What is the Relationship Between ‘Life’ and ‘Cells’?

- **What is “Cell Theory”? Is it really a “theory”?**
- **Spontaneous generation of life had to have occurred in the past:**
  - Present Earth conditions are likely unfavorable for starting “new” life.
  - All evidence indicates that life appeared only once.
  - There is no observed spontaneous generation of new types of life today.
  - “New” life would have to compete with established life!

Cell Types

- **Two cell types:**
  - **Prokaryotes** (Archaea and Eubacteria): no organelles or nucleus.
  - **Eukaryotes** (protists, fungi, plants and animals): many membrane-bound organelles, nucleus w/ nuclear membrane.

Individual living things (organisms) may be:

- **Unicellular** (‘one-celled’) life: prokaryotes, rickettsias, most protists, some fungi
- **Multicellular** (‘multi-celled’) life: some protists, many fungi, plants, animals.

Phylogeny of Life

- **Organisms** – individual ‘living things’
- **Populations** – freely-interbreeding organisms inhabiting the same place at the same time
- **Species** – all organisms that can actually or potentially interbreed and produce fertile offspring
- **Communities** – collections of populations of different species inhabiting the same place at the same time
- **Ecosystems** – living organisms (communities) and their non-living environments
- **Biosphere** – all of Earth’s ecosystems: every part of Earth where life exists

Emergent Properties of Life

Organisms are living systems (Eugene P. Odum)
- Systems are organized collections of parts.
- Systems are organized collections of parts.
- **Cells**: perform synthesis of large molecules and chromosomal replication.
- **Species**: have reproductive isolating mechanisms (behaviors, chromosomal or germ cell incompatibilities).
- **Communities**: have coevolutionary relationships between species (e.g., competitive, predator-prey or parasite-host, mutualistic), and undergo predictable changes with time (succession).
- **Ecosystems**: recycling of nutrients between living organisms and the non-living environment.
- **Biosphere**: living things affect, and are affected by, the Earth’s biogeochemistry and climatic conditions.

Characteristics of Life

- **Acquiring and using energy:**
  - **First law of thermodynamics (Law of Conservation of Energy):** energy can be neither created nor destroyed, only converted from one form to another (energy input = energy output):
    - Autotrophic organisms can convert radiant energy into chemical energy
      - Solar energy is converted to chemical energy by photosynthesis
    - Heterotrophic organisms obtain their energy from consuming other organisms (all animals are heterotrophic, but some rely on autotrophic endosymbionts)
  - **Second law of thermodynamics (Law of Entropy):** transformations of energy are not completely efficient
    - Some energy is lost during each energy transfer (as heat in organisms).
    - The result is increasing disorder within the system (entropy).
    - Thus, all levels of life (organisms to ecosystems) require continuous energy inputs to maintain their structure and function.
    - This limits the number of energy transfers possible in ‘food chains’.

Hierarchical Organization of Life

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Characteristics of Life

Metabolism:
- An organism’s metabolism is the total of all life-sustaining chemical reactions occurring within its body.
- Metabolic reactions require energy.
  - Organisms use adenosine triphosphate (ATP) as their ‘energy currency’ for metabolic reactions.
  - Organisms phosphorylate ATP using energy from organic molecules (respiration).
- Metabolic reactions occur faster at high temperatures:
  - Arrhenius principle: 10°C increase results in only a 3% increase in reactant kinetic energy, but a 200-300% increase in reaction velocity.
  - Activation energy of chemical reactions is further lowered by enzymes.

Homeostasis:
- Most of metabolism (and therefore most of the energy needed by organisms) involves maintaining the internal conditions of the organism (homeostasis).
- Maintaining homeostasis involves
  - Resisting internal entropy, and
  - Adjusting for changing external conditions.
- Many factors affect homeostasis, mainly:
  - Thermal (heat), ionizing, and non-ionizing radiations
  - Free water availability
  - Osmotic extremes (salinity, pH)
  - Low partial pressures of oxygen
  - External toxicants, waste products generated by metabolism
  - Atmospheric and hydrostatic pressure
  - Gravity

Growth and development:
- All organisms must grow before completing their life cycle.
  - Unicellular organisms must grow before they can divide again.
  - Enlarging individual cells of multicellular organisms (e.g., rotifers) allows only minimal growth. Most organisms grow by increasing cell numbers (cell proliferation).
- Most organisms pass through distinct developmental stages during their life cycle.
  - Plants: spores/seeds, shoots, and flowering stages.
  - Protists: often have many life cycle stages.
  - Fungi: spores, hyphae, and fruiting bodies.
  - Animals: eggs, larvae, adults.

Response to stimuli (irritability):
- Organisms must recognize changes in environmental conditions.
  - Important in maintaining homeostasis, finding food, avoiding predators.
  - Appropriate responses and physiological adjustments to these changes are necessary.
- Two types of stimuli:
  - Negative stimuli: indicate conditions that could interfere with homeostasis or survival.
  - Positive stimuli: recognition of these stimuli assists in maintaining homeostasis (e.g., finding food) or aids reproduction.

Reproduction and heredity:
- No organism is immortal. Organisms must therefore reproduce (produce replacements of themselves).
- The instructions for replacing the organism (as well as maintaining it), are intrinsic characteristics of organisms:
  - Instructions are contained within the genes of the organism.
  - These genetic instructions (genotypes) have to be passed along through subsequent generations (heredity).

Evolution and natural selection:
- Genotypes of organisms change through time (mutate).
- New versions of the genes (alleles) that appear by these random mutations may produce changes in how organisms are built and maintained (evolution).
- If the environment operates on the physical expressions of the genes (phenotypes) of organisms, such that allelic frequencies within a population are changed, then natural selection results.
- Accumulations of genetic changes can lead to reproductive isolation and eventual speciation.
Are viruses alive?

Of all of the characteristics of life, viruses show only reproduction, heredity, and evolution. In fact, the only thing that viruses do is reproduce themselves!

- Viruses contain the genetic instructions to reproduce themselves (heredity), but must invade the cell of a living organism to reproduce.
- Viruses do evolve and their new genotypes do undergo natural selection.
- Viruses do not grow and develop themselves!
-Viruses are ‘organized’, but not complex
  - Consist of a protein coat and either RNA or DNA
  - Do not maintain this complexity: no homeostasis, no acquisition or use of energy, no metabolism
- Viruses bond physiochemically to host receptors, but do not respond to stimuli

Chemical Elements Needed by Life

- All organisms are composed of matter
  - Chemical elements are organizations of matter that cannot be reduced in complexity through chemical means
  - 92 natural chemical elements (H through U)
  - Elements originate in stellar fusion reactions
- Chemical elements combine with the same or other elements by sharing electrons to form molecules (e.g., \( \text{O}_2 \), \( \text{H}_2 \text{O} \), \( \text{CO}_2 \), \( \text{CH}_4 \))
  - Biological function begins at the molecular level
  - Molecules that are combinations of two or more different elements are known as compounds

Evidence for the Common History of Life

- (Bio)chemistry
  - Similarities in body composition (including elements used for physiological functions), genetic structure/function, and physiology.
- Anatomy (homology of body structures)
  - Includes developmental changes, possession of similar structural and regulatory genes in distantly-related taxa.
- Biogeography
  - Present distribution of species based on location and ecological conditions
- Fossil Record
  - Allows reconstruction of evolutionary timetable of anatomical adaptations, phylogeny, and geographical distribution.

Biological Compounds (Biomolecules)

- Most biological molecules are composed of C, H, O, and N
  - Organic molecules are synthesized by organisms and always contain both C and H.
  - \( \text{CO}_2 \) and \( \text{H}_2 \text{O} \) are not organic, even though \( \text{H}_2 \text{O} \) makes up most of the mass of most organisms.
- Many organic molecules are macromolecules (e.g., complex carbohydrates, proteins, lipids, and nucleic acids).
- Most are macromolecules are polymers of simpler monomers
  - Complex carbohydrates or polysaccharides (e.g., cellulose, starch, chitin) are polymers of simple sugars (monosaccharides).
  - Proteins and enzymes (polypeptides) are polymers of amino acids.
  - Nucleic acids are polymers of nucleotides.
  - Lipids (fats) are complexes of fatty acids and alcohols.

Water

- Indispensable for all biochemical and physiological processes. The nature of life on Earth is largely due to the physical properties of water:
  - Water is a polar solvent, making it well-suited to dissolving biomolecules and salts. Polarity of water is due to the high electronegativity of oxygen and asymmetrical molecular shape, which also promote formations of exceptionally strong hydrogen bonds (attractions between the hydrogen atoms of one water molecule to the oxygen atoms of adjacent water molecules).
  - These bonds must be broken before vaporization can occur. Produces very high melting/bubbling points for a molecule its size.
  - When water is frozen, almost all the water molecules have formed hydrogen bonds, but frozen water is less dense than liquid water.
  - Water has a high surface tension, making it all but impossible to compress (among other things, this allows animals to live at the greatest ocean depths). Yet, water has low viscosity, which allows it to be forced through small tubules and between cells.

Other Essential Elements

- About 20 additional elements are essential for life: Ca, P, Mg, K, S, Na, Cl, Fe, Mn, F, Zn, Co, Cu, I, Mo, B, Cr, V, Sn, Se
  - Most of these are lighter elements (atomic number ≤ 34)
  - Of all of the elements needed by animals, only two are heavier than atomic number 34: strontium (element 39), and iodine (element 58)
- Boron and vanadium are required only by plants
- Chromium (carbohydrate metabolism in vertebrates), selenium (functional tails in spermatozoa), fluorine (teeth and skeletons of vertebrates), strontium (skeletons/tests of corals), and iodine (thyroid hormone of vertebrates) are required by some animals
- Need for these elements probably represents a combination of which elements are most abundant on Earth, together with their availability at the time that life’s chemical reaction pathways evolved (metals are much rarer in ocean water today).
Biochemical Evidence for a Single
Common Origin for Life

- All organisms use the same genetic material
  - Genetic material of all life is composed of the same 4 deoxyribonucleotides.
  - All life uses RNA as an intermediate in translating DNA sequence into a protein amino acid sequence.
  - RNA of all life is also composed of the same 4 ribonucleotides (A,U,C,G).
  - All life uses a common three-letter code \( \text{codons} \) to translate genetic sequences into protein sequences.
  - The ‘start’ codon (DNA = TAC, mRNA = AUG) and the three ‘stop’ codons for genes are the same for all life.
  - Each codon codes for the same amino acid in all species.

- Biochemical Evidence for a Single
Common Origin for Life

**Chirality ('handedness') of biomolecules**

- Life uses 'left-handed' amino acids in proteins
  - A stereoisomer (enantiomer) is one of a pair of molecular species that are 'mirror images'.
  - All amino acids but one (glycine) are chiral, having sinister (L- or S-) and dextral (D-) stereoisomers.
  - All proteins are made exclusively of L-amino acids (D-amino acids are known only from bacterial cell walls).
- DNA and RNA also exist in nature in only one chirality
  - Only the D-enantiomer of the sugar is present in nucleic acids.
  - DNA and RNA form right-handed helices as a result of the exclusive presence of D-sugars.
  - Replication of nucleic acids depends on the activity of proteins made of L-amino acids.

- Biochemical Evidence for a Single
Common Origin for Life

**Organisms have similar protein structures and functions**

- For example, alcohol dehydrogenases (AdHs) are enzymes that catalyze oxidation of alcohols and reduction of aldehydes and ketones are common to all living organisms, catalyzing the following reactions (where \( R_2 \) is H for aldehydes):

- Biochemical Evidence for a Single
Common Origin for Life

**Relationship between the number of amino acid substitutions and the last common ancestor**

- Homologous Anatomical Structures
■ Bony elements of the fins of lobe-finned fishes resemble the limbs of amphibians
  - Eusthenopteron was able to crawl along on the bottom mud; it had both lungs and "walking" fins.
  - Acanthostega had digits on both fore- and hindlimbs; its body dragged on the ground.

**Analogous Anatomical Structures**

Swordfishes, ichthyosaurs (Jurassic marine reptiles) and dolphins share several adaptations: (1) thunniform ("tuna-shaped", tapered cylindrical bodies), scythe-shaped tails (reduce drag when swimming), and elongated beaks (more efficient when preying on smaller, fast-moving fishes). Ichthyosaurs and dolphins evolved from ancestors with lungs. Their nostrils are on the top of their heads, which facilitates surface breathing.

**Biogeography and the Fossil Record**

[Image showing biogeographic patterns and fossil records.]