to exist
- Water performs three crucial roles for cells
  - contains dissolved organic chemicals within the cell
  - transports chemicals and other materials
  - plays an important role in chemical reactions within cells
    - e.g., in ATP reactions
- In searching for extra-terrestrial life, it makes sense to focus on locations in which liquid water can survive
  - not too hot, not too cold

Weighing up the pros and cons

Good for life	Bad for life
liquid water	ionizing radiation
organic chemicals	extreme temperatures
energy	vacuum
stability	

How might we search for life?

- Follow the water!
- OK - follow the liquid!
- Put samples under the microscope - identify organised structures.
- Look for chemicals being processed in manner we cannot explain using inorganic recipes - shake and bake...
- Biologically driven chemical disequilibrium.