Chapter 1

Science, Technology, and Society

Contents

Technology

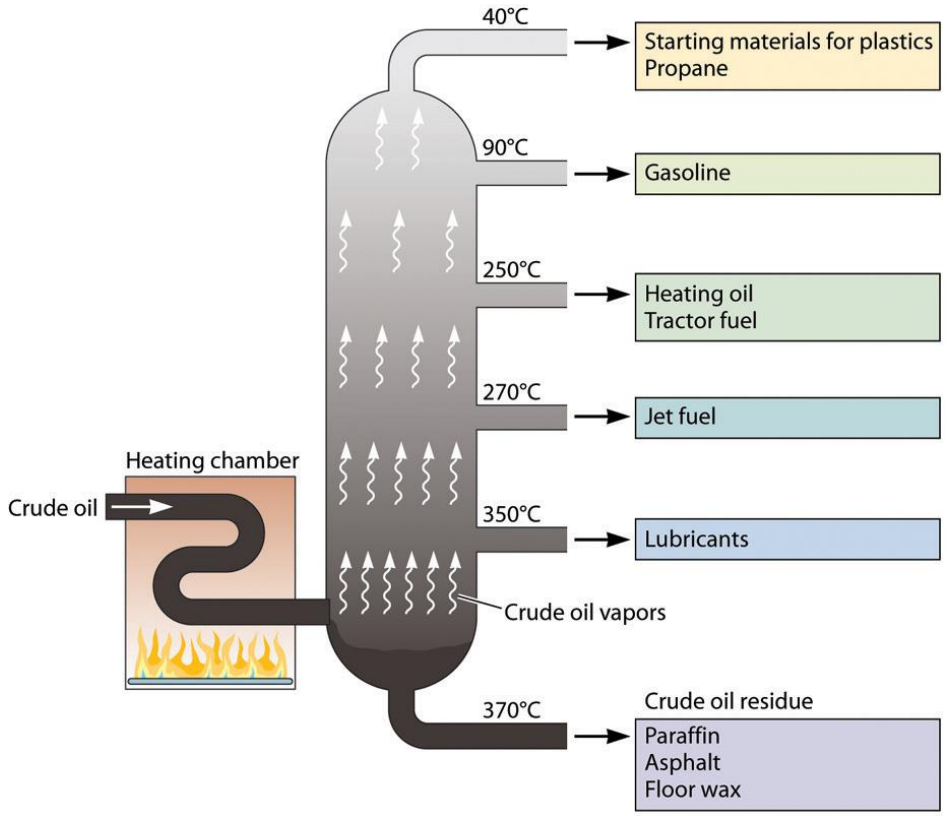
- Try to imagine a world without technology.
  - Computer
  - TV
  - Car
  - Heating (Energy)
  - Cooling
  - Clothes
  - Food
  - House
  - Lamp, paper, pen, chair, …..

Technology and Society

- Technology
  - Changes the environment and society
  - Webster's definition:

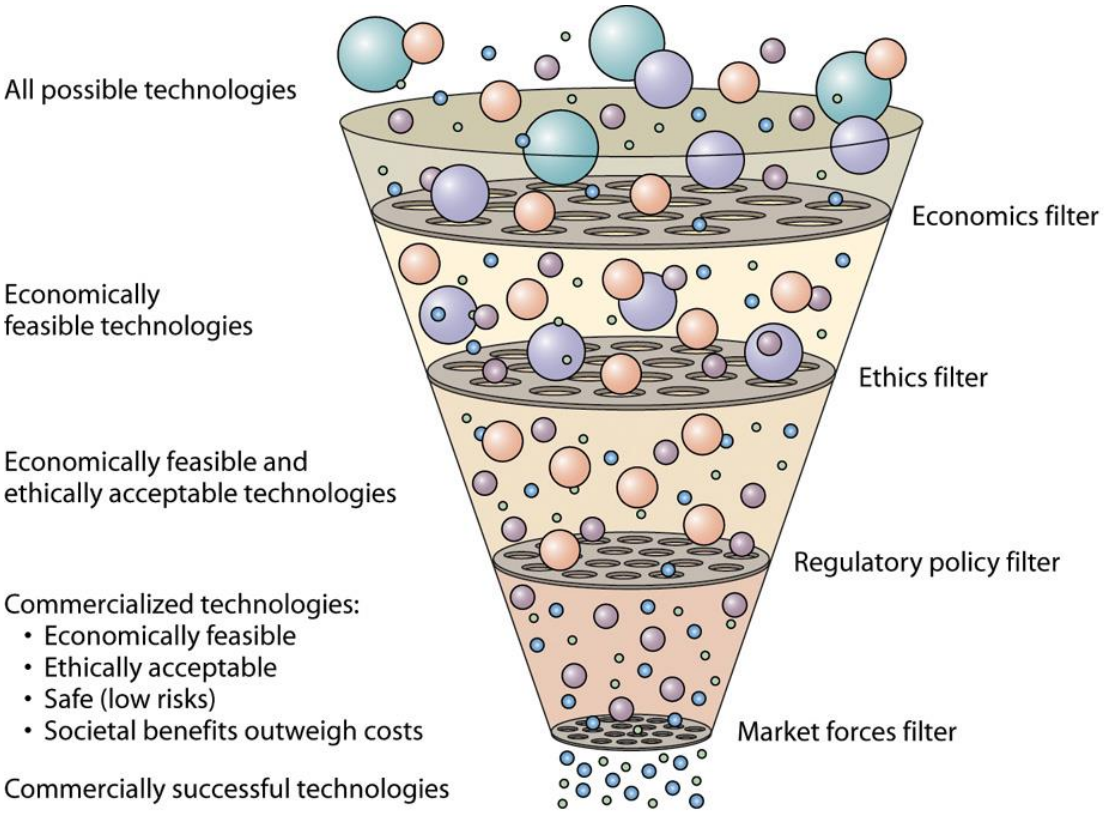
    "the totality of means employed to provide objects necessary for human sustenance and comfort"

Technology and Society



Technology and Society

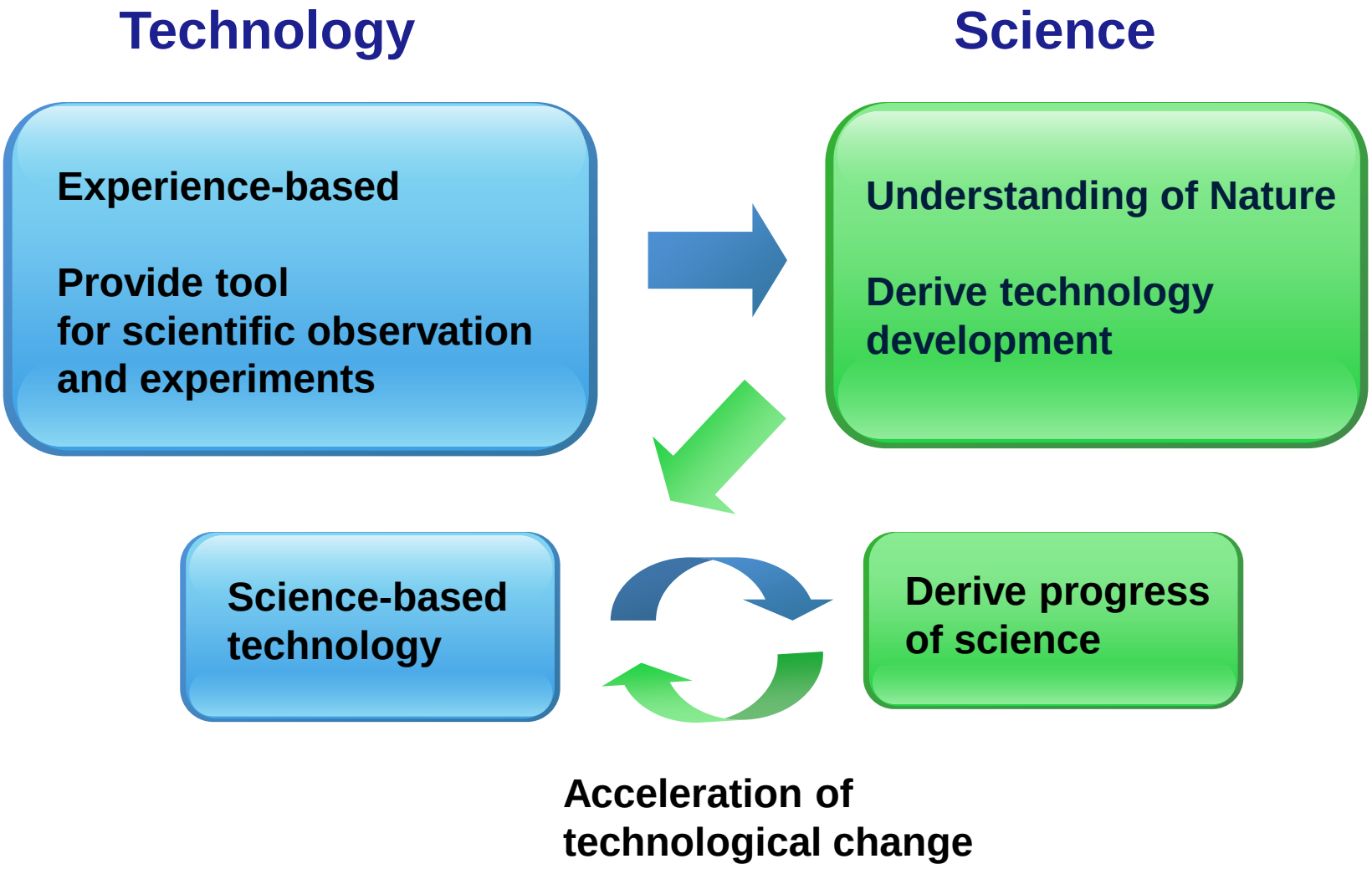
- Society
  - Creates filters for technology



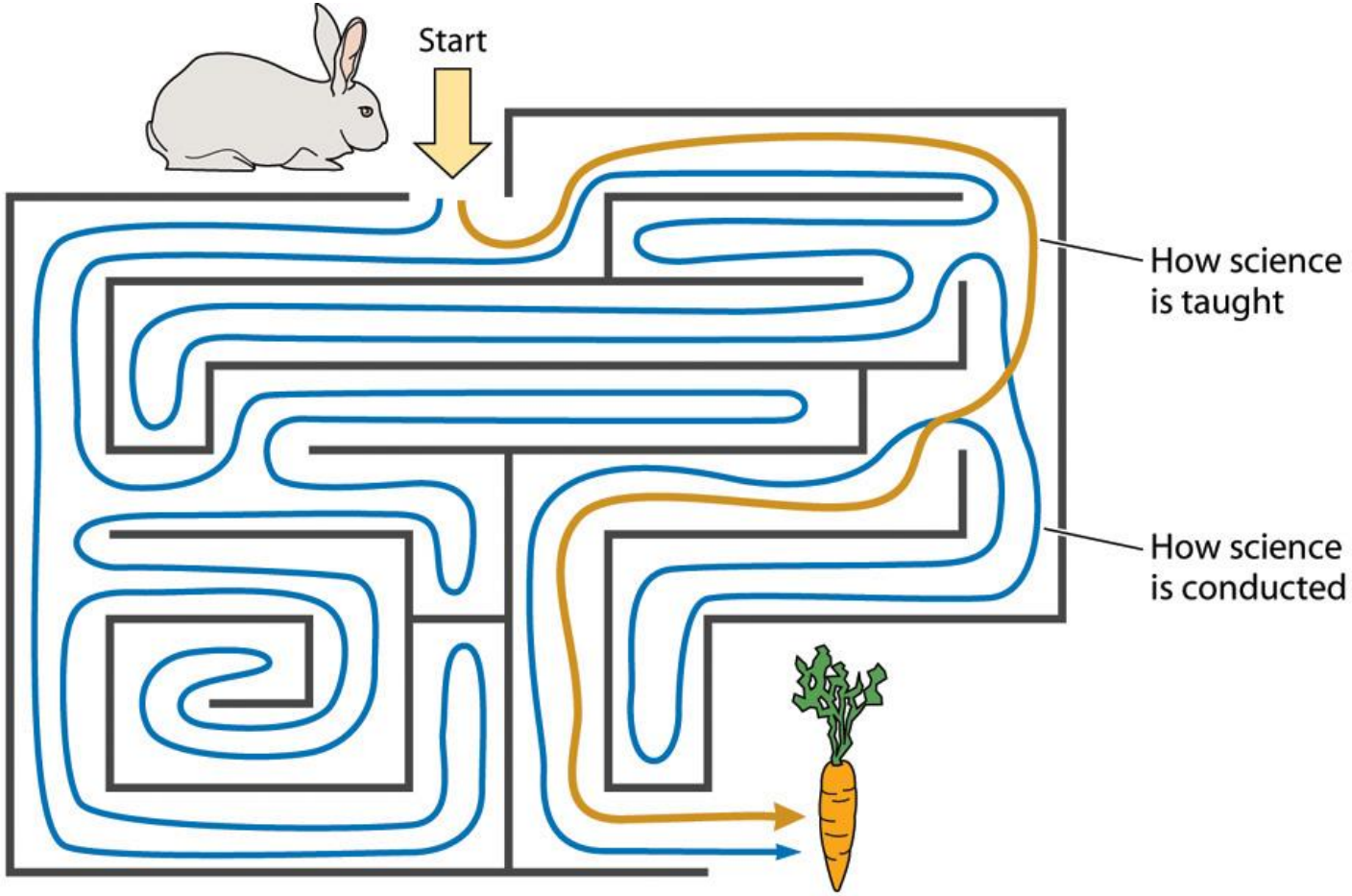
Science and Technology

- Science
  - Search for knowledge
  - Way of understanding ourselves and the physical world
  - Process of asking questions and finding answers, then creating broad generalizations
  - Looks for order or patterns in the physical world
  - Evaluated by how well the facts support the conclusion or theory
  - Limited by the ability to collect relevant facts
  - Discoveries give rise to technological advances
- Technology
  - Practical application of knowledge
  - Way of adapting ourselves to the physical world
  - Process of finding solutions to human problems to make lives easier and better
  - Looks for ways to control the physical world
  - Evaluated by how well it works
  - Limited by financial costs and safety concerns
  - Advances give rise to scientific discoveries

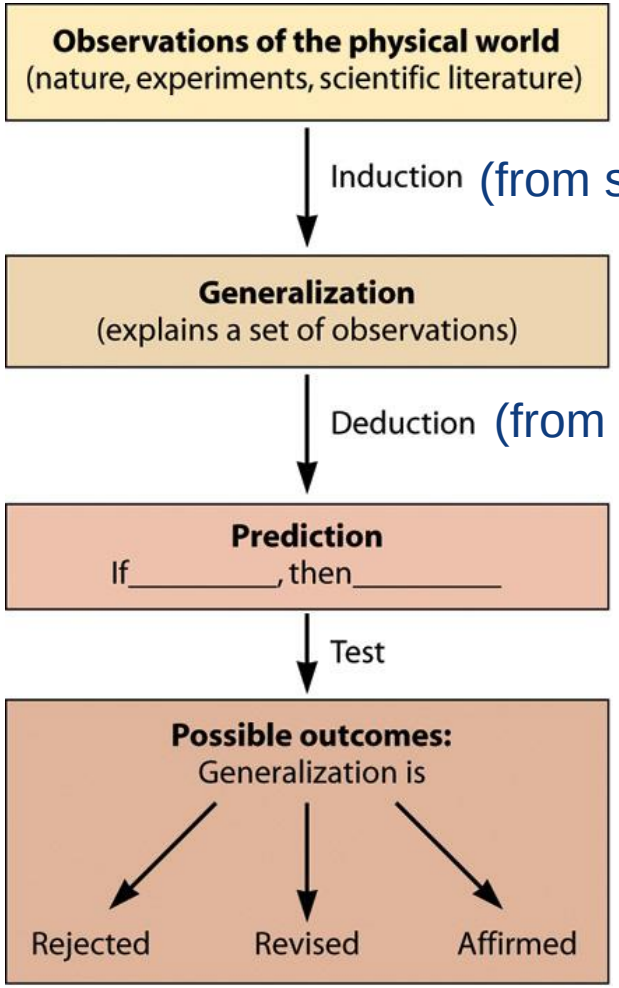
The Relationship Between Science and Technology



The Nature of Science



The Scientific Process



The Biology Century

- The past two centuries
  - Technology driven by physics and chemistry
  - Industrial Revolution, Information Age, Green Revolution
- The Biology Century will be fueled by biotechnology.

Biotechnology

- Definition
  - The use of living organisms or life processes to solve problems or make useful products
- Ancient biotechnology
  - Trial and error-based
- Modern biotechnology
  - The use of cells and biological molecules or cellular and biomolecular processes to solve problems and make useful products

Types and Applications of Biotechnology

Biotechnology

- Bioprocessing technol.
- Cell culture technol.
- Recombinant DNA technol. (genetic engineering)
- Monoclonal antibody tech.
- Biosensor technol.
- Microarray technol.
- Protein engineering tech.

Industry

- Human health care
- Agricultural production
- Food and beverages
- Enzyme industry
- Chemical manufacturing
- Energy
- Waste treatment

Characteristics of Cells and Biomolecules

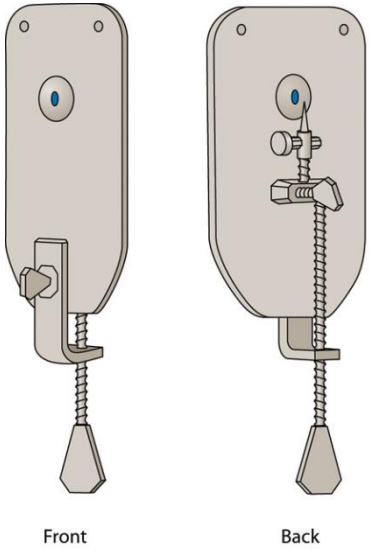
- Specificity, precision, and predictability
- Unity and flexibility
- Reproduction and renewable resources

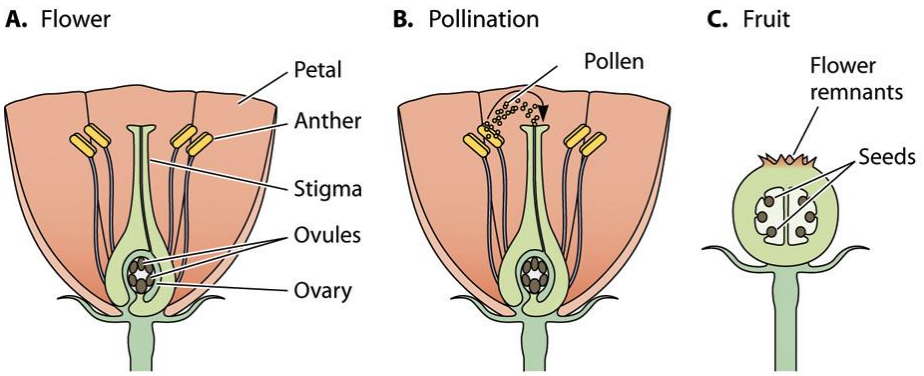
The History of Crop Genetic Modification

- Stage1
  - Genetic modification through seed selection

The History of Crop Genetic Modification

- Stage 2
  - Genetic modification through plant breeding and selection
    - Invention of the microscope
    - Hand pollination





The History of Crop Genetic Modification

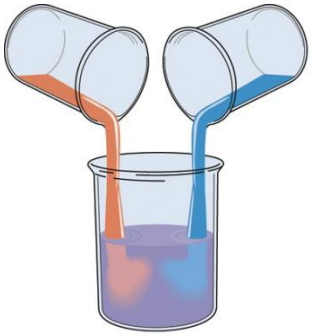
- Stage 3
  - Science-based plant breeding
    - Based on Mendel's work
- Stage 4
  - Plant genetic engineering

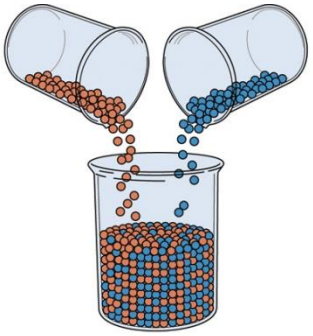
Model of Inheritance

- Fluid-blending model
- Discrete-particle model
  - Mendel's theory of inheritance

    (1865, proved in 1900)

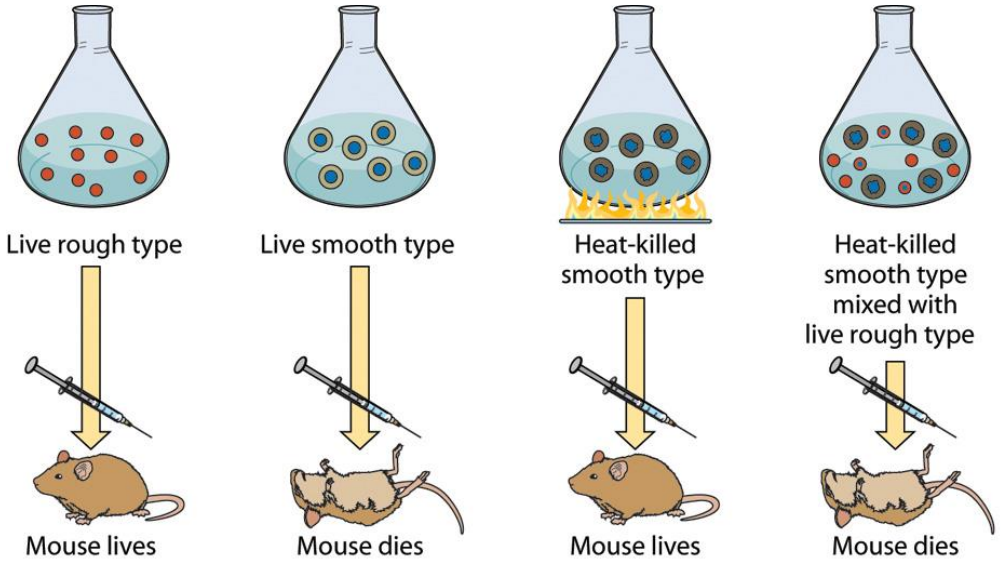
    - Discrete-particle (now known as gene) model





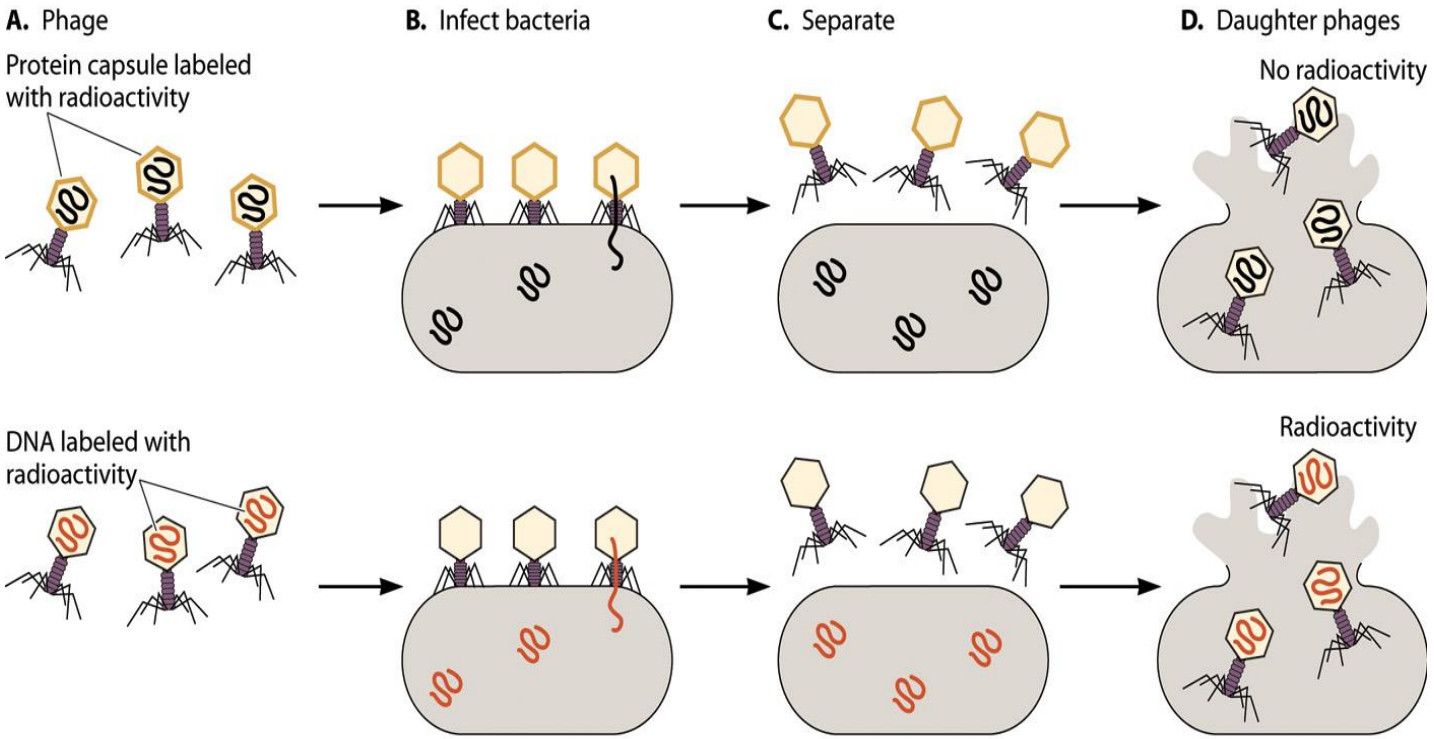
The Nature of Genetic Material

- Frederick Griffith (1928)
  - ‘Transforming factor’ transferred from dead smooth virus to rough virus
- O.T. Avery (1943)
  - The ‘transforming factor’ was DNA



The Genetic Material
Protein or DNA?

- The DNA-vs.-protein debate was resolved.
  - Alfred Hershey and Martha Chase (1952)
    ----- Identification of DNA as genetic material



DNA Double Helix

by J. Watson and F. Crick

No. 4356 April 25, 1953 NATURE 737

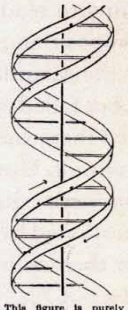
MOLECULAR STRUCTURE OF NUCLEIC ACIDS

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 biological interest.

A structure for nucleic acid has already been proposed by Pauling and Corey[1]. They kindly made their manuscript available to us in advance of publication. Their model consists of three inter-twined chains, with the phosphates near the fibre axis, and the bases on the outside. In our opinion, this structure is unsatisfactory for two reasons: (1) We believe that the material which gives the X-ray diagrams is the salt, not the free acid. Without the acidic hydrogen atoms it is not clear what forces would hold the structure together, especially as the negatively charged phosphates near the axis will repel each other. (2) Some of the van der Waals distances appear to be too small.

Another three-chain structure has also been suggested by Fraser (in the press). In his model the phosphates are on the outside and the bases on the inside, linked together by hydrogen bonds. This structure as described is rather ill-defined, and for this reason we shall not comment on it.



This figure is purely diagrammatic. The two ribbons symbolize the two phosphate—sugar chains, and the horizontal rods the pairs of bases holding the chains together. The vertical line marks the fibre axis

We wish to put forward a radically different structure for the salt of deoxyribose nucleic acid. This structure has two helical chains each coiled round the same axis (see diagram). We have made the usual chemical assumptions, namely, that each chain consists of phosphate di-ester groups joining β-D-deoxy-ribofuranose residues with 3′,5′ linkages. The two chains (but not their bases) are related by a dyad perpendicular to the fibre axis. Both chains follow right-handed helices, but owing to the dyad the sequences of the atoms in the two chains run in opposite directions. Each chain loosely resembles Furberg's[2] model No. 1; that is, the bases are on the inside of the helix and the phosphates on the outside. The configuration of the sugar and the atoms near it is close to Furberg's 'standard configuration', the sugar being roughly perpendicular to the attached base. There 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 hydrogen bonds are made as follows: purine position 1 to pyrimidine position 1; purine position 6 to pyrimidine position 6.

If it is assumed that the bases only occur in the structure in the most plausible tautomeric forms (that is, with the keto rather than the enol configurations) it is found that only specific pairs of bases can bond together. These pairs are: adenine (purine) with thymine (pyrimidine), and guanine (purine) with cytosine (pyrimidine).

In other words, if an adenine forms one member of a pair, on either chain, then on these assumptions the other member must be thymine; similarly for guanine and cytosine. The sequence of bases on a single chain does not appear to be restricted in any way. However, if only specific pairs of bases can be formed, it follows that if the sequence of bases on one chain is given, then the sequence on the other chain is automatically determined.

It has been found experimentally[3,4] that the ratio of the amounts of adenine to thymine, and the ratio of guanine to cytosine, are always very close to unity for deoxyribose nucleic acid.

It is probably impossible to build this structure with a ribose sugar in place of the deoxyribose, as the extra oxygen atom would make too close a van der Waals contact.

The previously published X-ray data[5,6] on deoxyribose nucleic acid are insufficient for a rigorous test of our structure. So far as we can tell, it is roughly compatible with the experimental data, but it must be regarded as unproved until it has been checked against more exact results. Some of these are given in the following communications. We were not aware of the details of the results presented there when we devised our structure, which rests mainly though not entirely on published experimental data and stereochemical arguments.

It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material.

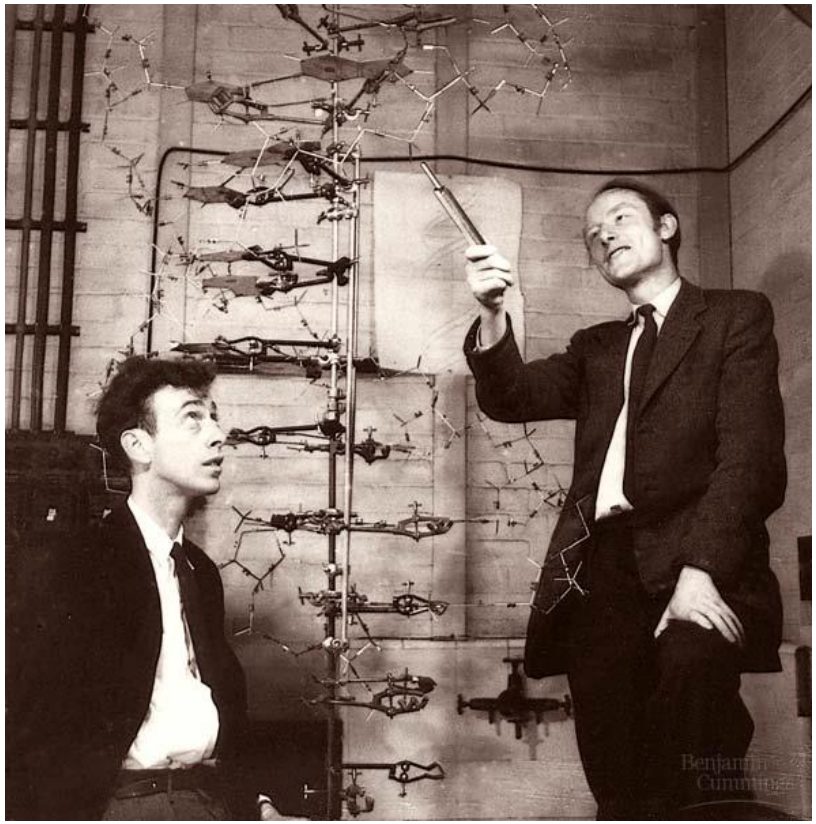
Full details of the structure, including the conditions assumed in building it, together with a set of co-ordinates for the atoms, will be published elsewhere.

We are much indebted to Dr. Jerry Donohue for constant advice and criticism, especially on interatomic distances. We have also been stimulated by a knowledge of the general nature of the unpublished experimental results and ideas of Dr. M. H. F. Wilkins, Dr. R. E. Franklin and their co-workers at King's College, London. One of us (J. D. W.) has been aided by a fellowship from the National Foundation for Infantile Paralysis.

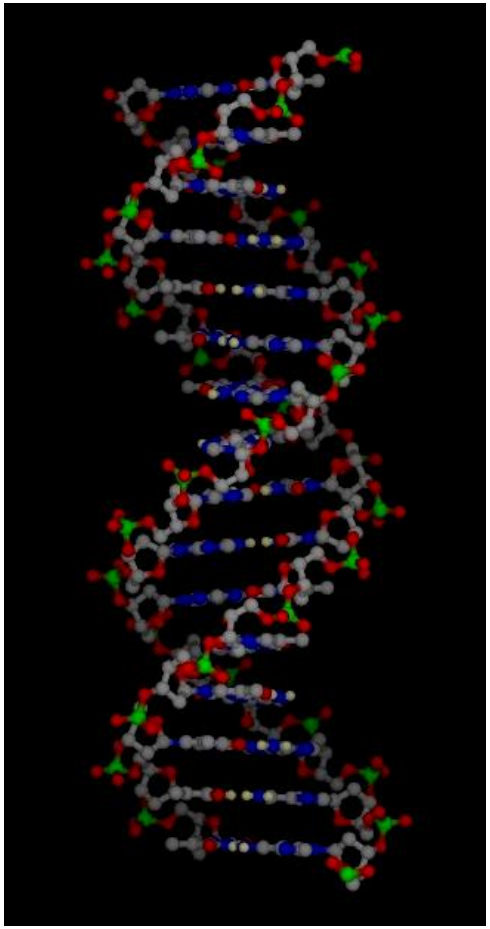
J. D. WATSON
F. H. C. CRICK

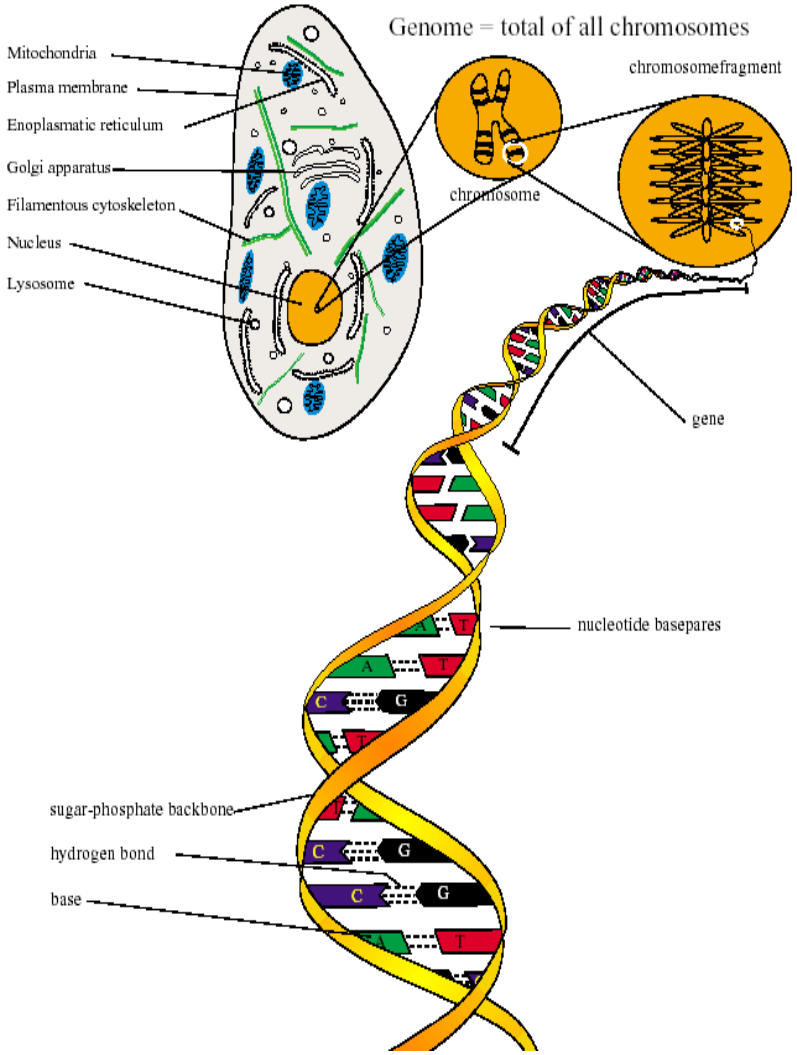
Medical Research Council Unit for the Study of the Molecular Structure of Biological Systems,
Cavendish Laboratory, Cambridge.
April 2.

[1] Pauling, L., and Corey, R. B., *Nature*, 171, 346 (1953); *Proc. U.S. Nat. Acad. Sci.*, 39, 84 (1953).
[2] Furberg, S., *Acta Chem. Scand.*, 6, 634 (1952).
[3] Chargaff, E., for references see Zamenhof, S., Brawerman, G., and Chargaff, E., *Biochim. et Biophys. Acta*, 9, 402 (1952).
[4] Wyatt, G. R., *J. Gen. Physiol.*, 36, 201 (1952).
[5] Astbury, W. T., Symp. Soc. Exp. Biol. 1, Nucleic Acid, 66 (Camb. Univ. Press, 1947).
[6] Wilkins, M. H. F., and Randall, J. T., *Biochim. et Biophys. Acta*, 10, 192 (1953).



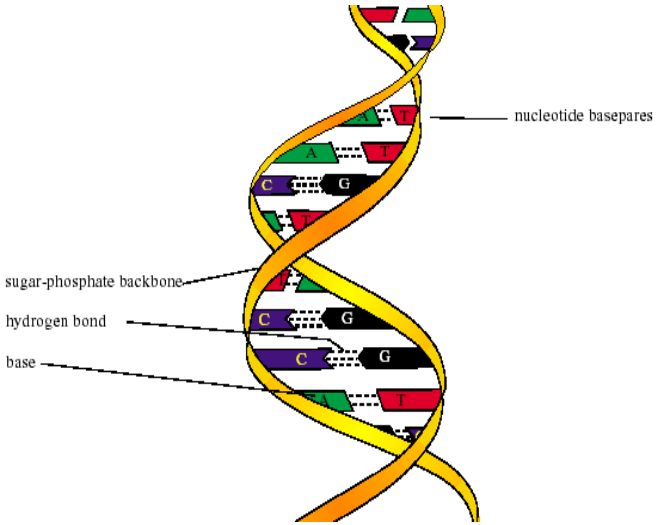
DNA Double Helix

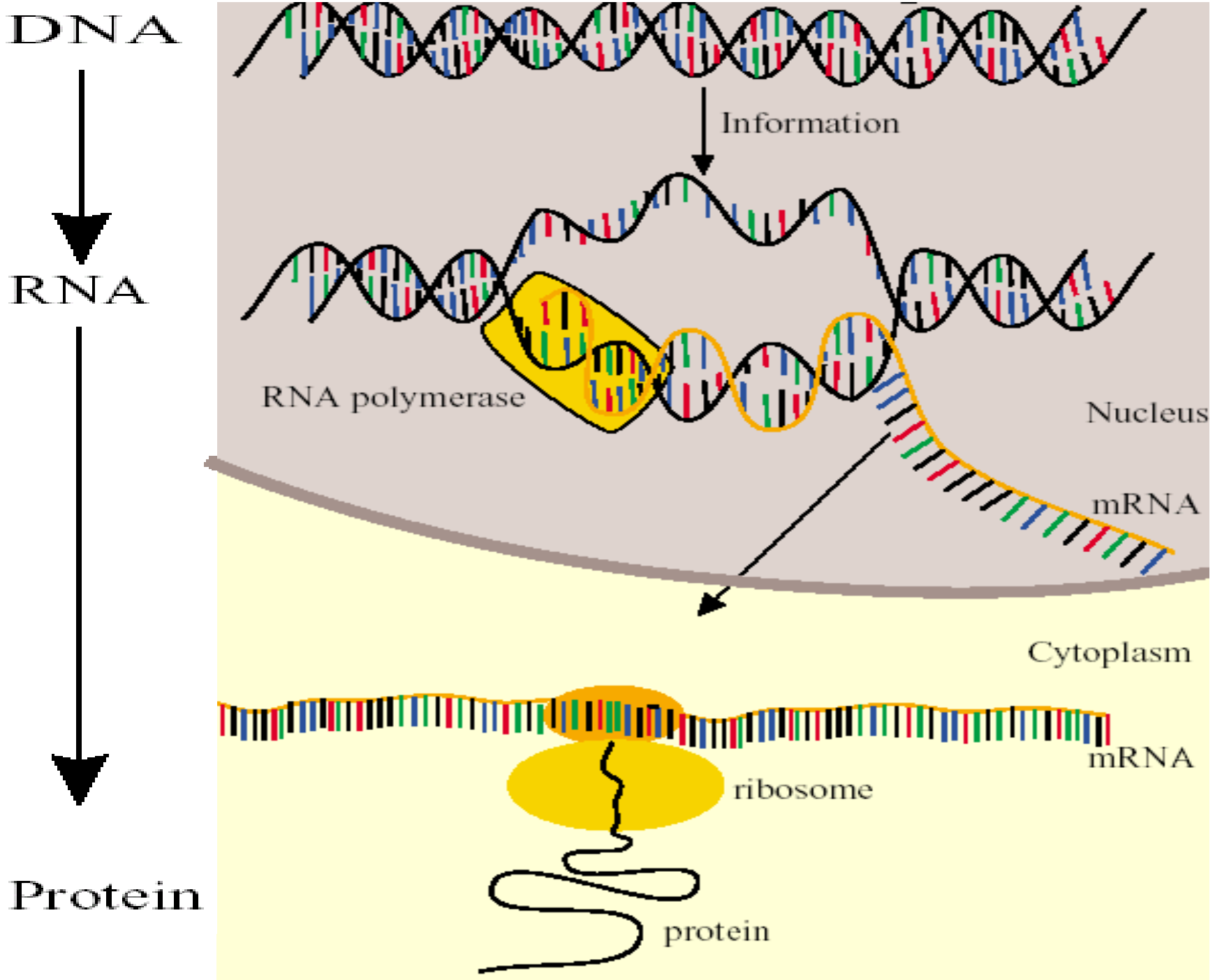




Central Dogma
by F. Crick

DNA → **RNA** → **Protein**



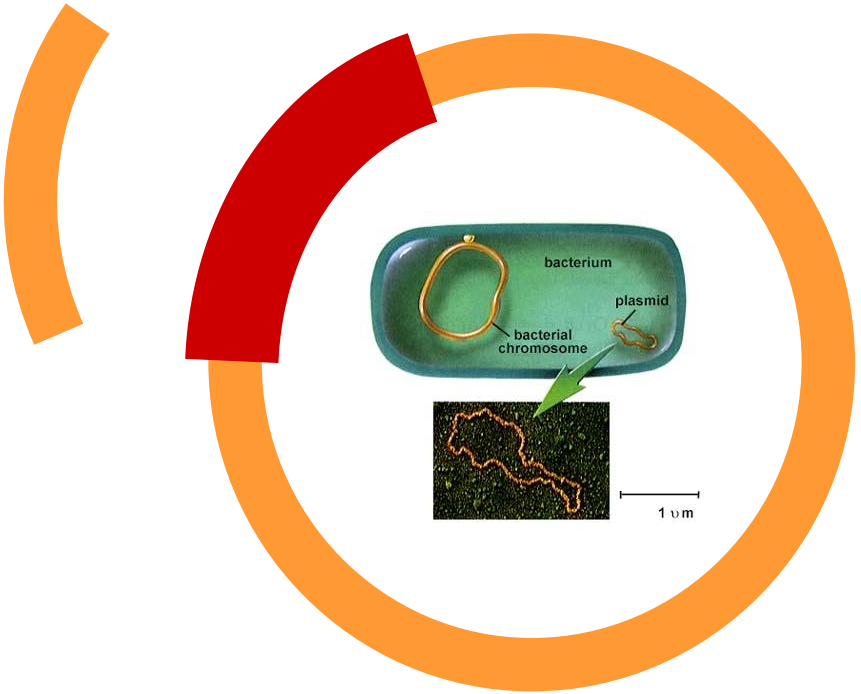

DNA
RNA
Protein
Information
RNA polymerase
Nucleus
mRNA
Cytoplasm
mRNA
ribosome
protein

Biotechnology & Bioindustry

- **Egypt, Fermentation**
  (bread, cheese, wine, beer)
- **1850s, Pure Cultures of Microorganisms**
- **1940s, Random mutation**
- **1973, Recombinant DNA technology**

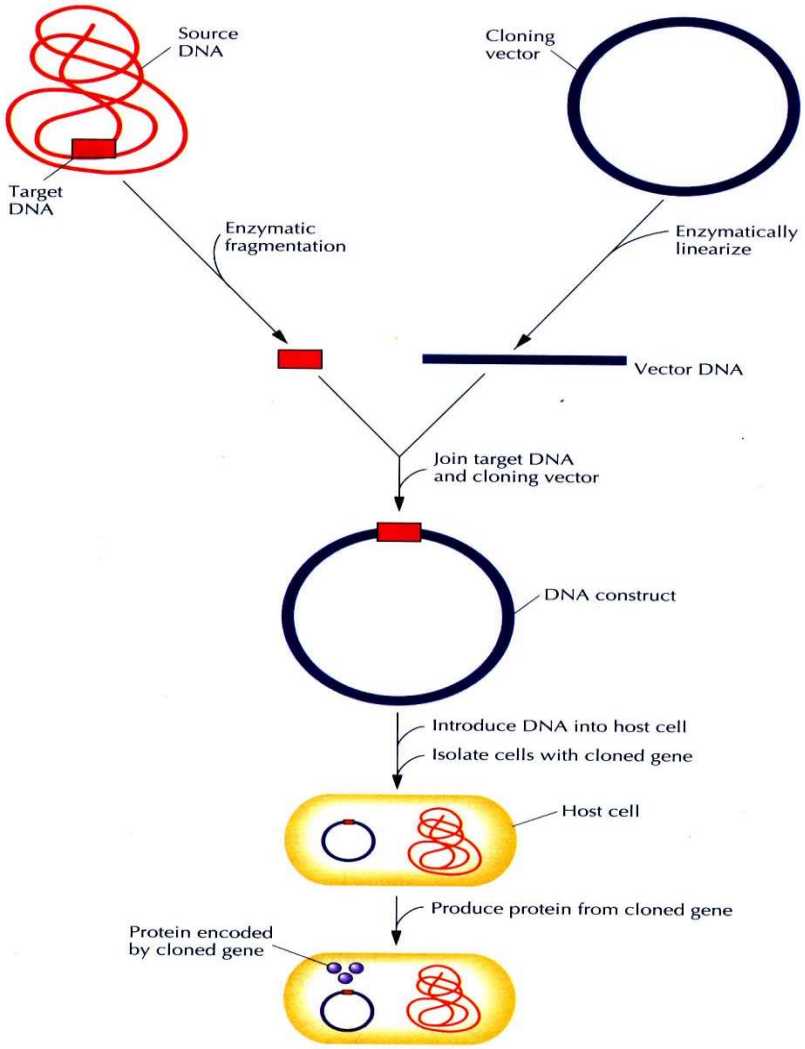
Recombinant DNA Technology

- Discovery of restriction enzyme and ligase
- Development of recombinant DNA technology
  - Herbert Boyer and Stanley Cohen (1973)

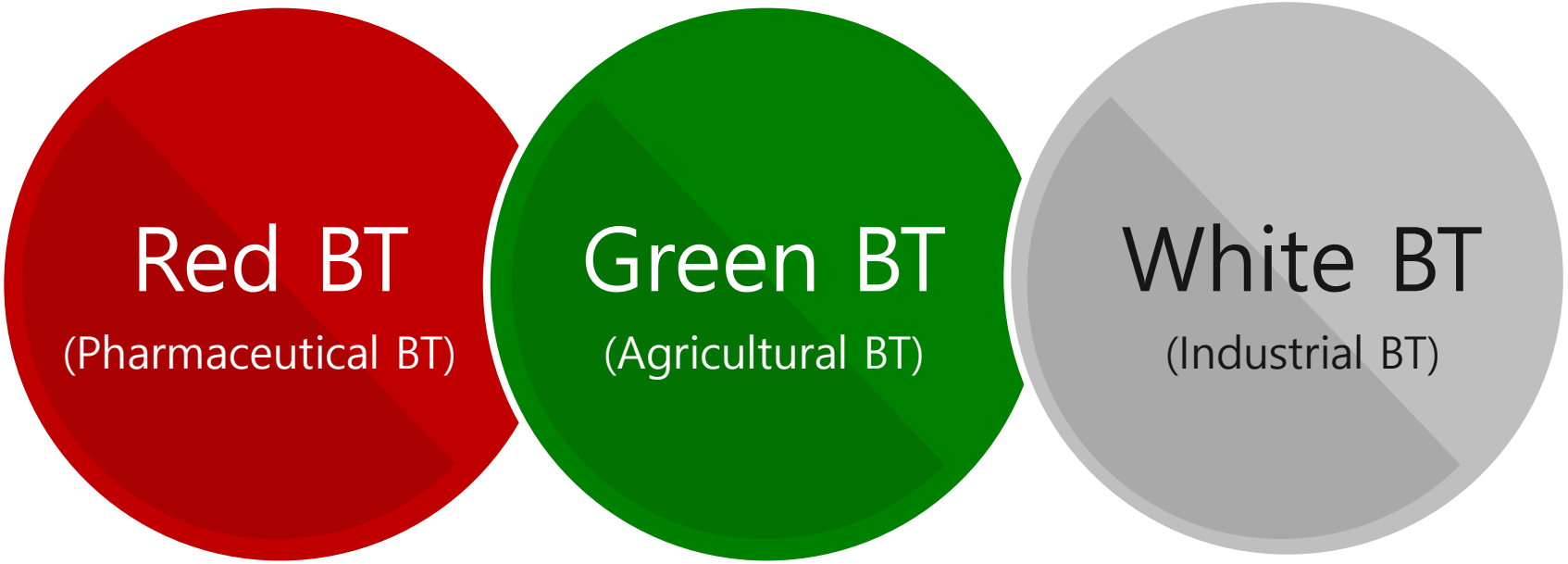


Cutting and Joining DNA Molecules

Recombinant DNA Technology



Trends in Bio-industry



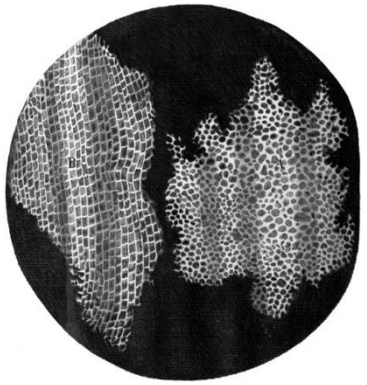
Chapter 2

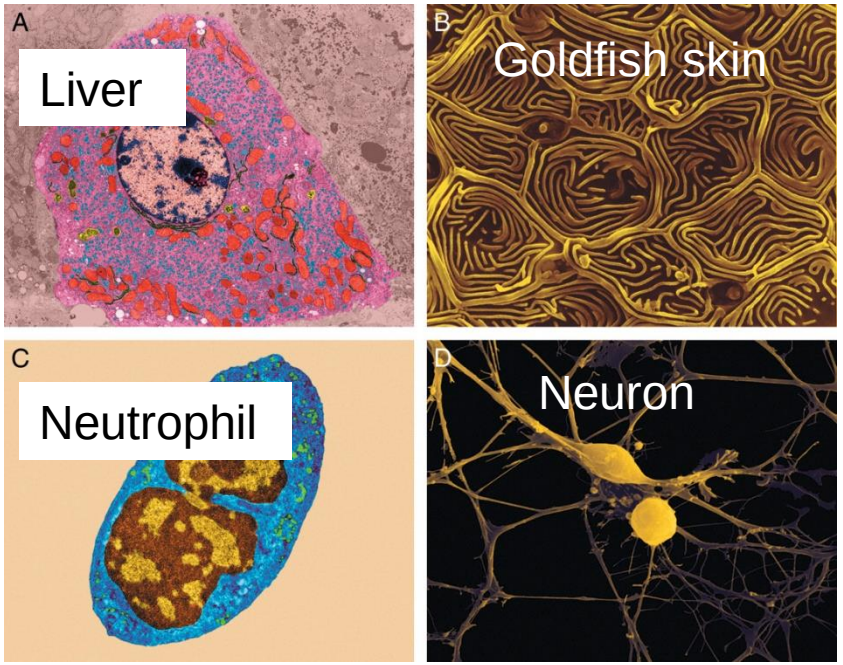
The Cell: the Basic Unit of Life

Contents

Cells

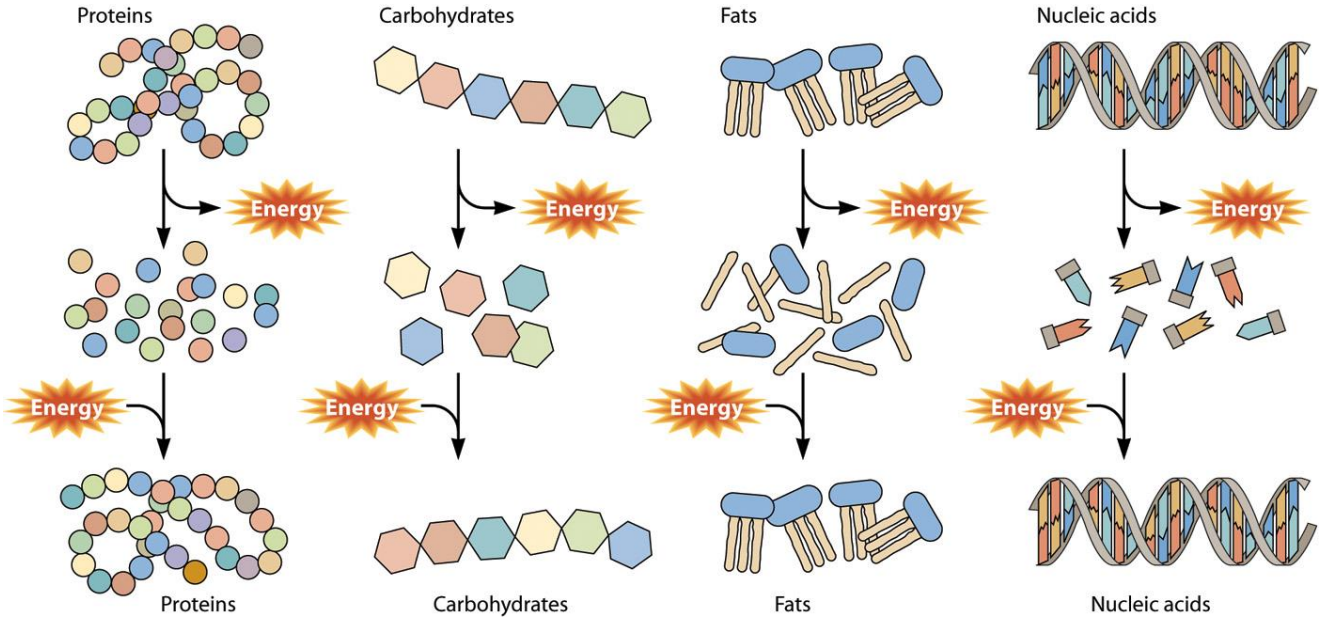
- Basic unit of living organism
- First named by Robert Hook in the 17th century
- Different types but the same essential properties
- Same building blocks: proteins, carbohydrates, fats, and nucleic acids





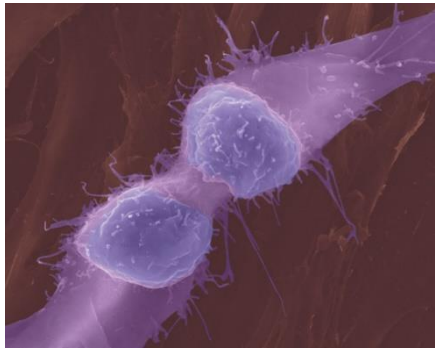
Essential Functions of Living Cells 1

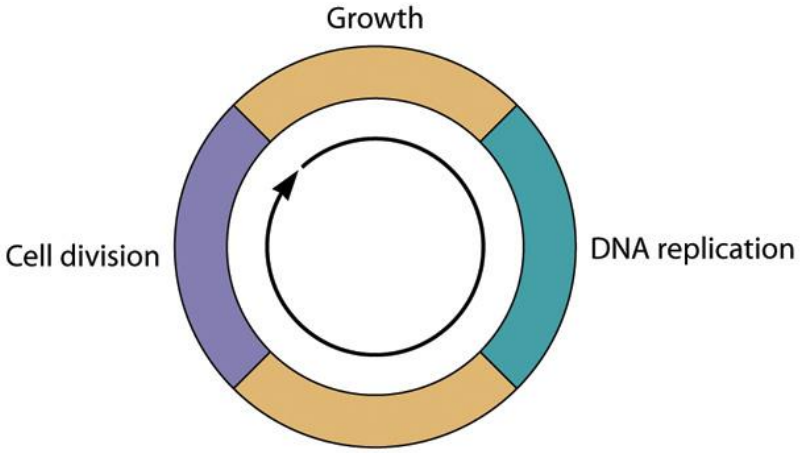
- Growth
  - Metabolism
    - Catabolism: breaking down large molecules to generate building blocks and energy
    - Anabolism: Generation of large molecules using building blocks and energy



Essential Functions of Living Cells 2

- Reproduction
  - Cell cycle
    - Cyclical process of cell growth and division
    - Daughter cell must receive a correct copy of genetic material
      →DNA replication before cell division





Cell cycle

Essential Functions of Living Cells 3

- Maintenance of internal environments
  - Use energy to maintain the internal environments
    - Unique molecules
      - Specific proteins, DNA etc.
    - Some same molecules as outside but with different concentrations
      - Water, salts, sugar etc.

Amoeba

Essential Functions of Living Cells 4

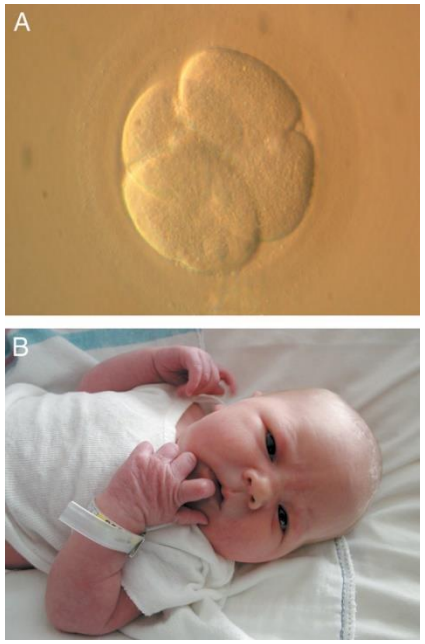
- Response to external environments
  - Sense a change in their environment
  - Respond
    - Maintaining osmotic homeostasis
    - Bacterial chemotaxis
    - Release of digestive enzymes from stomach cells
    - …..

Essential Functions of Living Cells 5

- Communication with each other
  - Between cells in an organism
    - e.g. Nerve cell and muscle
  - Between single cell organisms
    - e.g. Mating of yeast cells, quorum sensing of bacteria

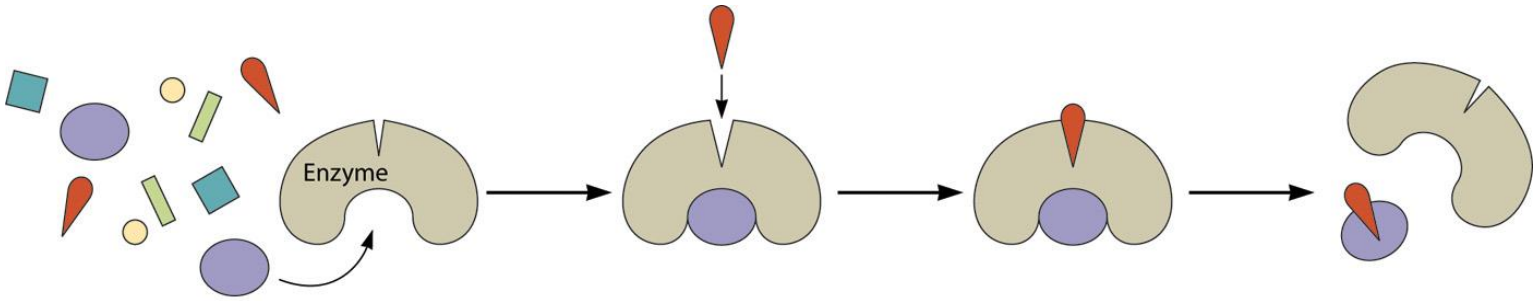
Essential Functions of Living Cells 6

- Differentiation in multicellular organisms
  - Cells differentiate to cells with specific functions
  - Specific cells organize into different tissues and organs



Common Cellular Processes

- Constant supply of energy
  - Need energy for all the cellular activities
  - Energy source
    - Sun: photosynthetic plant or bacteria
    - Food and Chemicals
- Chemical reactions
  - Enzymes: protein catalyst accelerating chemical reactions

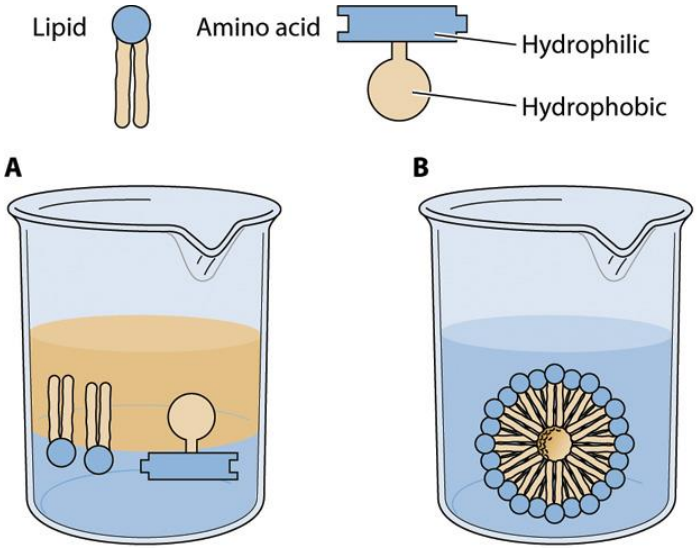


Common Cellular Processes

- Cell processes occur in a series of small steps
  - Pathway: a process consisting of a series of steps
- Regulation of processes
  - Regulation of various processes by regulation of protein-protein and protein-DNA interactions
  - Cell cycle, blood sugar levels, blood pressure, body water balance etc.

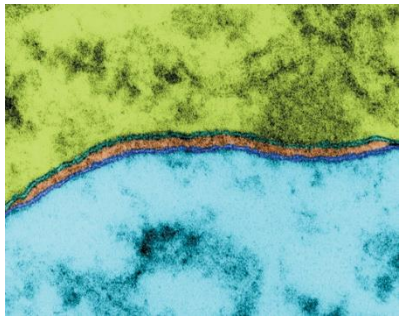
Cell Organization

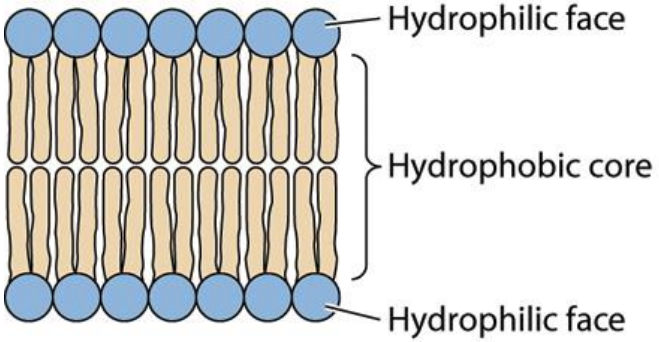
- Interaction of molecules with water
  - Important factor for determining the molecular organization within a cell
  - Hydrophilic (water soluble) or Hydrophobic (water insoluble)
    - Congregation of hydrophilic parts with other hydrophilic parts
    - Congregation of hydrophobic parts with other hydrophobic parts
- Binding of molecules
  - Specificity of molecular bindings determines cellular processes
  - Binding: fitting between molecules
    - Depends on shape and chemical properties (charge)



Cellular Membranes I

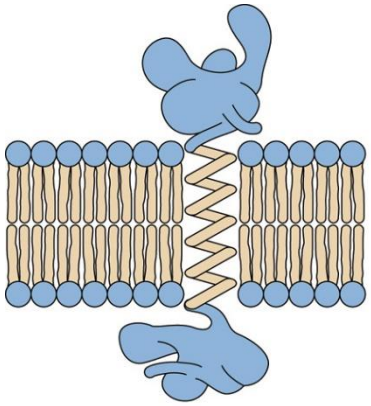
- Provide structural organization
  - Lipid bilayer with hydrophobic core and hydrophilic face
  - Plasma (cell) membrane: Hydrophobic barrier between inside (cytoplasm) and outside of the cell
  - Internal membranes
    - Nucleus
    - Endoplasmic reticulum, Golgi apparatus
    - Mitochondria
    - Chloroplast





Cellular Membranes II

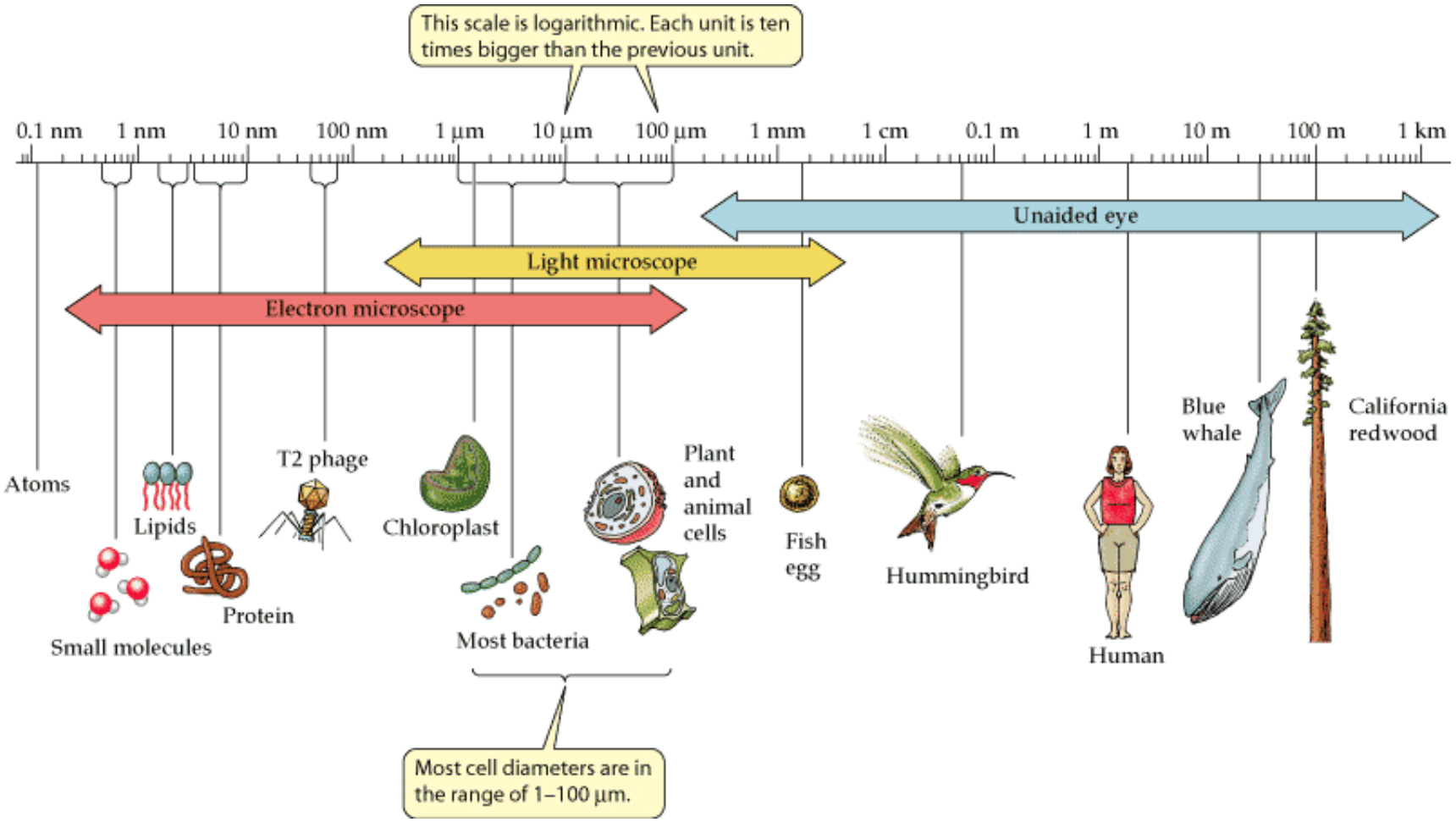
- Control molecular transport across the membrane
  - Free diffusion
    - Small, electrically neutral or slightly charged molecules (CO_2, O_2, water)
  - Transport through membrane-bound channels and transporters



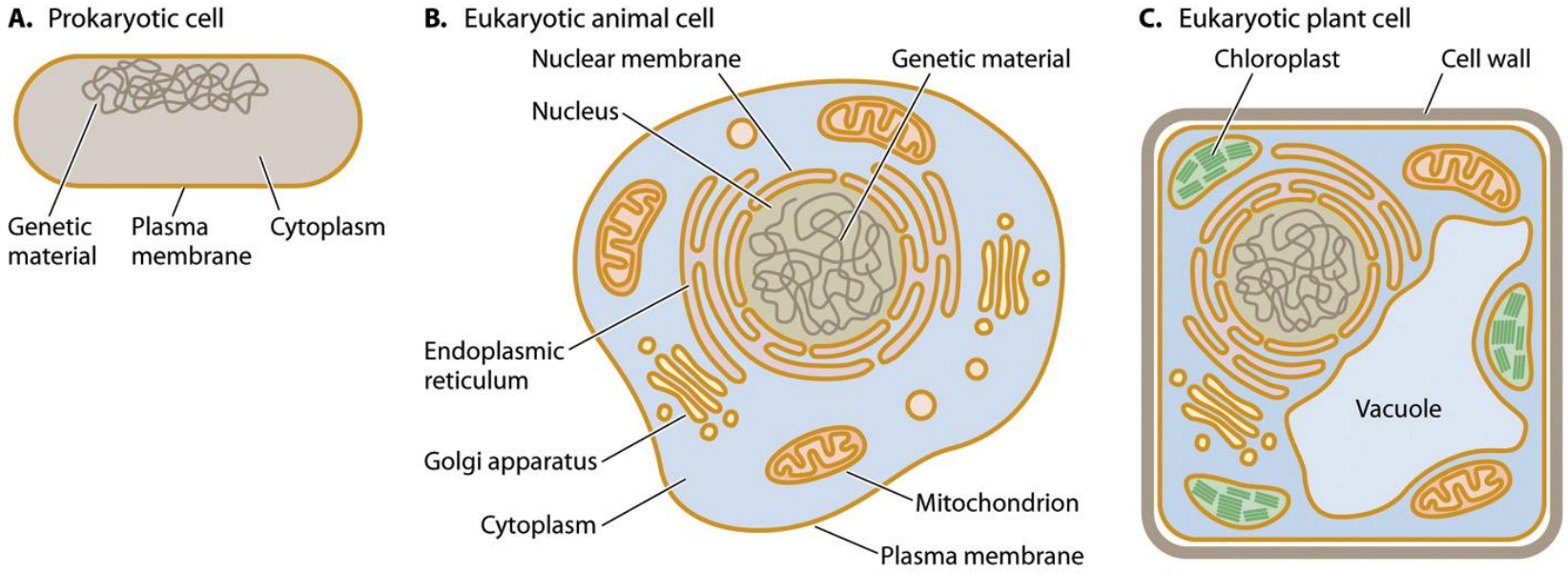
Two Fundamental Cell Types

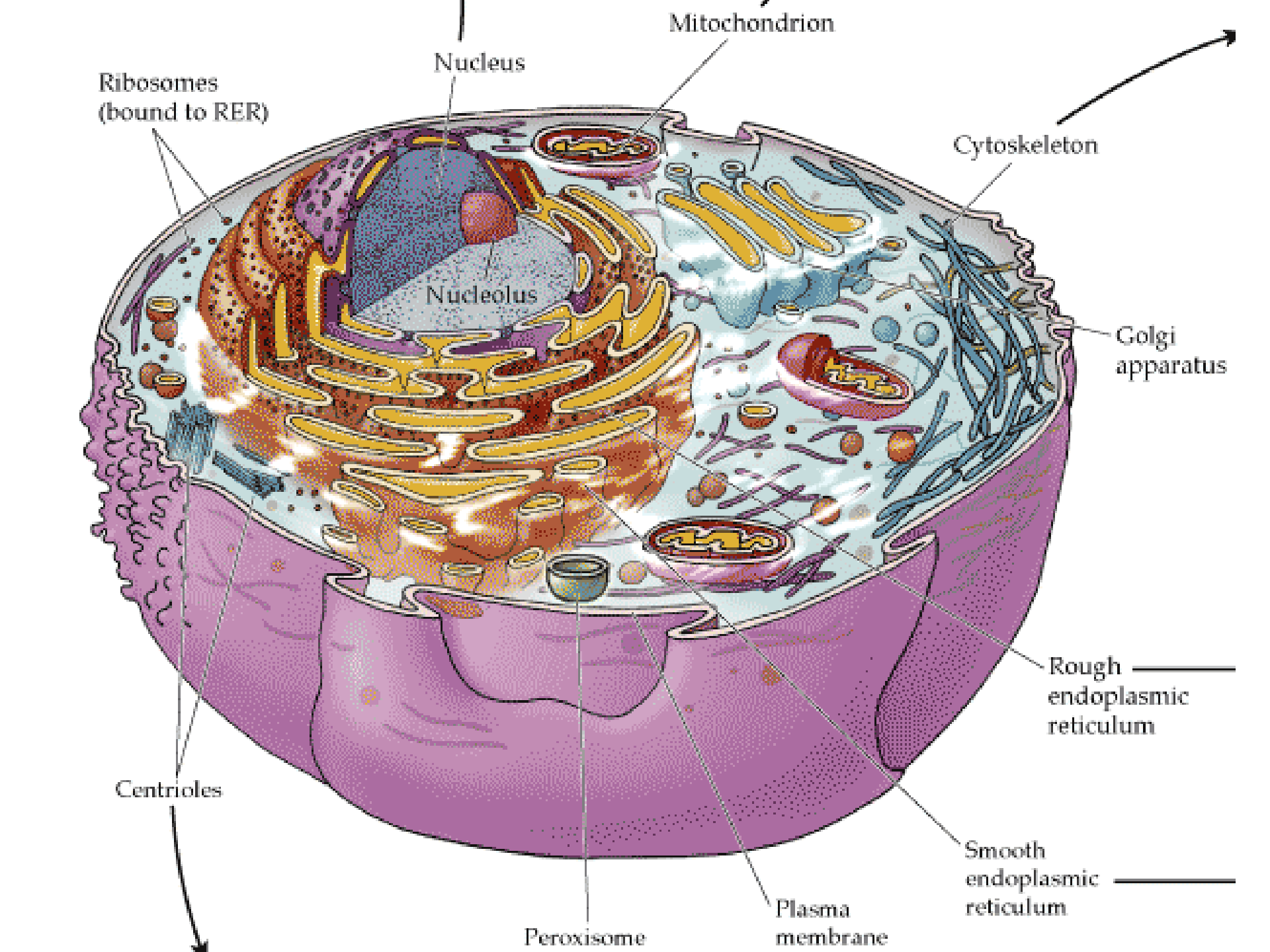
- Prokaryotic cells
  - Prokaryote (pro; before, karyon: kernel or nucleus)
  - No nuclear membrane
  - Small (0.2-2 μm), mostly single-celled organisms
    - Eubacteria : common bacteria, e.g. *E. coli*, blue-green algae
    - Archaea (Archaebacteria)
- Eukaryotic cells
  - Eukaryote (well-formed nucleus)
  - Nuclear and internal membranes → organelles
  - Larger than prokaryotes (10-100 μm)
    - Single-celled: yeast, green algae, amoebae
    - Multicellular: fungi, plant, animal

The Scale of Life



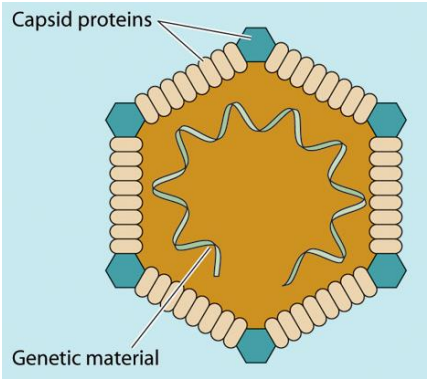
Two Fundamental Cell Types




Mitochondrion
Nucleus
Ribosomes
(bound to RER)
Cytoskeleton
Nucleolus
Golgi
apparatus
Rough
endoplasmic
reticulum
Centrioles
Smooth
endoplasmic
reticulum
Plasma
membrane
Peroxisome

Viruses

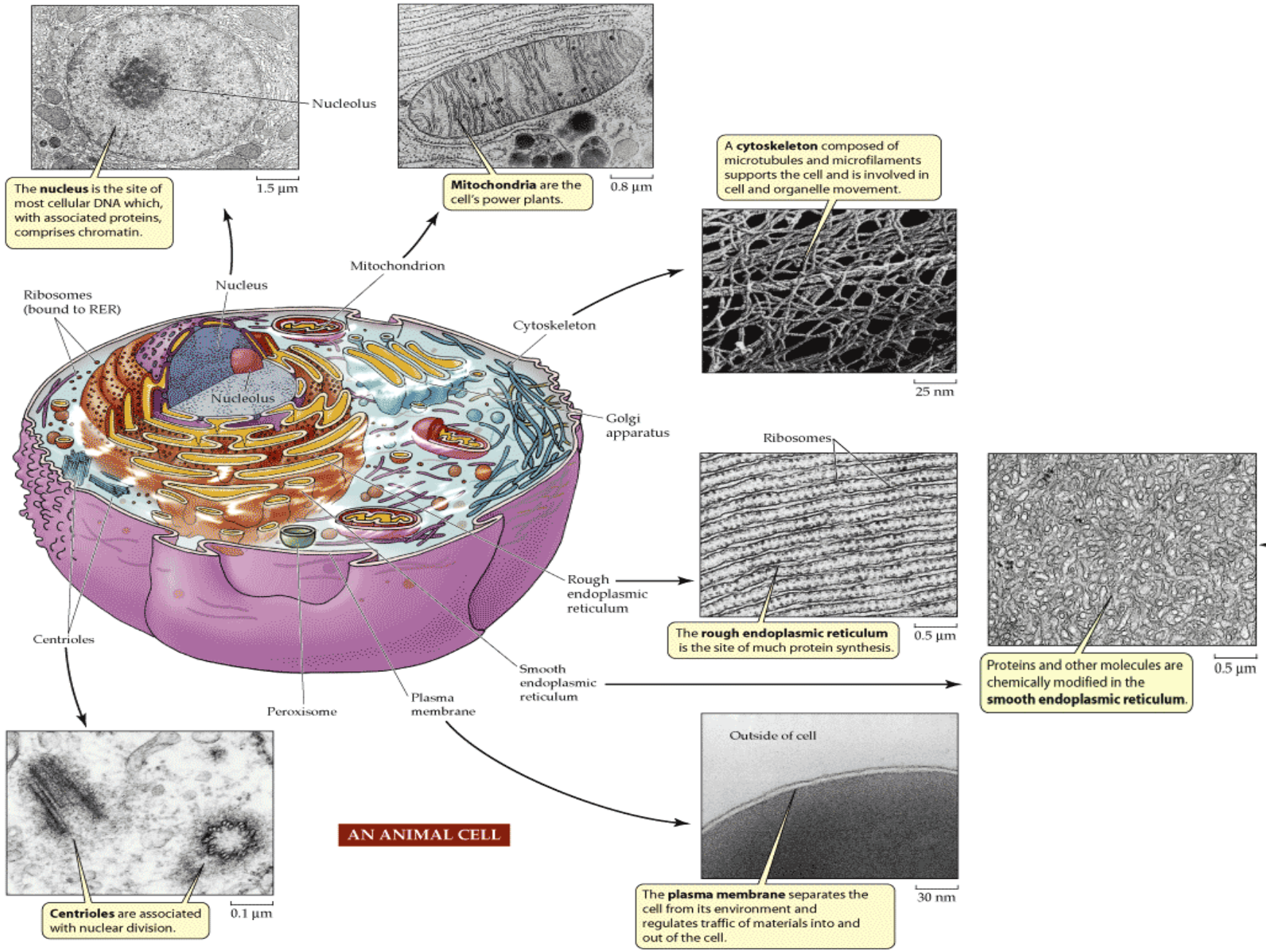
- Not cells
- No independent reproduction (not alive by itself)
  - Genetic material (DNA or RNA)
  - Proteins (Capsid)



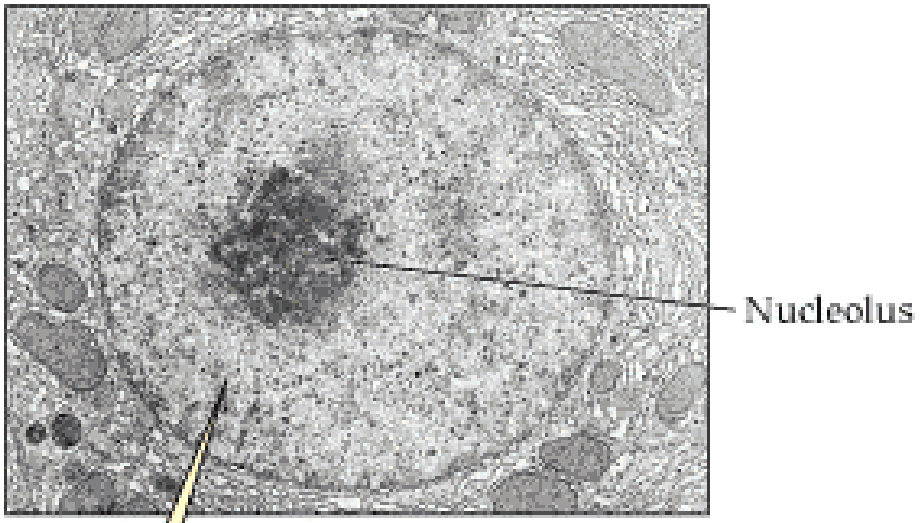
- "Viruses are in the semantic fog between life and non-life." (Campbell and Reece, *Biology*, 6e, p 339.)
- Are viruses living beings?

  "The answer to that question is 'no', inasmuch as viruses are incapable of independent life." (de Duve, *Life Evolving,* p.313)
- Conclusion:

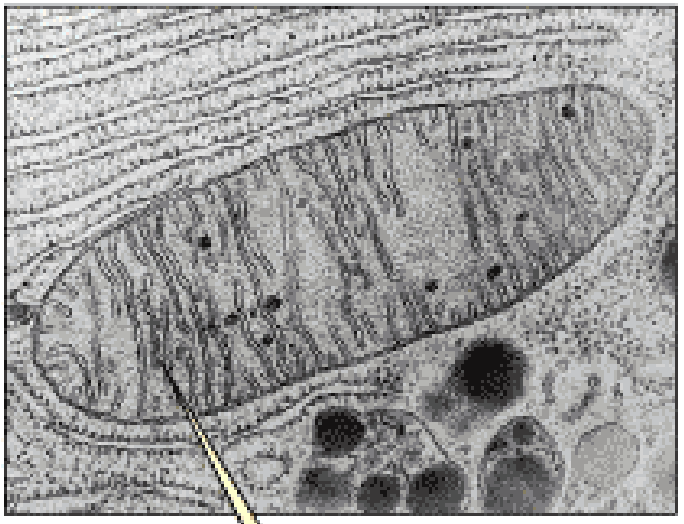
  Viruses do not fit the basic definition of cellular life.
  - Require host for all cellular activities
  - No metabolic capability of their own


Nucleolus
1.5 µm
The **nucleus** is the site of most cellular DNA which, with associated proteins, comprises chromatin.
Mitochondria are the cell's power plants.
0.8 µm
A **cytoskeleton** composed of microtubules and microfilaments supports the cell and is involved in cell and organelle movement.
25 nm
Mitochondrion
Nucleus
Ribosomes (bound to RER)
Cytoskeleton
Nucleolus
Golgi apparatus
Ribosomes
Rough endoplasmic reticulum
The **rough endoplasmic reticulum** is the site of much protein synthesis.
0.5 µm
Centrioles
Smooth endoplasmic reticulum
Proteins and other molecules are chemically modified in the **smooth endoplasmic reticulum**.
0.5 µm
Peroxisome
Plasma membrane
Outside of cell
AN ANIMAL CELL
Centrioles are associated with nuclear division.
0.1 µm
The **plasma membrane** separates the cell from its environment and regulates traffic of materials into and out of the cell.
30 nm

Nucleus and Mitochondria

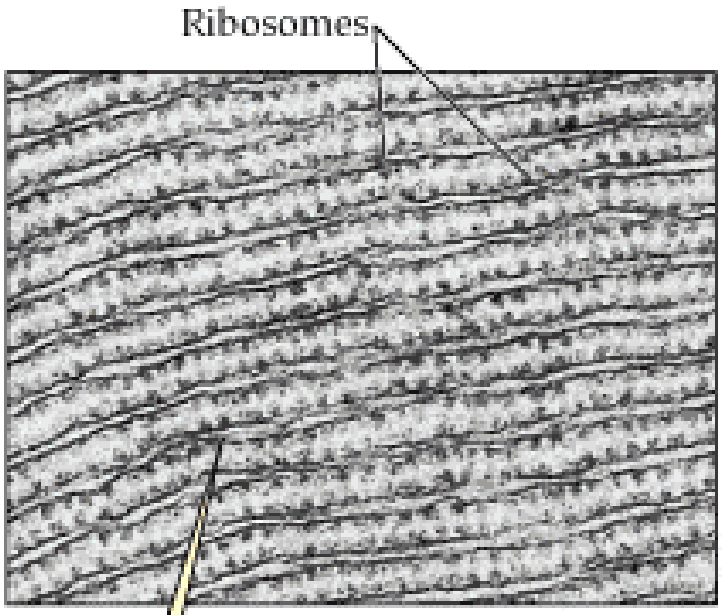


The **nucleus** is the site of most cellular DNA which, with associated proteins, comprises chromatin.



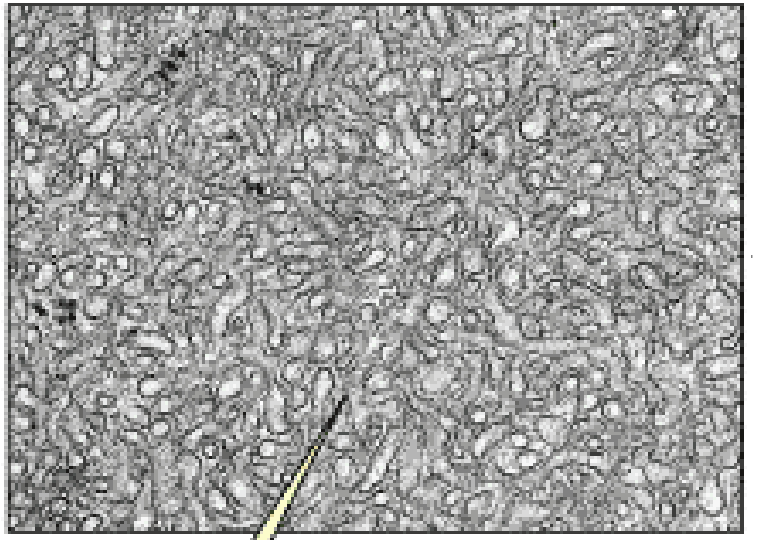
Mitochondria are the cell's power plants.

Endoplasmic Reticulum



The **rough endoplasmic reticulum** is the site of much protein synthesis.

0.5 µm



Proteins and other molecules are chemically modified in the **smooth endoplasmic reticulum**.

0.5 µm

Cytoskeleton and Centrioles