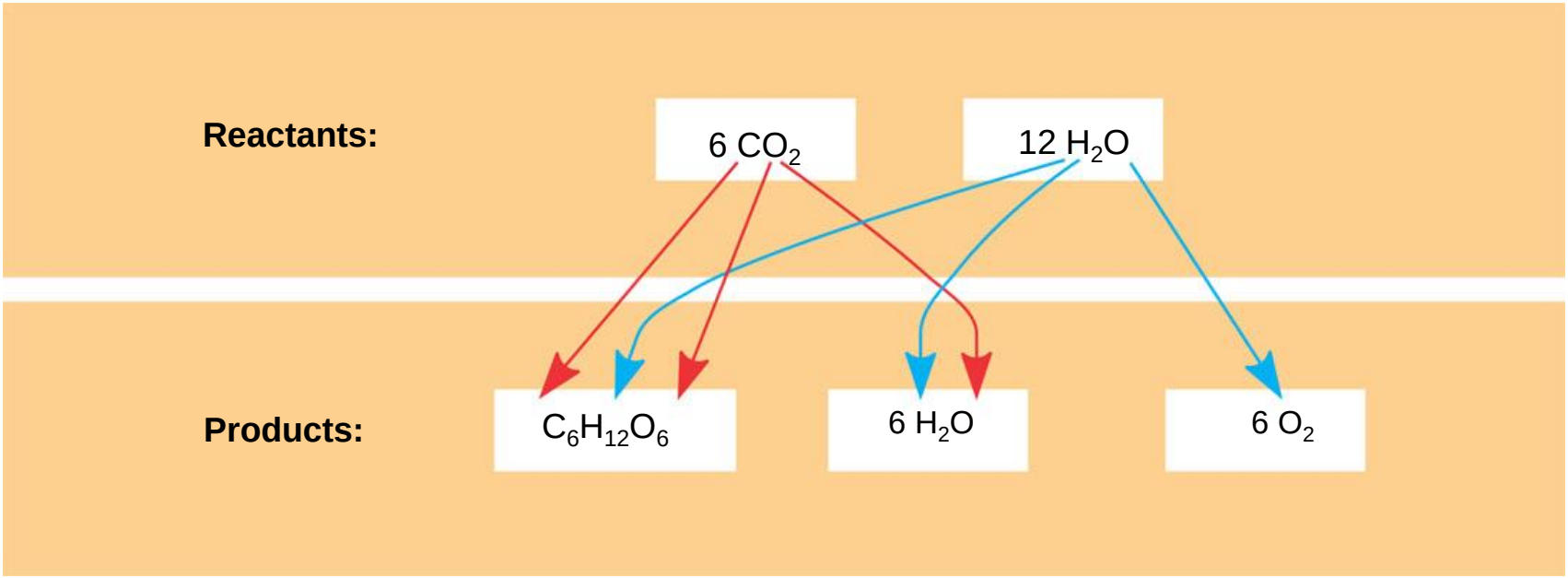
Photosynthesis

The Process That Feeds the Biosphere

Chloroplasts split water into

– Hydrogen and oxygen, incorporating the electrons of hydrogen into sugar molecules

Photosynthesis is a redox process in which H_2O



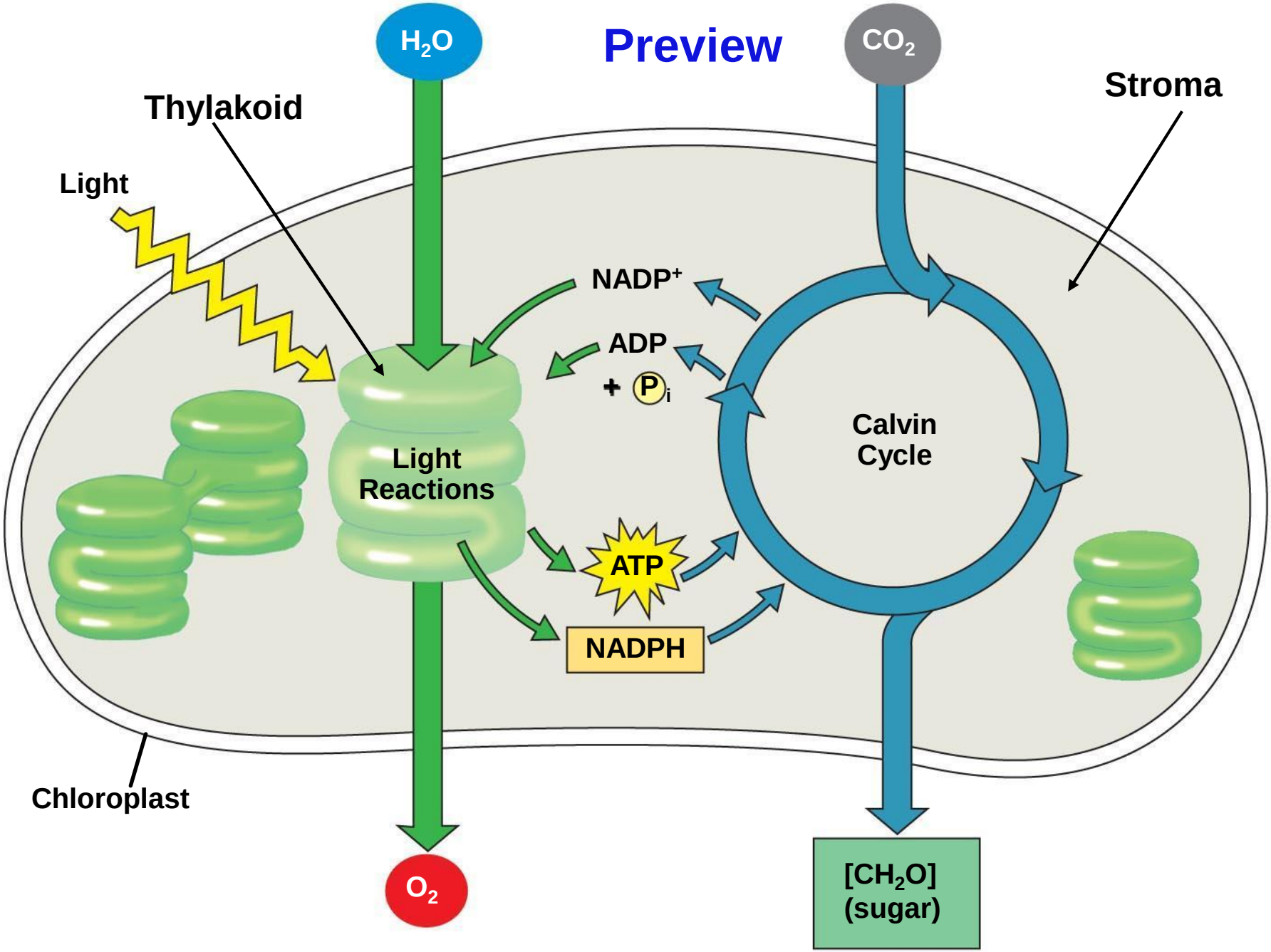
$$6\ CO_2 + 12\ H_2O + \text{Light energy} \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$$

Respiration Reaction:

$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$ + Energy (ATP + heat)

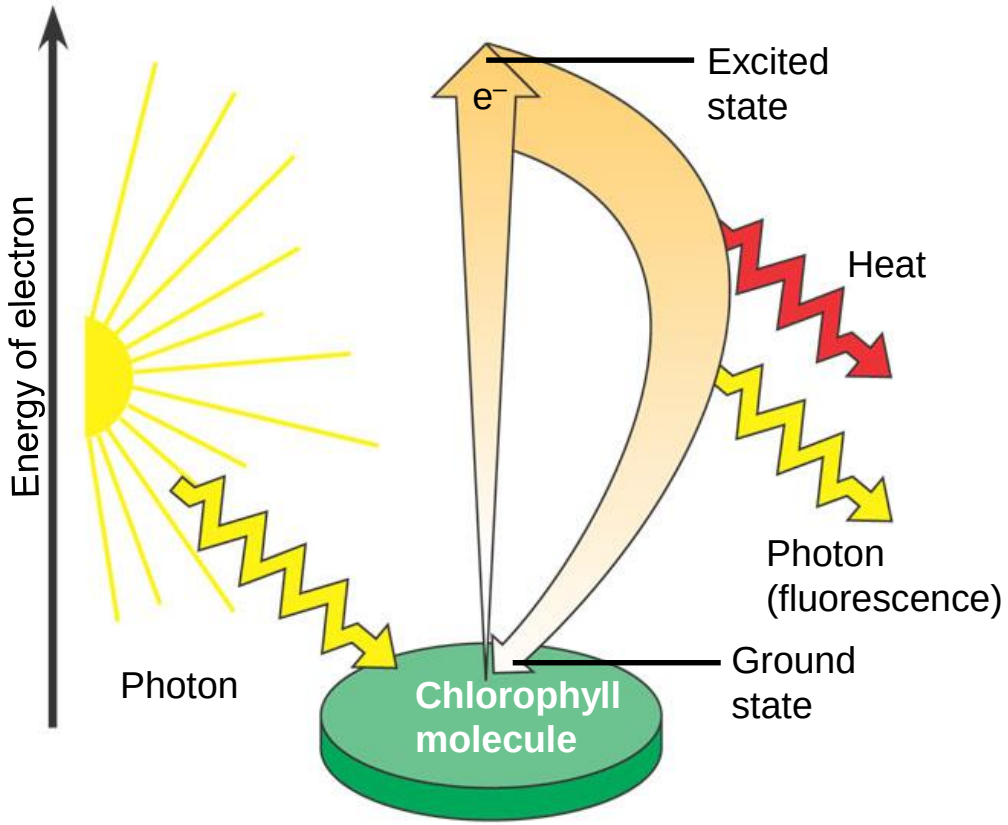
(Organic)

We use glucose here to simplify the relationship **between photosynthesis and respiration,** but the direct product of the photosynthesis is actually a **3 C sugar that can be used to make glucose.**

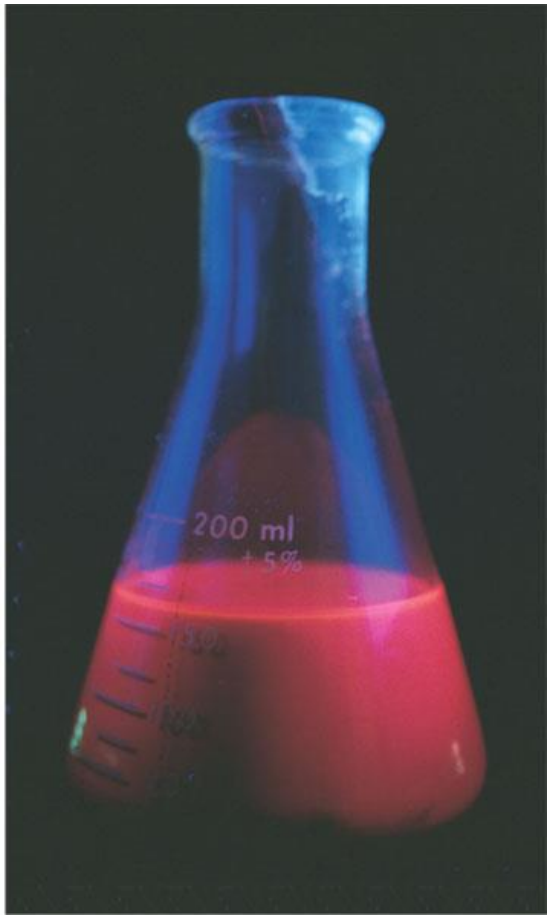


Analogs to energy coupling

Excitation of isolated chlorophyll by light



Excitation of isolated chlorophyll molecule



Fluorescence

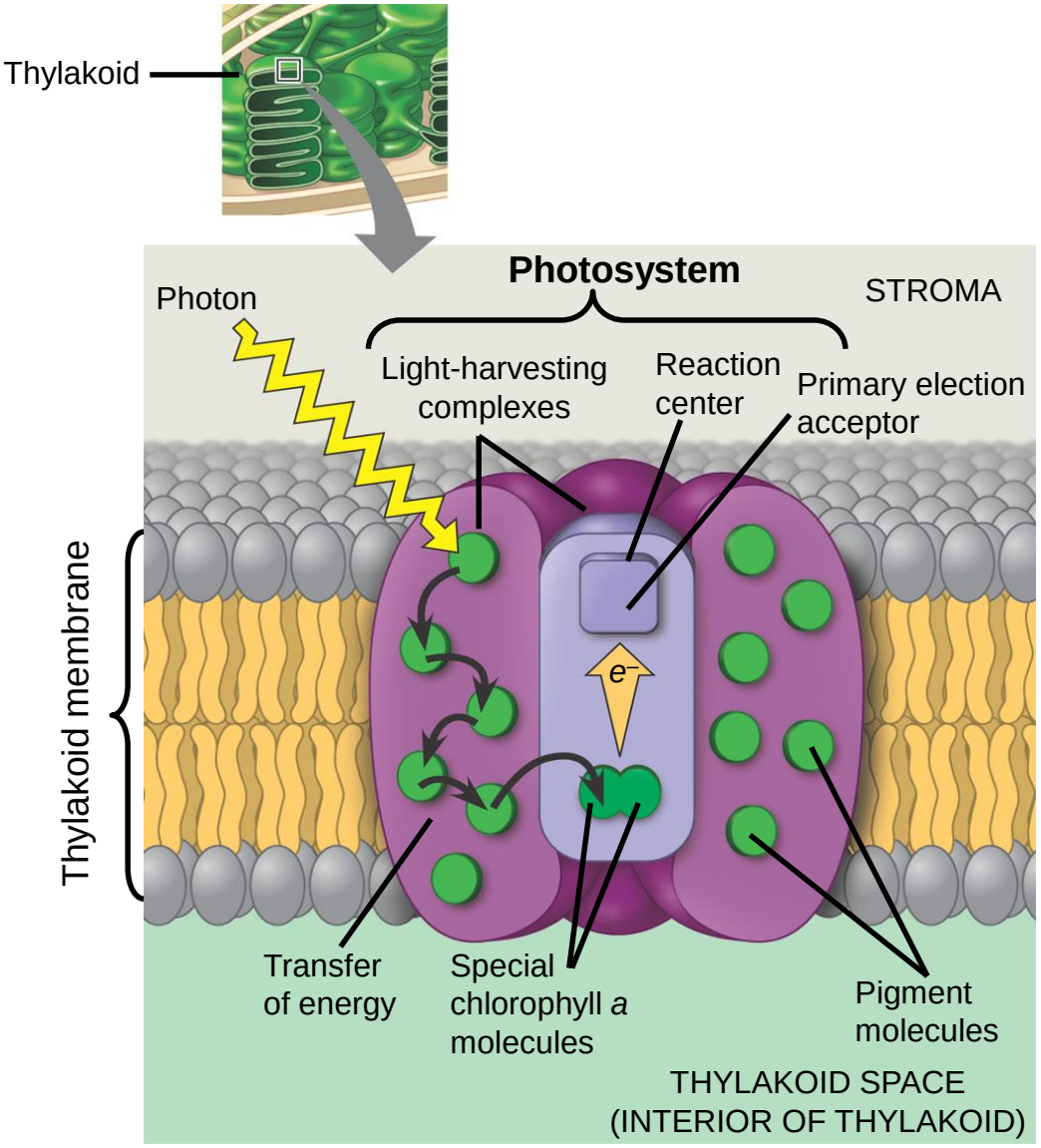
A Photosystem: A Reaction-Center Complex Associated with Light-Harvesting Complexes

- A **photosystem** consists of a **reaction-center complex** (a type of protein complex) surrounded by light-harvesting complexes
- The **light-harvesting complexes** (pigment molecules bound to proteins, Chlorophyll a, b, and carotenoids) funnel the energy of photons to the reaction center
- A **primary electron acceptor** in the reaction center accepts an excited electron from chlorophyll *a*
- Solar-powered transfer of an electron from a **chlorophyll *a* molecule to the primary electron acceptor** is the first step of the light reactions

How a photosystem harvests light

A photosystem

Is composed of a reaction center surrounded by a number of light-harvesting complexes



- There are two types of photosystems in the thylakoid membrane

- **Photosystem II (PS II)** functions first and is best at absorbing a wavelength of 680 nm

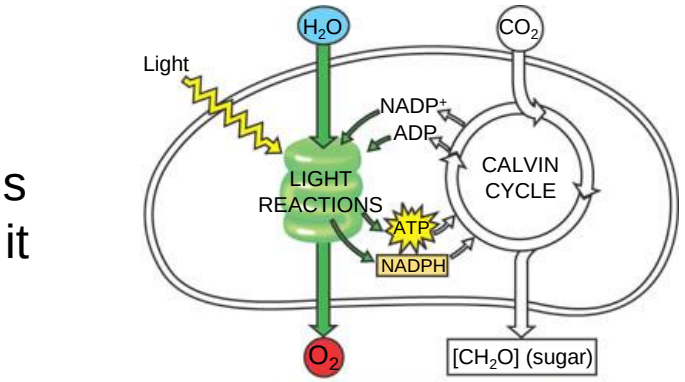
- The reaction-center complex of **chlorophyll *a* of PS II** is called P680

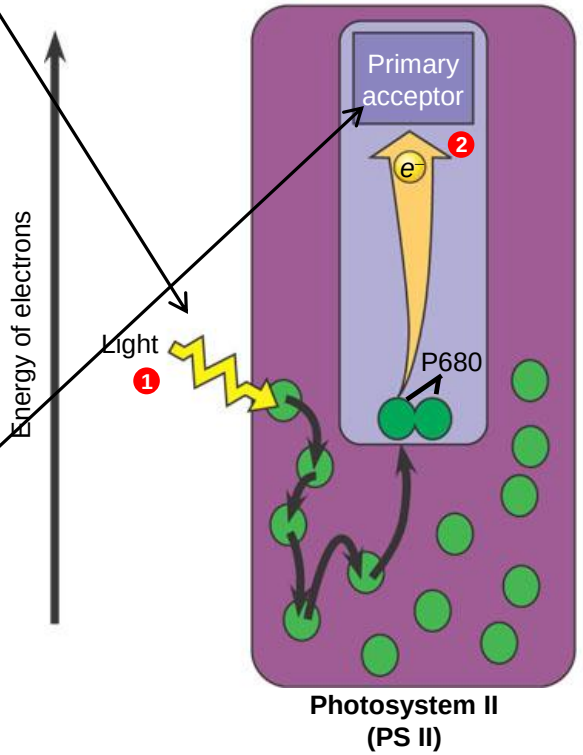
- **Photosystem I (PS I)** is best at absorbing a wavelength of 700 nm

- The reaction-center **chlorophyll *a* of PS I is called P700**

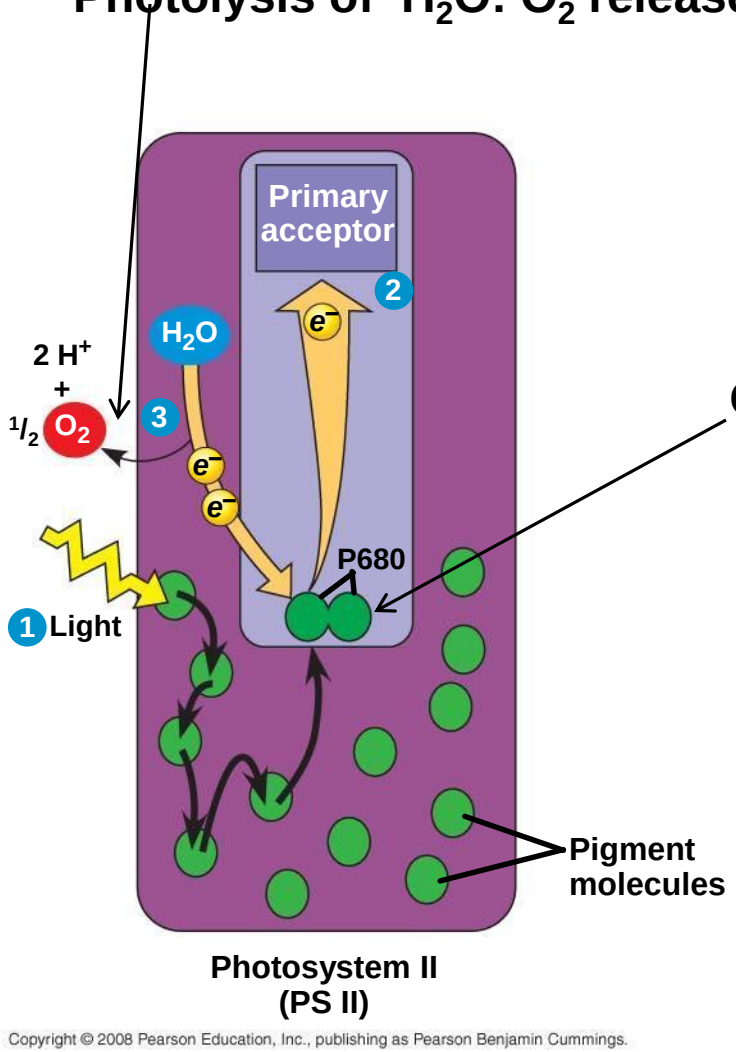
A photon hits a pigment and its energy is passed among pigment molecules until it excites P680

An excited electron from P680 is transferred to the primary electron acceptor





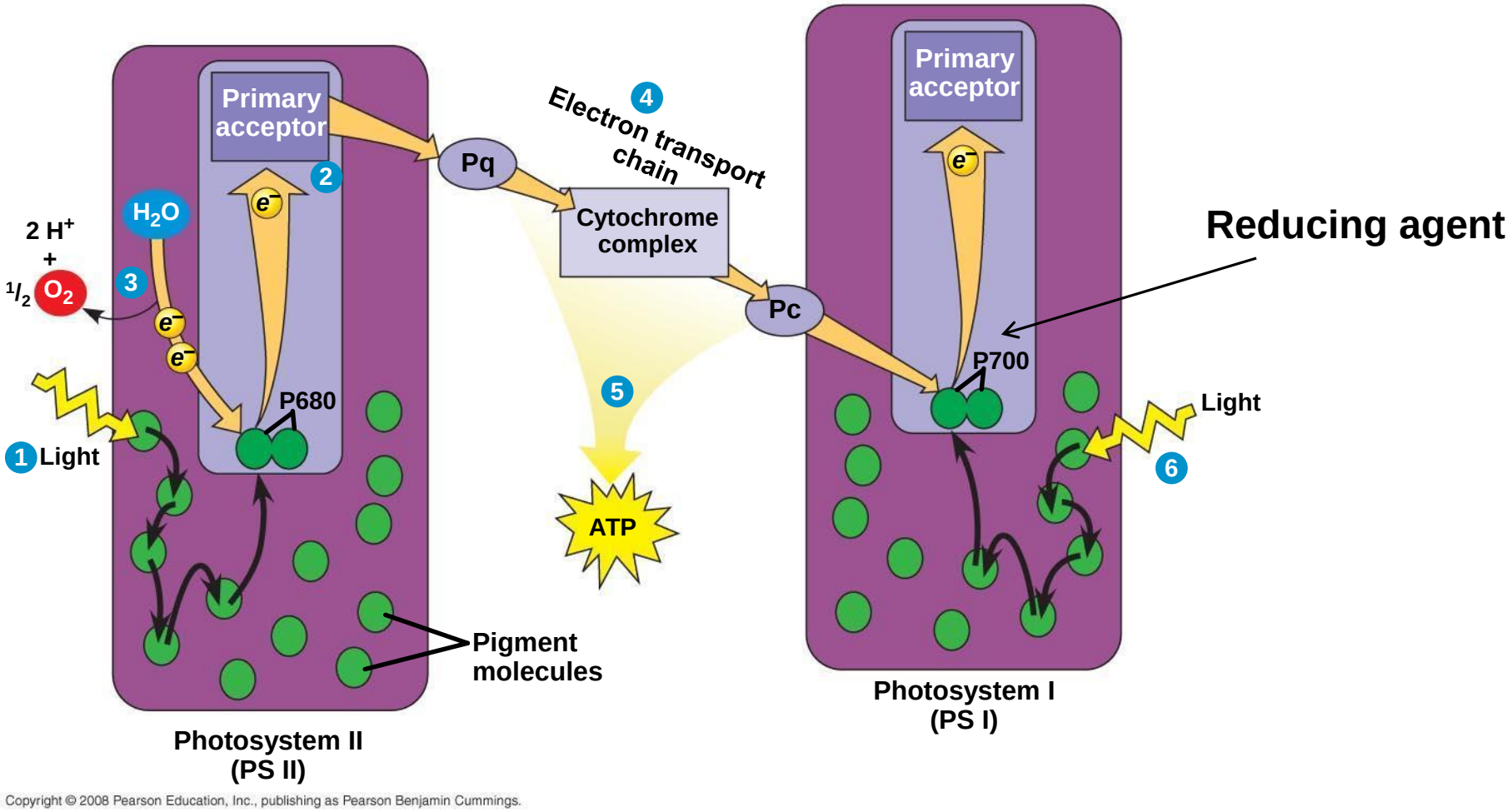
Photolysis of H_2O



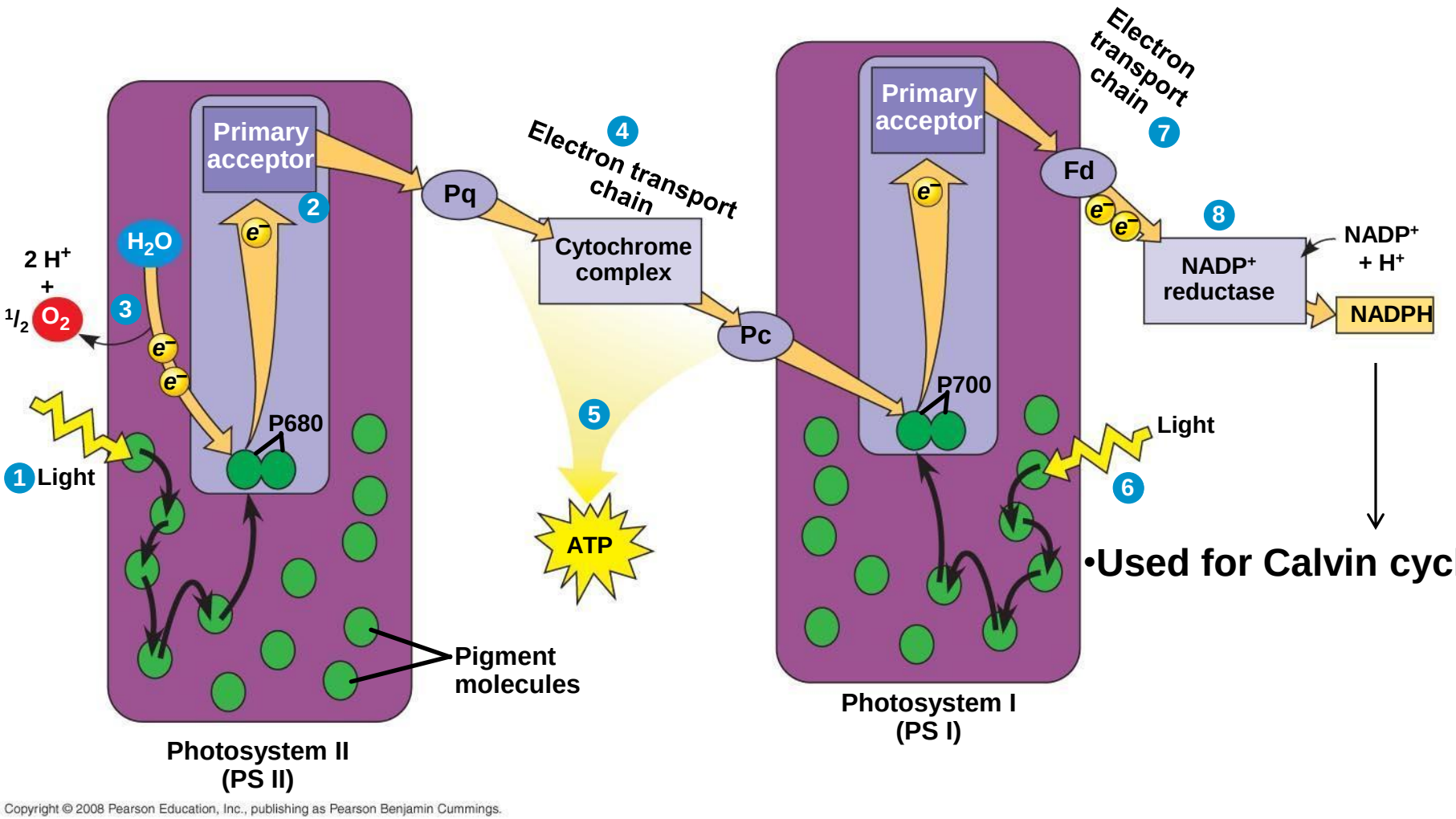
$P680^+$ ($P680$ that is missing an electron) is a very strong oxidizing agent

The oxygen-evolving complex, (OEC) also known as the water-splitting complex, is a water-oxidizing enzyme involved in the photooxidation of water during the light reactions of photosynthesis. OEC appears to have a metalloenzyme core containing both **manganese and calcium**

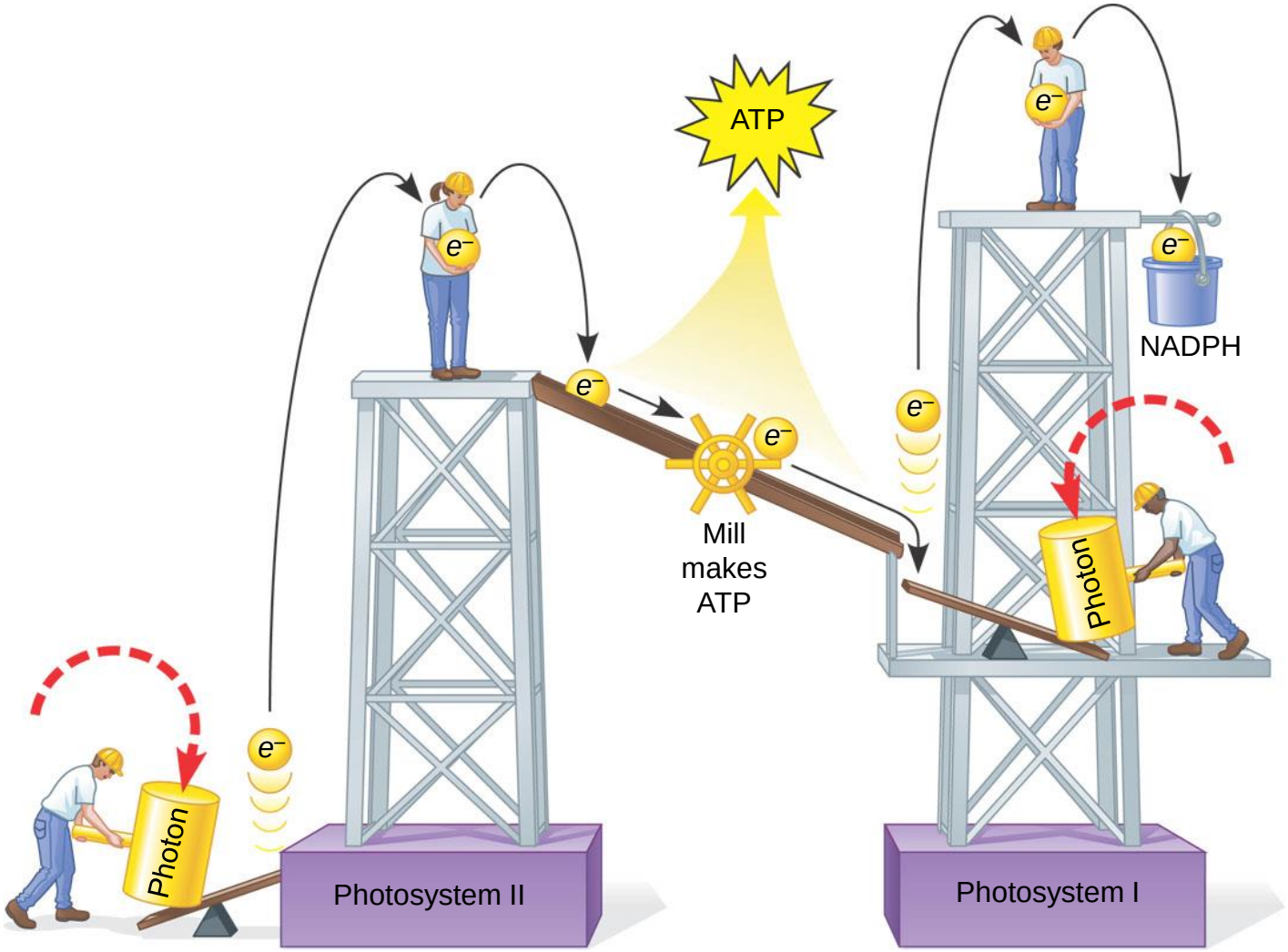
Electron fall and electron transport



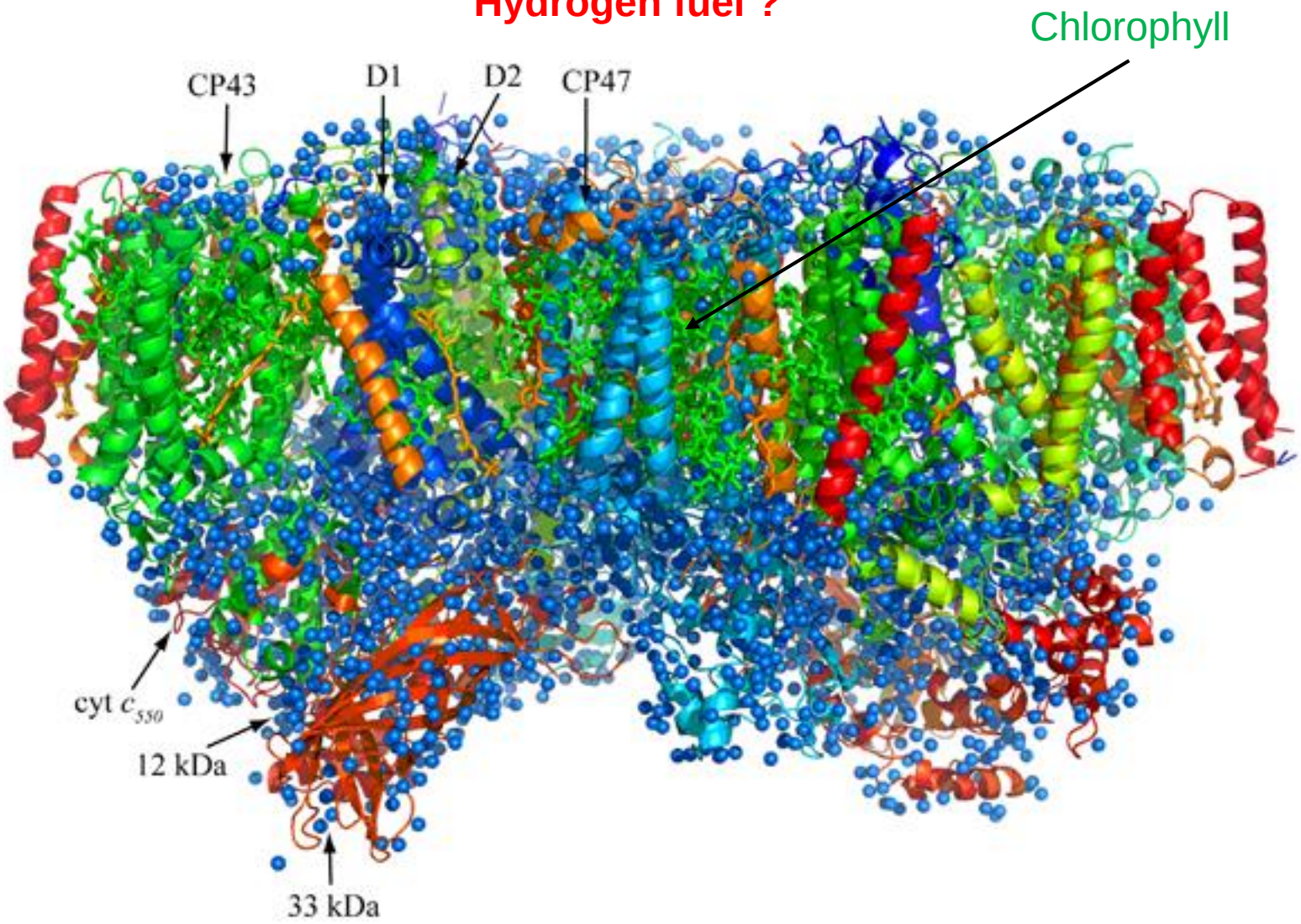
- **Proton motive force: ATP synthesis**



A mechanical analogy for the light reactions



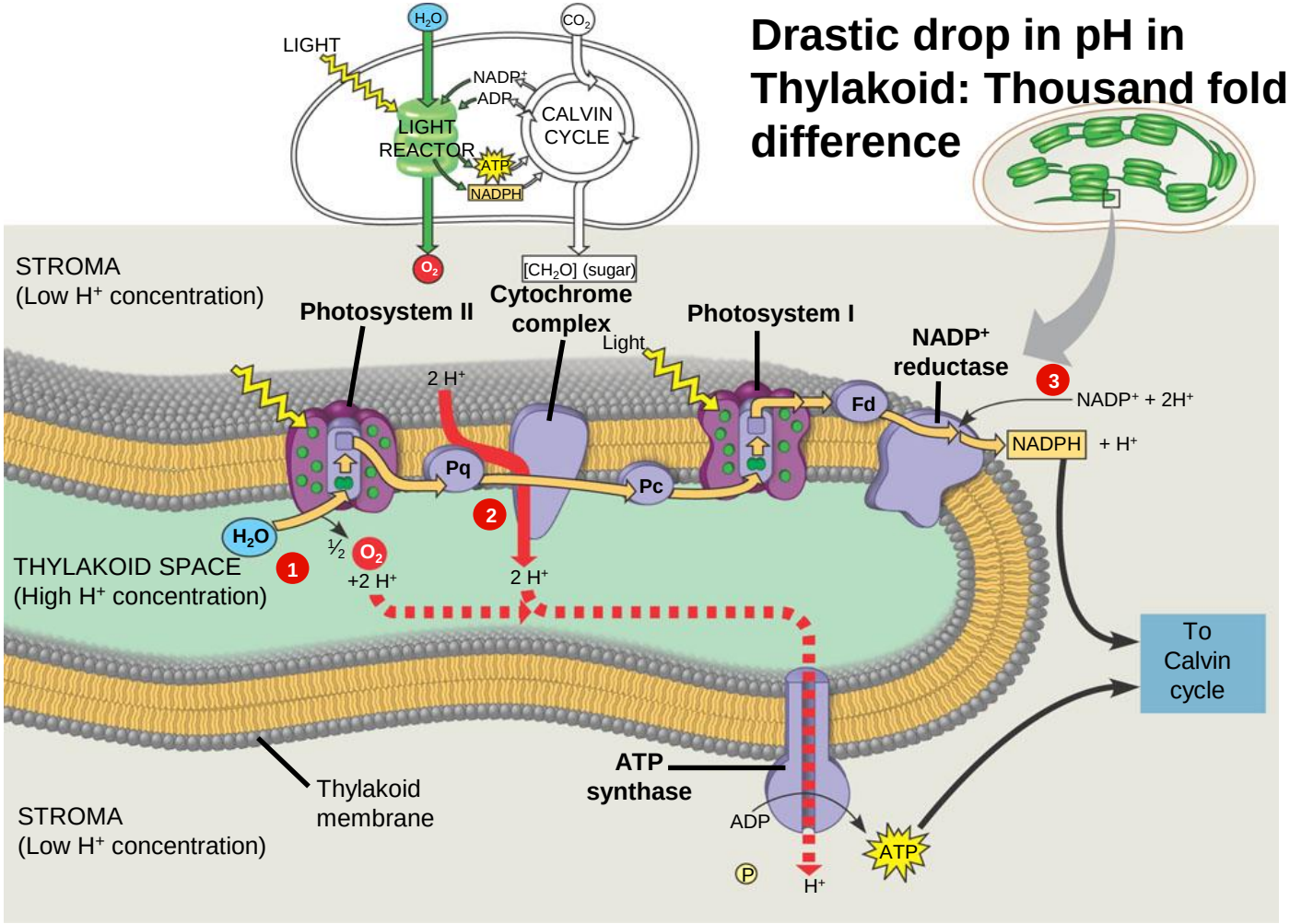
Hydrogen fuel ?



Structure of photosystem II: Nobel Prize for Chemistry: Robert Huber, Johann Deisenhofer and Hartmut Michel

If we know the low cost technology of splitting water **molecule into H2 and O2**, we do not need fossil fuels. H2 can be used as fuels like in Spacecraft.

The light reactions and chemiosmosis: Production of ATP and NADPH: Substrates for Calvin Cycle



Drastic drop in pH in Thylakoid: Thousand fold difference

In mitochondria, protons are pumped to the **intermembrane space and drive ATP synthesis as they diffuse back into the mitochondrial matrix**

Respiration: Glucose to NADH to Electron transport chain to O2.

THE CALVIN CYCLE USES ATP AND NADPH TO CONVERT CO_2 TO SUGAR

•The Calvin cycle, like the citric acid cycle, regenerates its starting material after molecules enter and leave the cycle

•The cycle builds sugar from smaller molecules by using ATP and the reducing power of electrons carried by NADPH

•Carbon enters the cycle as CO_2 and leaves as a sugar named **glyceraldehyde-3-phospate (G3P)**

•For net synthesis of 1 G3P, the cycle must take place three times, fixing 3 molecules of CO_2

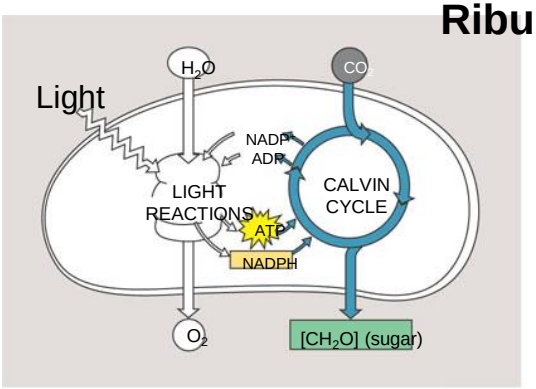
The Calvin cycle has three phases:

•**Carbon fixation** (catalyzed by **rubisco**)

•**Reduction**

•**Regeneration of the CO_2 acceptor (RuBP)**

The Calvin cycle



Ribulose-1,5-bisphosphate carboxylase/oxygenase

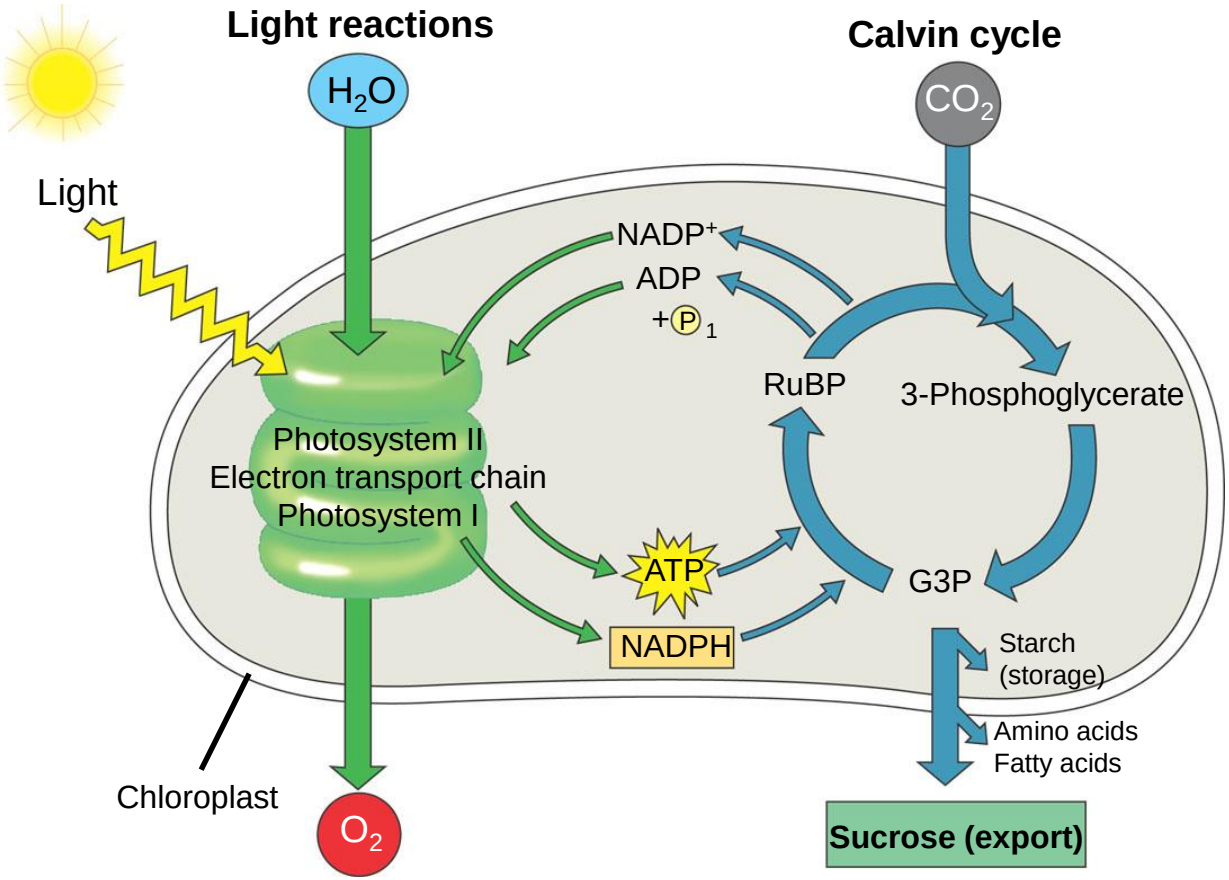
COO^- (Carboxylic) → **CHO (Aldehyde)**

Similarity and differences b/w Citric acid and Calvin cycle

While the citric acid cycle is catabolic and, oxidizing glucose to synthesize ATP, calvin cycle is anabolic, building carbohydrate from the smaller molecules and consuming energy like ATP

Photosynthesis is **emergent property of the intact chloroplast**, which integrates the two stages of photosynthesis.

Review..



Light reactions:

- Are carried out by molecules in the thylakoid membranes
- Convert light energy to the chemical energy of ATP and NADPH
- Split H_2O and release O_2 to the atmosphere

Calvin cycle reactions:

- Take place in the stroma
- Use ATP and NADPH to convert CO_2 to the sugar G3P
- Return ADP, inorganic phosphate, and NADP+ to the light reactions

Photosynthesis connection to Engineering

- Engineers are faced with the challenge of designing energy efficient systems for heating buildings or creating fuel-efficient vehicles.
- The photosynthetic process serves as an excellent model for highly efficient engineering design. Plants convert readily available resources into plant fuel (glucose). The only byproduct of the process is oxygen, which is an environmentally friendly product that is consumable by other organisms.
- Engineers who are working to optimize fuel efficiency and minimize hazardous emissions can look to the effective process of photosynthesis as an example.

- Describe how the relationship between photosynthesis and respiration sustain life on this planet.
- Explain the relationship between plants and animals in the oxygen-carbon dioxide cycle.
- Identify ways in which engineers could utilize knowledge of photosynthesis.
- Introducing novel photosynthetic capacity into microorganisms

C4 Rice engineering Project: Research Grant from the Bill & Melinda Gates Foundation (BMGF) : Rs ~200 crore project

C4 plants are more efficient in carbon dioxide concentration that results in increased efficiency in water and nitrogen use and improved adaptation to hotter and dryer environments.

- Biologically inspired engineering: Engineering “artificial leaf,” which uses a catalyst to **make sunlight split** water into hydrogen and oxygen, with a **bacterium engineered to convert carbon dioxide plus hydrogen into the liquid fuel isopropanol.**

Efficiency rate of converting light to energy is approximately 6% in photosynthesis, compared to 10% in photovoltaics. Where plants outpace PV cells, however, is in the amount of light they absorb. Both photosynthesis and photovoltaic systems absorb very high-energy light, but plants are nearly 100% efficient at absorbing light from the visible spectrum — the range of colors from red to blue.

- Engineers and scientist are investigating ways to create photovoltaics from actual plant proteins. Engineered to use light from all areas of the spectrum, they would combine the best of both natural and synthetic efficiencies.
- “The biological perspective gives so much insight into ways we can improve photovoltaics in the future.”

Cell: The Fundamental Unit of Life

- All organisms are made of cells
- The cell is the simplest collection of matter that can live
- Cell structure and cell function are related
- All cells come from earlier cells

- When you read the book, the contraction **of muscle cells** moves your eyes as read the sentence; when you decide to turn the next page, **nerve cell transmi**t the decision form your brain to **the muscle cells** of your hand. Each action of an organism begins at **the cellular level**.

To study cells

- How can be cell biologists possibly investigate the **inner workings of such tiny** entireties?

Cell size: 10 - 120 micron in diameter, length can be up to 1m in neurons

To study cells, biologists **use microscopes and tools of biochemistry**.

- Microscopes are used to see cells and the complex details of cells invisible to the unaided eye
- Light microscope is the simplest
- In a **light microscope (LM)**, visible light passes through a specimen and then through glass lenses, magnifying the image

The process of cell fractionation

Cytology: The study of cell structure.
Biochemistry: The study of the molecules and chemical process (metabolism) of cells.

Biochemistry and cytology **help correlate cell function with structure**

APPLICATION Cell fractionation is used to isolate (fractionate) cell components, based on size and density.

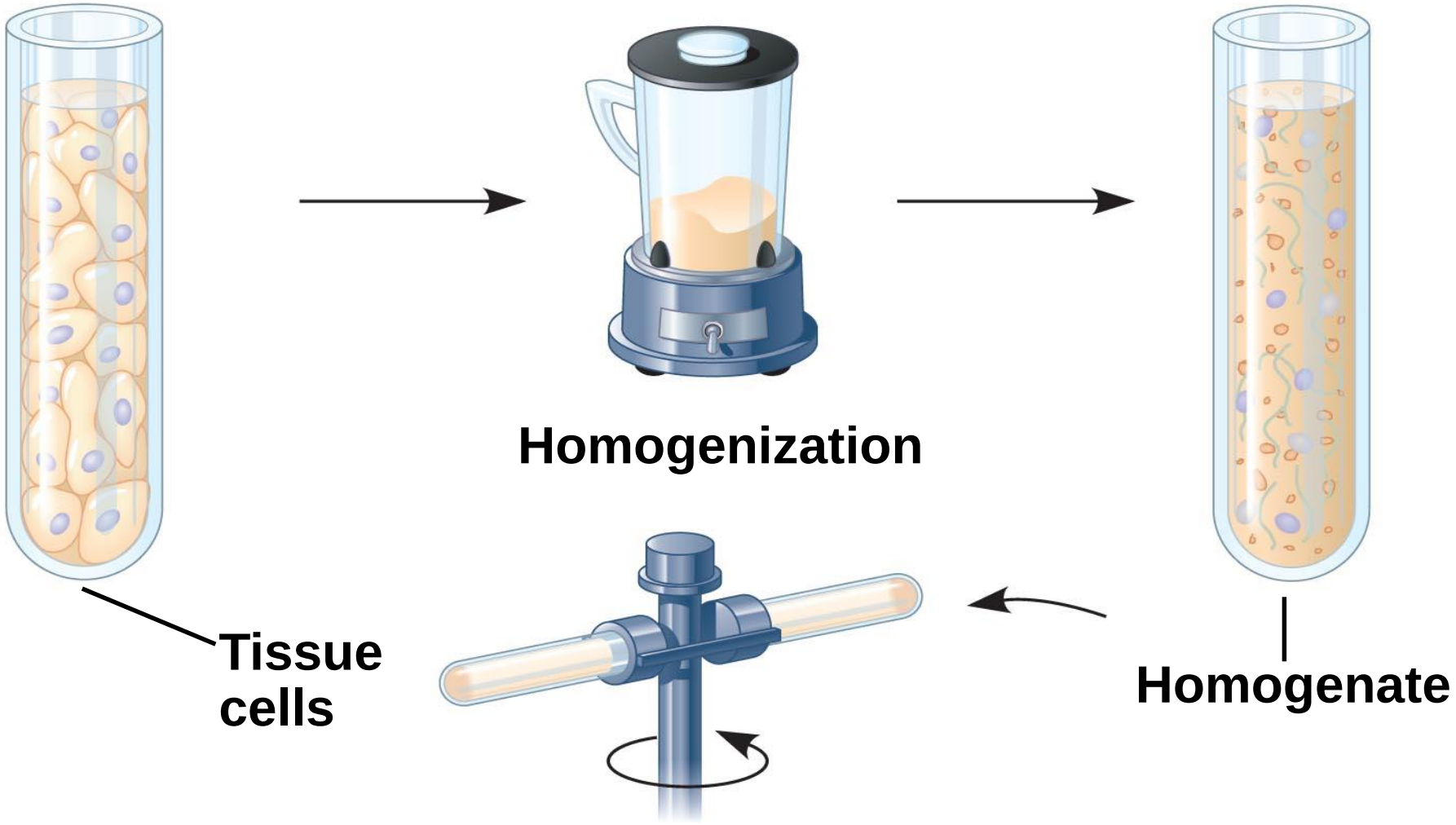
TECHNIQUE First, cells are homogenized in a blender to break them up. The resulting mixture (cell homogenate) is then centrifuged at various speeds and durations to fractionate the cell components, forming a series of pellets.

Centrifuge: Which **spins test tubes holding mixtures of disrupted cells at** various speeds. The resulting forces cause a **fraction of the cell components to settle to the bottom of the tube, forming a pellet**. At lower speeds, the pellet consists of larger components, and higher speeds yield a pellet with smaller components.

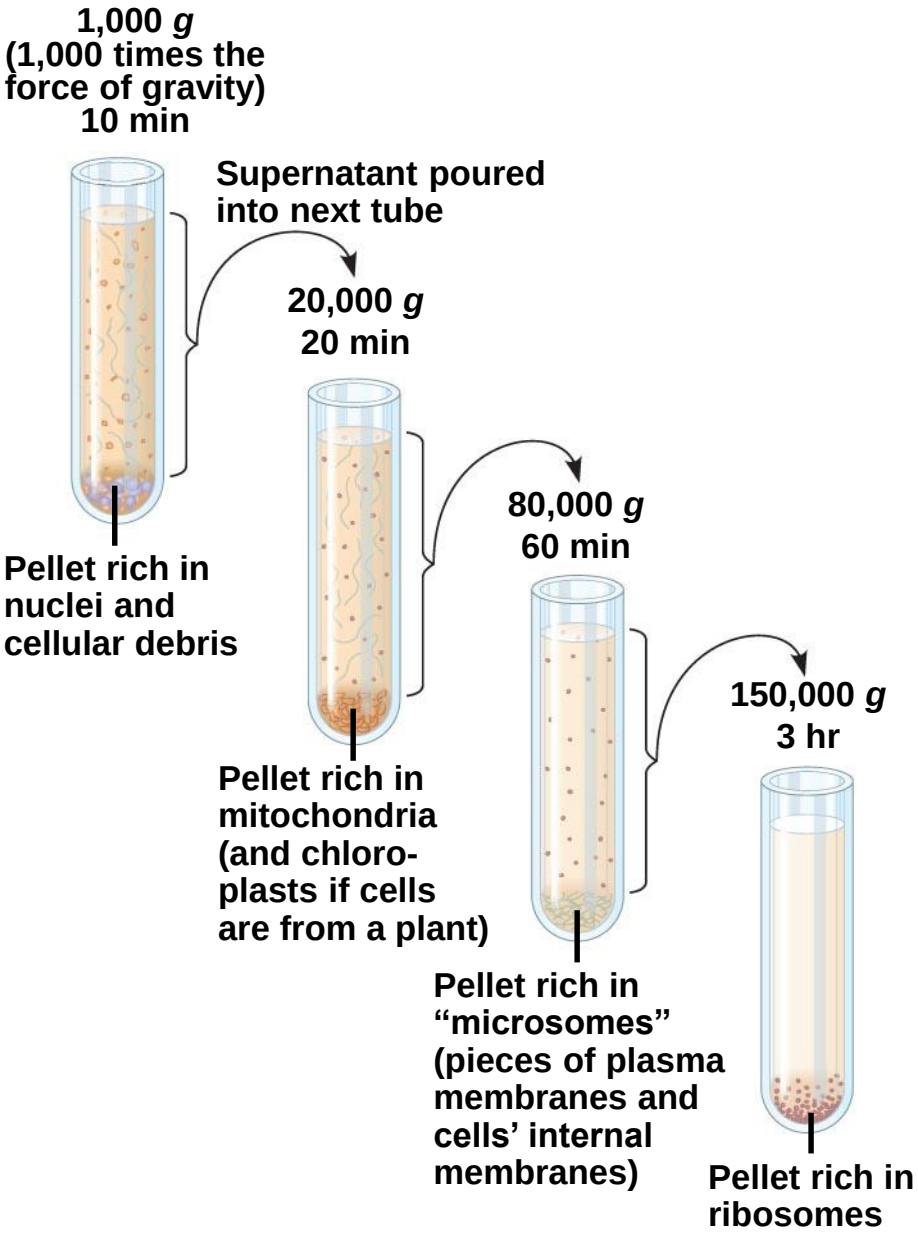
Cell Fractionation

The most powerful machines are called ultracentrifuges, spin up to 1,30,000 revolutions per minute and apply forces on particles of more than 1 million times the force of gravity.

TECHNIQUE



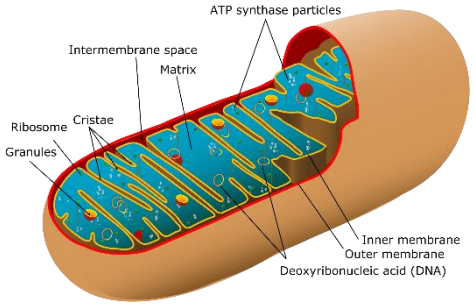
TECHNIQUE (cont.)



RESULTS

- In the original experiments, the researchers used microscopy to **identify the organelles in each pellet,** establishing a baseline for further experiments.
- In the next series of experiments, **researchers used biochemical methods to determine** the **metabolic functions associated with each type of organelle**.
- Researchers currently use cell fractionation to isolate particular organelles in order to study further details of their function.

- For example biochemical tests showed that one of the cell fractions produced by centrifugation **included enzymes involve in cellular respiration**.
- Electron microscope revealed that **this fraction contained large numbers of organelles called mitochondria.** Together, these data helped biologists determine the **mitochondria are the sites of cellular respiration**. Biochemistry and cytology thus complement each **other in correlating cell function with structure**.



Centrifugation to isolate
Electron microscopy
(Cytology)

Cellular respiration

(Biochemical study)

Eukaryotic cells have internal membranes that compartmentalize their functions

- All cells are either prokaryotic or eukaryotic cells
- Bacteria & Archaeabacteria are prokaryotic cells
- Protists, fungi, animals, and plants are eukaryotic cells
- Basic features of all cells:
  - Plasma membrane
  - Semifluid substance called **cytosol**
  - Chromosomes (carry genes)
  - Ribosomes (make proteins)

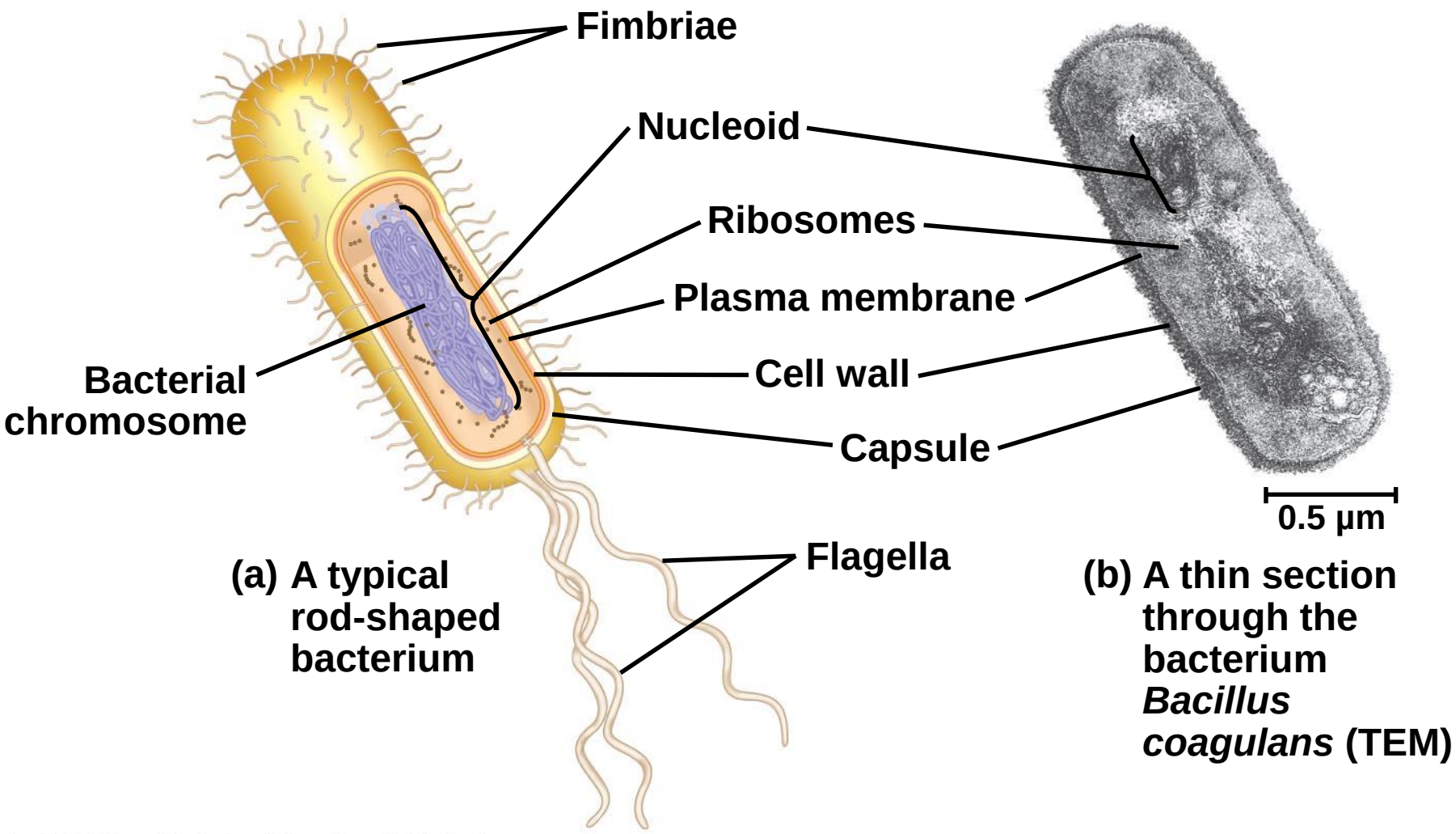
Prokaryotic cells are characterized by having

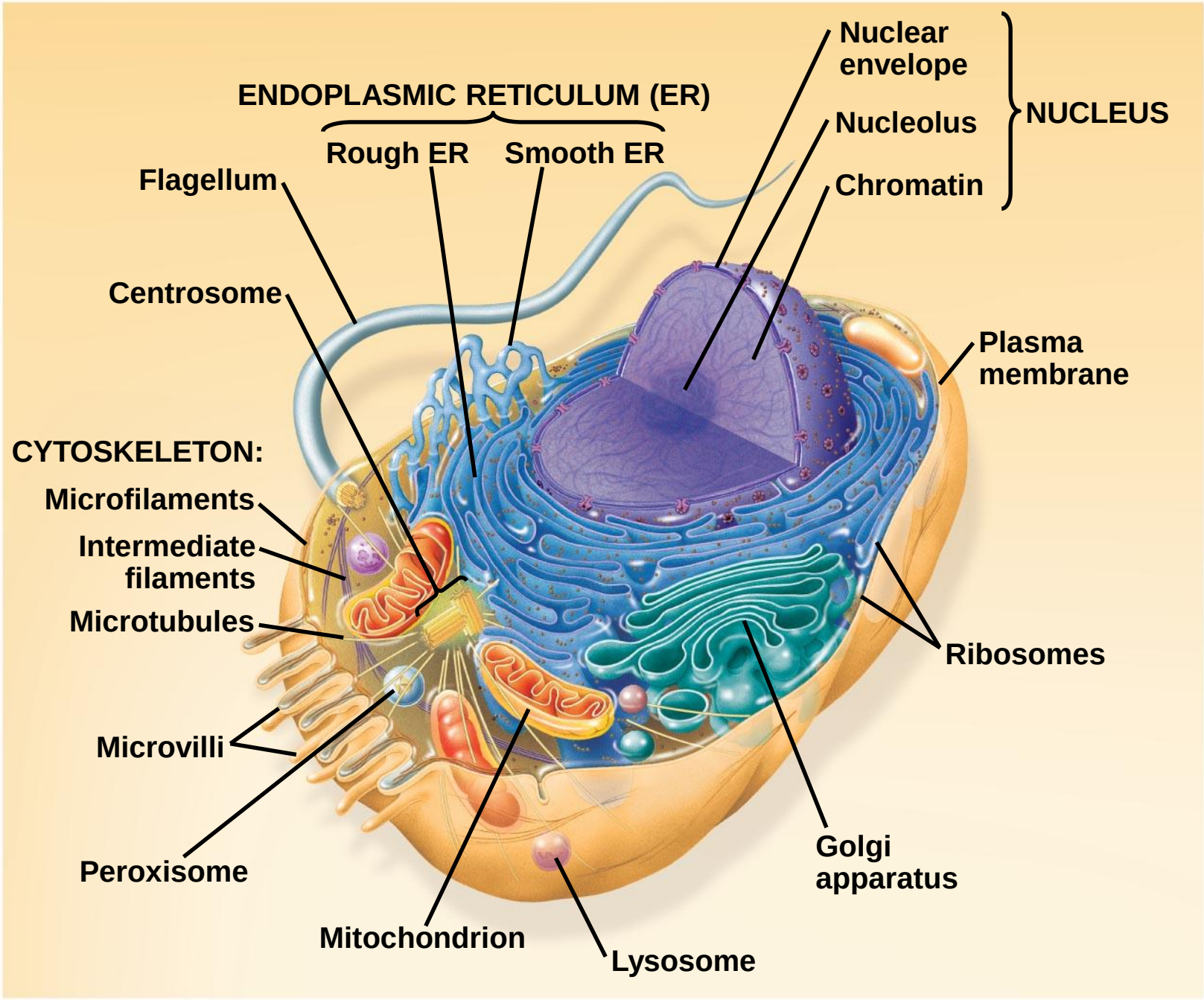
No nucleus

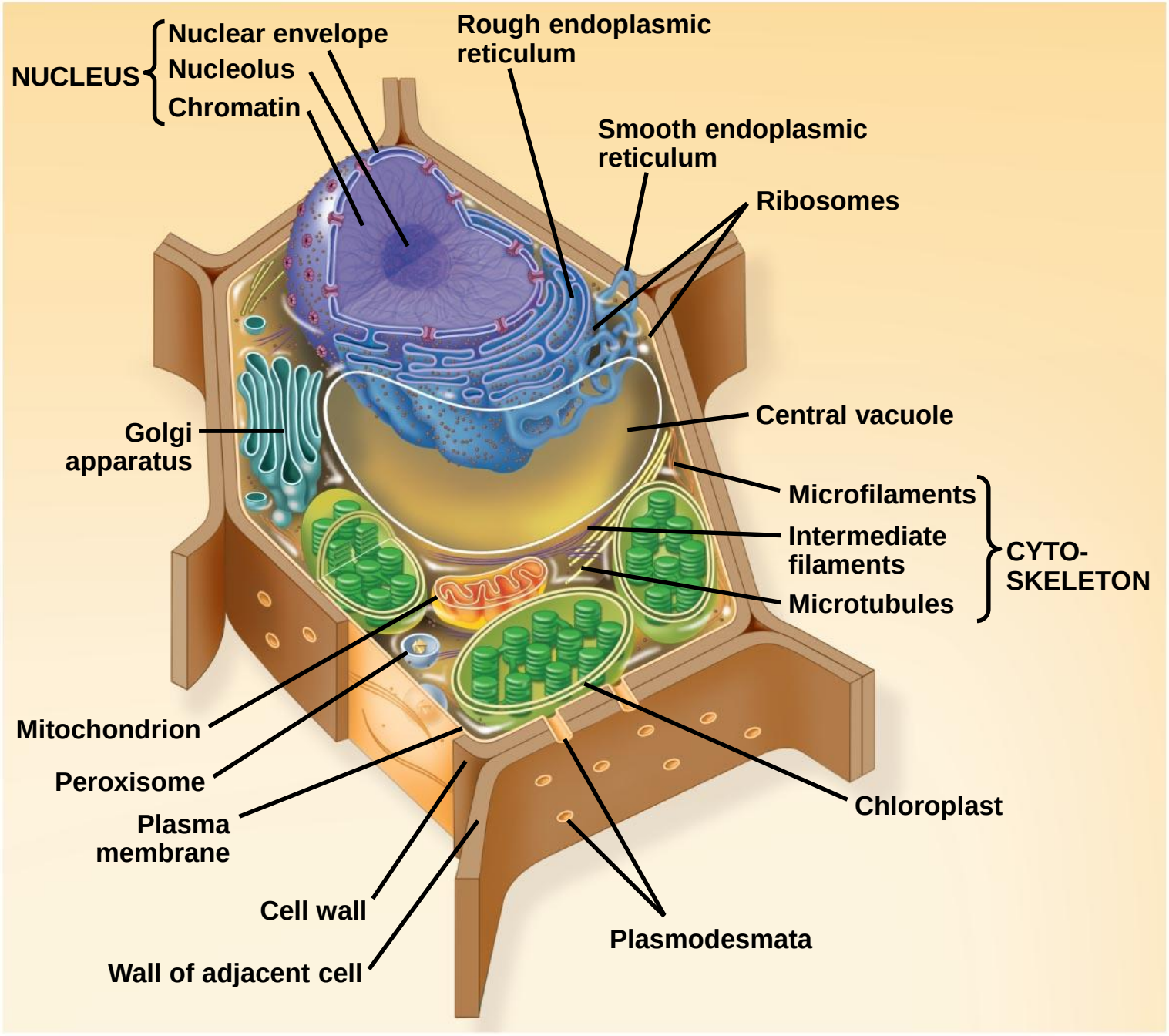
DNA in an unbound region called the **nucleoid**

No membrane-bound organelles

Cytoplasm bound by the plasma membrane







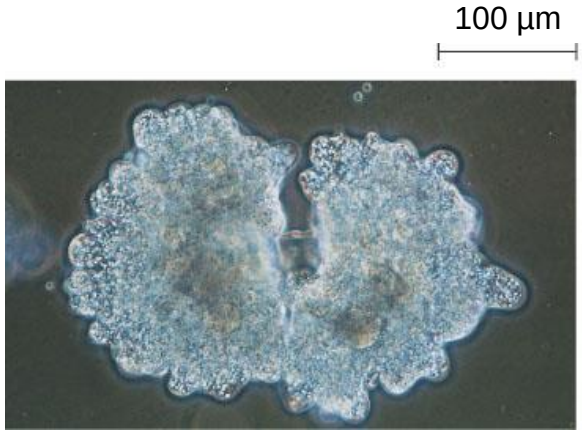
THE CELL CYCLE and CLL DIVISON

Quote from German Physician Rudolf Virchow (1855)

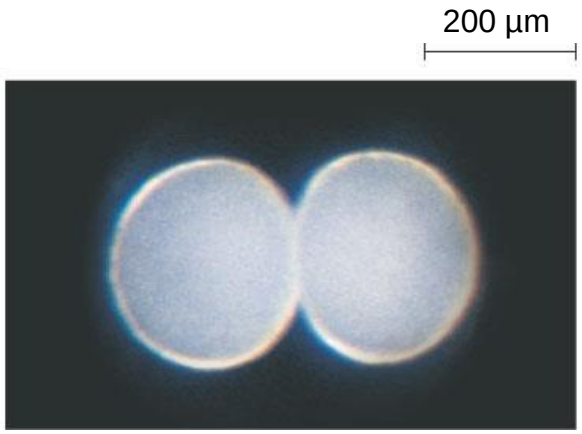
"Where a cell exists, there must have been a preexisting cell, just as the animal arises from the animal and the plant from the plant"

- The continuity of life from one cell to another is based on the reproduction of cells via **cell division**.

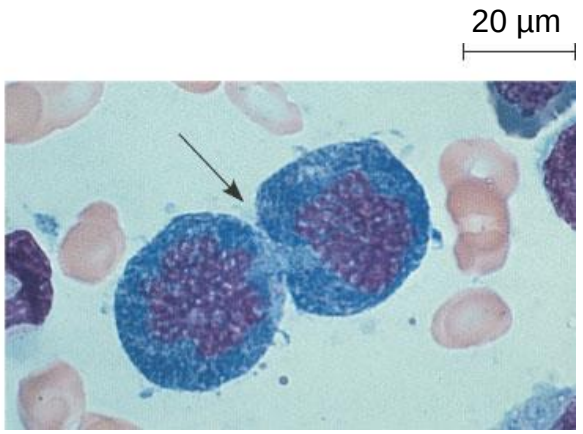
Key roles of cell division



(a) Reproduction. An amoeba, a single-celled eukaryote, is dividing into two cells. Each new cell will be an individual organism (LM).



(b) Growth and development. This micrograph shows a sand dollar embryo shortly after the fertilized egg divided, forming two cells.

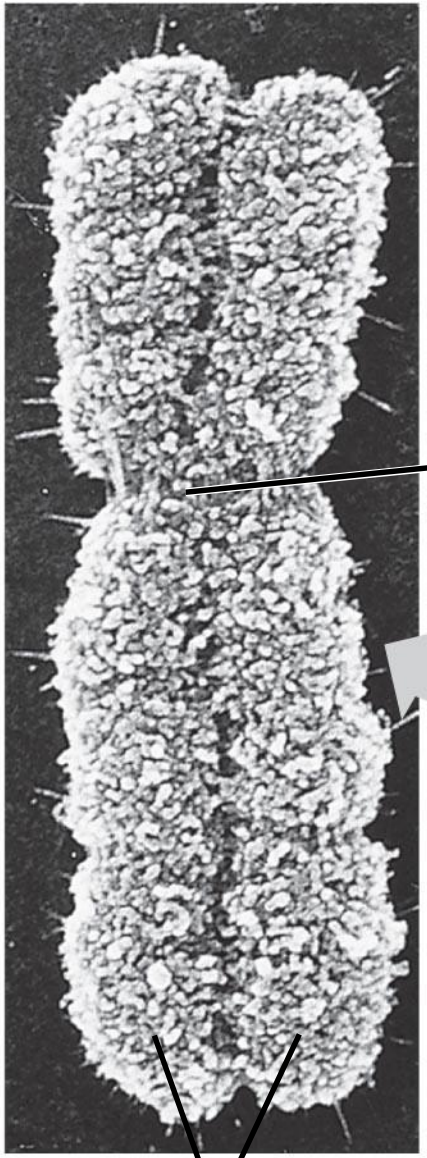


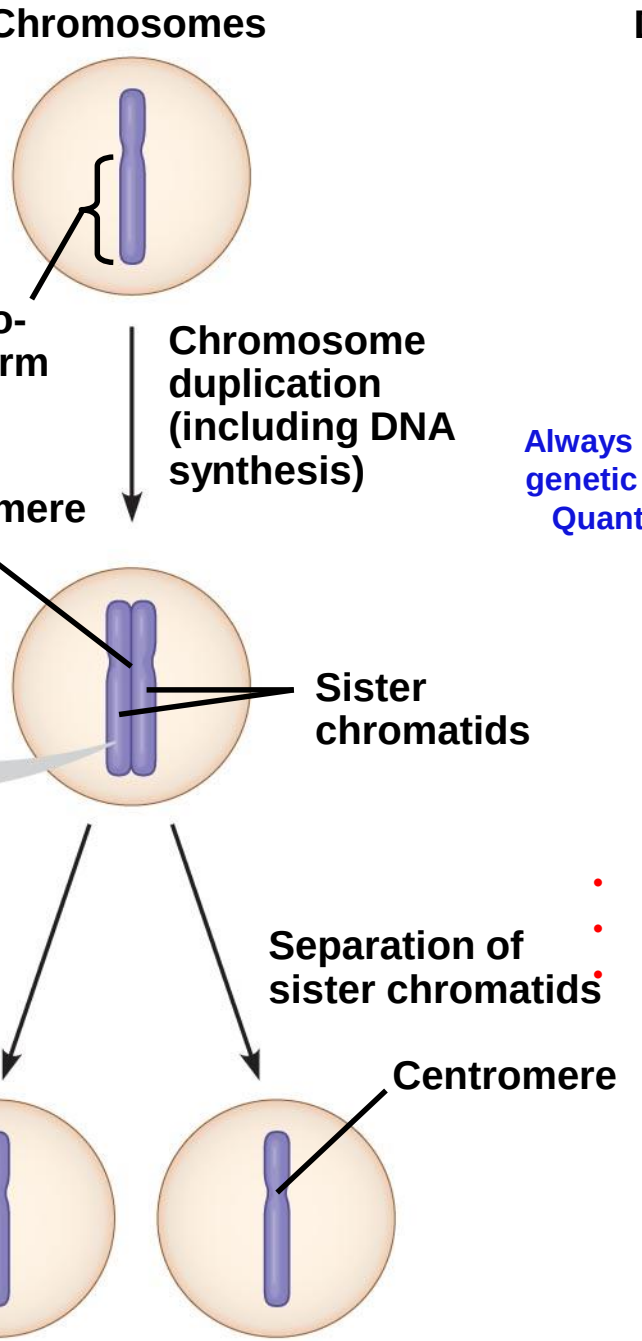
(c) Tissue renewal. These dividing bone marrow cells (arrow) will give rise to new blood cells (LM).

A human cell must duplicate about 2 m of DNA and separate the two copies such that each daughter cell ends up with a complete genome (DNA).

- A dividing cell duplicates its DNA, allocates **the two copies to opposite ends of** the cell, and then splits into two daughter cells.
- Passing **identical genetic material to cellular offspring is a crucial function of cell division**.

Roles of cell division: Genetically Identical Daughter Cell





Always associated with division of genetic material into equal halves: Quantitatively and qualitatively

- Miss regulation: Disorder
- No dilution
- Each has a complete and identical set of chromosomes

Nobody can pack as nature is packing: DNA Condensation

Nucleus size : 20 uM

(6-12 uM)
0.6-1.2* 10^4 nm

(1.4 uM)
1400 nm

300 nm

10-15 * 10^3 fold

30 nm

700 fold

11 nm

12 cm (1.2* 10^8 nm)

2nm

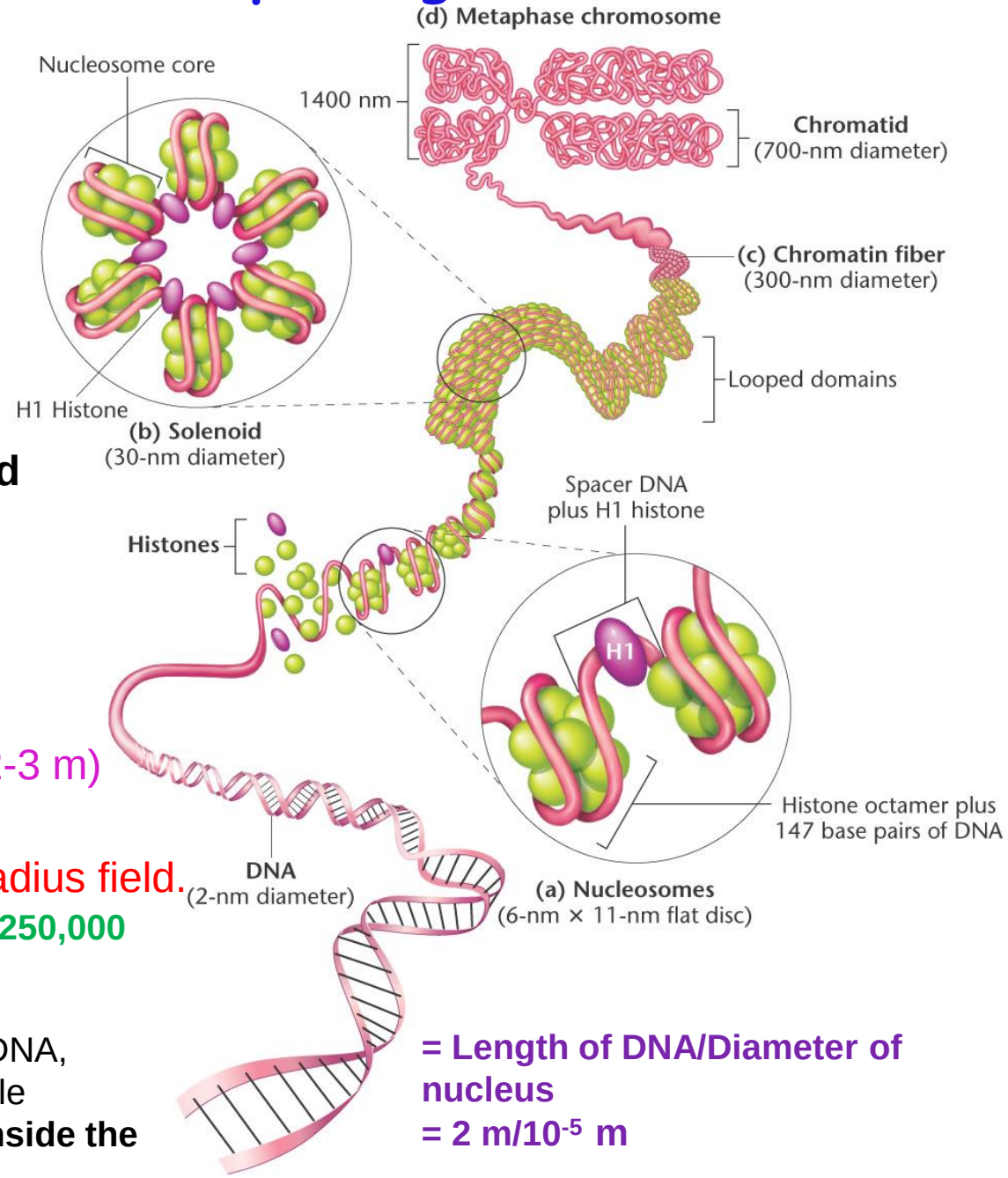
(Total length of DNA= 2-3 m)

Length **Diameter**

- ~2.5 lakh km rope put into 1 km radius field.

Length of the DNA in the cell is about 250,000 times more than cell's diameter

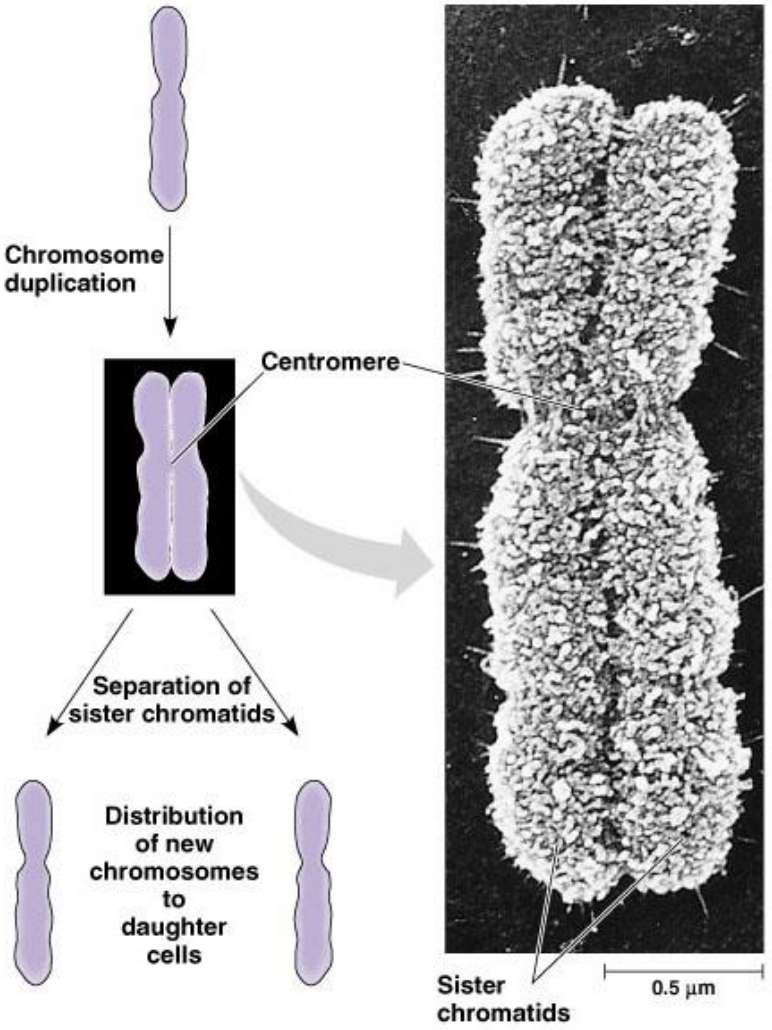
Replication and distribution of so much DNA, equally into daughter cells, is manageable because **DNA molecules are packed inside the chromosome**.



= Length of DNA/Diameter of nucleus
= 2 m/10^{-5} m

DNA molecules are packed into chromosomes.

- Each eukaryotic chromosome consists of a long, linear DNA molecule.
- Each chromosome has hundreds or thousands of genes, the units that specify an organism's inherited traits.
- Associated with DNA are proteins that maintain its structure and help control gene activity.
- This DNA-protein complex, **chromatin,** is organized into a long thin fiber.
- After the DNA duplication, chromatin condenses, coiling and folding to make a smaller package.



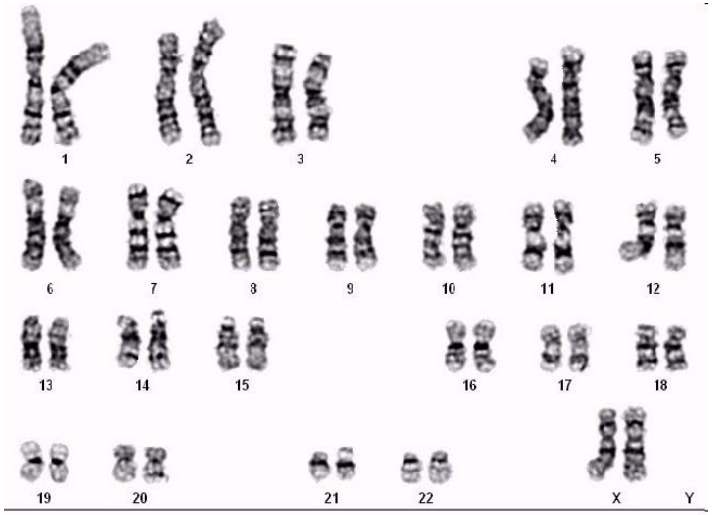
Human Genome

Diploid:

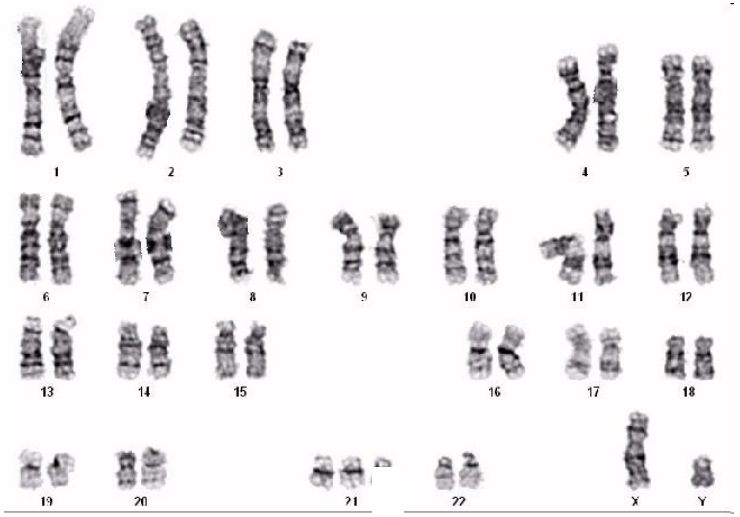
- Two copies of each chromosome (Autosome, 22 pair)
- A pair of (23rd) chromosomes (allosome) (Male: XY and female: XX

Polyploidy: Wheat (Diploid to polyploid), Cotton (Tetraploid), Salmon (Tetraploid)

Haploid: Gametes



Female Karyotype



Male karyotype

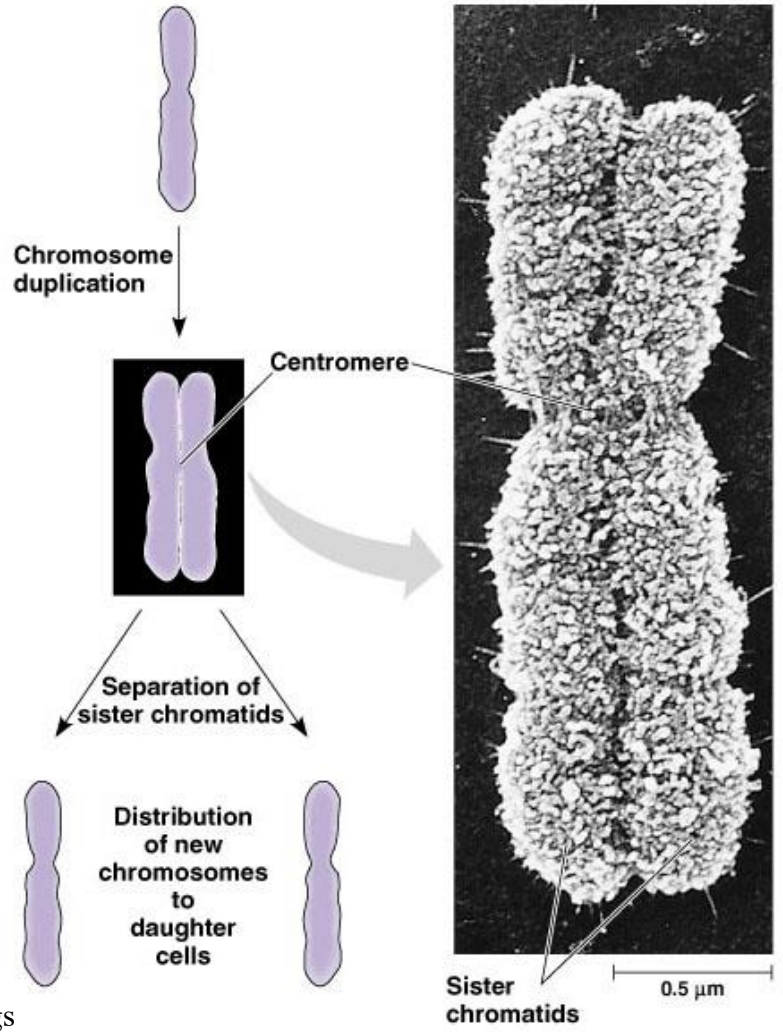
Aneuploidy: Chromosome number being different for the species

- Klinefelter syndrome (47, XXY)
- Turner syndrome (45, X)

Mitosis

- The process of the formation of the two daughter nuclei which has exact number of chromosomes, but single sister chromatid..
- These processes take one cell and produce two cells that are the genetic equivalent of the parent.

- The fertilized egg or zygote underwent trillions of cycles of mitosis and cytokinesis to produce a fully developed multicellular human.
- These processes continue every day to replace dead and damaged cell.
- Essentially, these processes produce clones - cells with the same genetic information.

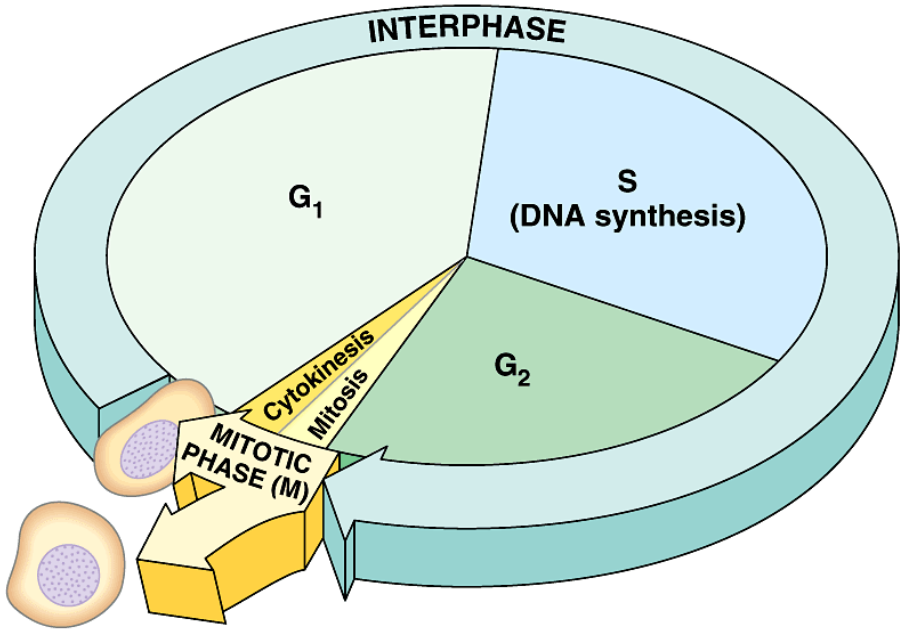


Meiosis

- In contrast, gametes (eggs or sperm) are produced only in gonads (ovaries or testes).
- In the gonads, cells undergo a variation of cell division, **meiosis**, which yields four daughter cells, each with half the chromosomes of the parent.
  - In humans, meiosis reduces the number of chromosomes from 46 to 23.
- Fertilization fuses two gametes together and doubles the number of chromosomes to 46 again.

The mitotic phase alternates with interphase in the cell cycle: *an overview*

- The **mitotic** (**M**) **phase** of the cell cycle alternates with the much longer **interphase**.
  - The M phase includes mitosis and cytokinesis.
  - Interphase accounts for 90% of the cell cycle.



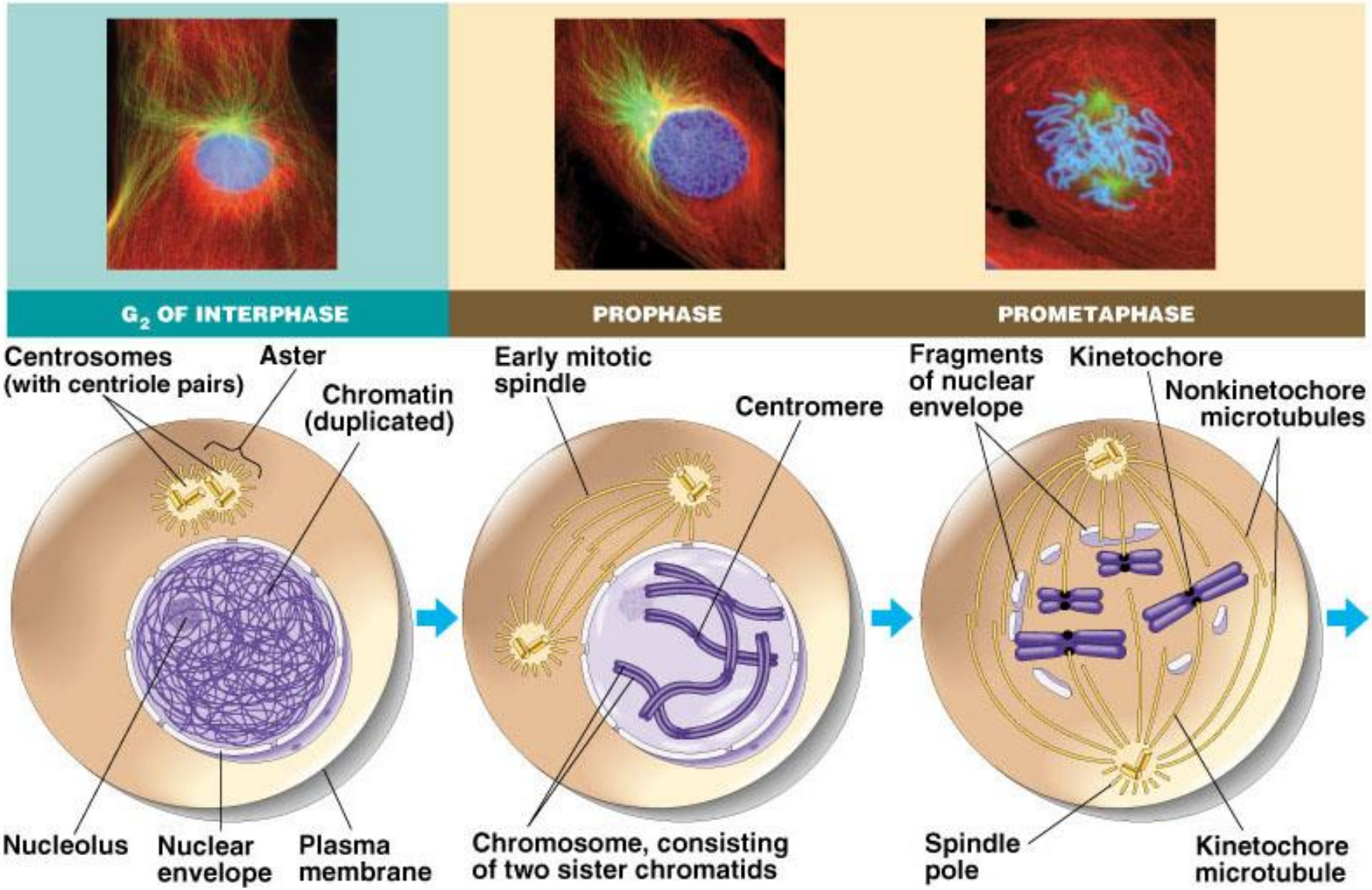


Fig. 12.5 left

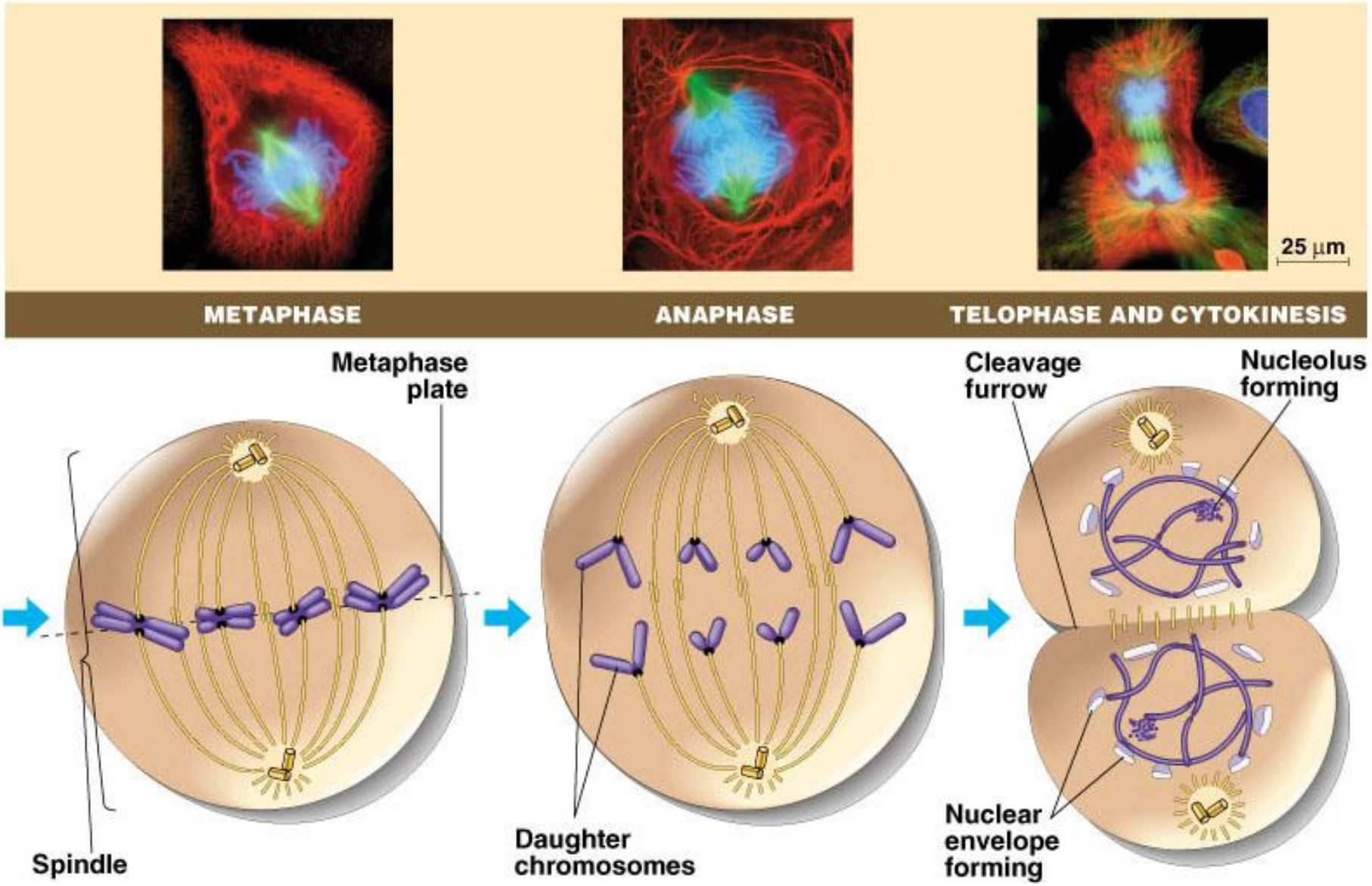


Fig. 12.5 right

Video

Life cycle: Meiosis

- **The human life cycle**
- **Meiosis is a special form of cell division that produces gametes**
- **There is a special mechanism to produce gametes**
- **Each gamete has a single set of chromosomes**
- **22 Autosomes and a single sex chromosome**