Organization and Structure of Cells

All living things fall into one of the two categories:

- prokaryotes
- eukaryotes

The distinction is based on whether or not a cell has a nucleus. Prokaryotic cells do not have nuclei, while eukaryotic cells do. Also, eukaryotic cells have organelles.

*pro* = means “prior to”
*eu* = means “true”
*karyote* = means “nucleus”

Early Evolution of Cells

Contemporary evidence favors the view that all living organisms should be grouped into three lineages (or classes):

- Archaea
- Eubacteria (or just bacteria)
- Eucarya (or eukaryotes)

Archaea and eubacteria are both prokaryotic (single cell organisms without nucleus). It is believed (estimated) that all three lineages evolved approximately 3.5 billion years ago from a common ancestral form called progenote.

However, it is now accepted that eukaryotic cells are composed of various prokaryotic contributions, making the dichotomy artificial.

In contrast to eukaryotes, prokaryotes lack structural diversity. What is often used to classify prokaryotes is their physiological, ecological, and morphological diversity.

Archaea

- derived from the word “ancient”
- most recently discovered lineage
- similar in shape to bacteria, but genetically they are as distinct from bacteria as they are from eucarya (whole genome sequencing of the archaeon *Methanococcus jannaschii* showed 44% similarity to the known genes in eubacteria and 56% of genes that were new to science)
- based on their physiology, archaea can be classified into three subcategories:
  - methanogens - prokaryotes that produce methane (CH₄)
  - halophiles - prokaryotes that live at very high concentrations of salt (NaCl)
  - thermo(acido)(psychro)philes - prokaryotes that live at very high temperatures (>100°C) or in acidic environments or at very low temperatures (<10°C)
Eubacteria

- ubiquitous single cell organisms
- differ from archaea in chemical content of the cell wall and cell membrane
- based on morphology, physiology, and ecology, some of the important representatives are:
  - photosynthetic purple and green bacteria (blue-green algae) – convert the energy of light into chemical energy, but do not produce oxygen
  - cyanobacteria – thought to have given rise to eukaryotic chloroplasts; live in fresh water and marine habitats and are a part of a complex microbial community called plankton
  - spirochetes – genetically are a distinct group of bacteria; some are pathogens for animals (syphilis, lyme disease, etc.)
  - spirilla – live in fresh water and like oxygen; can be pathogenic
  - myxobacteria (a group of gliding bacteria) – live in soil or animal dung
  - lithotrophs – requires inorganic compounds as sources of energy (this mechanism also exists in archaea). For example, the nitrifying bacteria can convert NH$_3$ to NO$_2$, and NO$_2$ to NO$_3$; may play an important role in primary production of organic material in nature
  - pseudomonads and their relatives – most commonly free-living organisms in soil and water; have flagella
  - enterics – can ferment glucose and are present in humans; very well studied and the most important organism is *E. Coli*

and there are many many more.

Eubacteria come in various shapes:
- little balls
- medicine capsules
- segmented ribbons
- little rods

*Escherichia coli* (abbr. *E.Coli*) is one of the very important model organisms and one of the best studied organisms. It is one of the main species of bacteria that live in the lower intestines of warm-blooded animals (including birds and mammals) and are necessary for the proper digestion of food. However, it may become harmful if it makes it out of the lower intestines (e.g. dysentery).

Eukaryotes

- are single-cell or multi-cell organisms in which each cell contains a nucleus and organelles
- eukaryotes are subdivided into four categories
  - animals – typically divided into vertebrates (e.g. mammals) and invertebrates (e.g. snails)
  - plants – trees, flowers etc.
  - fungi – sometimes in popular literature considered as plants
  - protists – all other organisms, e.g. yeast.
Prokaryotic Cell

Major elements and features of a typical prokaryotic cell:

- **cell wall** – a rigid framework of polysaccharide cross-linked by short peptide chains; provides mechanical support, shape, and protection; it is a porous nonselective barrier that allows most small molecules to pass
- **cell membrane** – 45:55% lipid:protein ratio; bilayer; highly selective and controls the entry of most substances into the cell; important proteins are located in the cell membrane
- **nucleoid** (DNA) – repository of the cell’s genetic information; contains a single tightly coiled DNA molecule
- **ribosomes** – sites where proteins are synthesized; consists of a small and a large subunit; a bacterial cell has about 15,000 ribosomes; 35% of a ribosome is protein, the rest is RNA
- **storage granules** – granules where polymerized metabolites are stored (e.g. sugars); when needed the polymers are liberated and degraded by energy-yielding pathways in the cell
- **cytosol** – the site of intermediary metabolism (sets of chemical reactions by which cells generate energy and form precursors necessary for biosynthesis of macromolecules essential to cell growth and function
**Eukaryotic Cell**

- much larger in size (1,000 to 10,000 times larger than prokaryotic cells)
- much more complex
- metabolic processes are organized into compartments, with each compartment dedicated to a particular function (enabled by a system of membranes)
- possess a nucleus, the repository of cell’s genetic material which is distributed among a few or many chromosomes

**Animal Cell**

Major elements and features of a typical animal cell:

- **extracellular matrix** – a complex coating which is cell specific, serves in cell-cell recognitions and communication, also provides a protective layer
- **cell (plasma) membrane** – roughly 50:50% lipid:protein ratio; selectively permeable membrane; contains various systems for influx of extracellular molecules (pumps, channels, transporters); important proteins are located here
- **nucleus** – separated from the cytosol by a double membrane; repository of genetic information – DNA complexed with the basic proteins (histones) to form chromatin fibers, the material from which the chromosomes are made
- **nucleolus** – a distinct RNA-rich part of the nucleus where ribosomes are assembled
- **mitochondria** – organelles surrounded by two membranes that differ significantly in their protein and lipid composition; mitochondria are power plants of eukaryotic cells where ATP is produced
- **Golgi apparatus** – involved in packaging and processing of macromolecules for secretion and for delivery of other cellular compartments
- **endoplasmic reticulum (ER)** – the ER is a labyrinthine organelle where both membrane proteins and lipids are synthesized;
- **ribosomes** – organelle composed of RNA and ribosomal proteins; eukaryotic ribosomes are much larger than prokaryotic ribosomes; attached to ER
- **lysosomes** – function in intracellular digestion of certain materials entering the cell; they also function in the controlled degradation of cellular components
- **peroxisomes** – act to oxidize certain nutrients such as amino acids; in doing so they form potentially toxic hydrogen peroxide and then decompose it by means of the peroxy-cleaving enzyme (protein)
- **cytoskeleton** – is composed of a network of protein filaments and it determines the shape of the cell and gives it stability; cytoskeleton also mediates internal movements that occur in the cytoplasm, such as migration of organelles and movement of chromosomes during cell division

A word on ribosomes: ribosome consists of two subunits that fit together and work as one to translate the mRNA into a polypeptide chain (side and front view are below)
Plant Cell

Major elements and features of a typical plant cell (only what differs from the animal cell):

- **cell wall** – consists of cellulose fibers embedded in a polysaccharide and protein matrix; provides protection from the osmotic and mechanical rupture; channels for fluid circulation and for the cell-cell communication pass through the walls
- **chloroplasts** – a unique family of organelles (the plastids) of which the chloroplast is the prominent example; significantly larger than mitochondria; they are the site of photosynthesis, the reaction by which light energy is converted to metabolically useful chemical energy in the form of ATP
- **mitochondria** – a major source of energy in the dark
- **vacuole** – a very large vesicle enclosed by a single membrane; vacuoles grow; they function in transport and storage of nutrients; by accumulating water, the vacuole allows the plant cell to grow dramatically with no increase in cytoplasmic volume
The Central Dogma of Molecular Biology

DNA contains the complete genetic information that defines the structure and function of an organism. Proteins are formed using the genetic code of the DNA. Three different processes are responsible for the inheritance of genetic information and for its conversion from one form to another:

1. **Replication**: a double stranded nucleic acid is duplicated to give identical copies. This process perpetuates the genetic information.
2. **Transcription**: a DNA segment that constitutes a gene is read and transcribed into a single stranded sequence of RNA. The RNA moves from the nucleus into the cytoplasm.
3. **Translation**: the RNA sequence is translated into a sequence of amino acids as the protein is formed. During translation, the ribosome reads three bases (a codon) at a time from the RNA and translates them into one amino acid.

In eukaryotic cells, the second step (transcription) is necessary because the genetic material in the nucleus is physically separated from the site of protein synthesis in the cytoplasm in the cell. Therefore, it is not possible to translate DNA directly into protein, but an intermediary must be made to carry the information from one compartment to another.
Viruses

- supramolecular complexes of nucleic acid (DNA or RNA) encapsulated in a protein coat
- viruses act as parasites of cells
- the protein coat (capsid) serves to protect the nucleic acid
- in some instances, it is also surrounded by a membrane

- viruses for all types of cells are known
- different viruses infect animal and plant cells
- viruses infecting bacteria are called bacteriophages (“bacteria eaters”)

- often times, viruses cause the lysis (destruction) of cells
- in some cases the viral genetic elements may integrate into the host chromosome and become quiescent
- some viruses are implicated in transforming cells into a cancerous state, that is, in converting their hosts to an unregulated state of cell division and proliferation

- because all viruses are heavily dependent on their host for the production of viral progeny, viruses must have arisen after cells were established in the course of evolution (presumably, the first viruses were fragments of nucleic acid that developed the ability to replicate independently of the chromosome and then acquired the necessary genes enabling protection, autonomy, and transfer between cells.
Sources: Biochemistry by Reginald H. Garrett and Charles M. Grisham
Molecular Biology for Computer scientists by Lawrence Hunter
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