Chapter 6

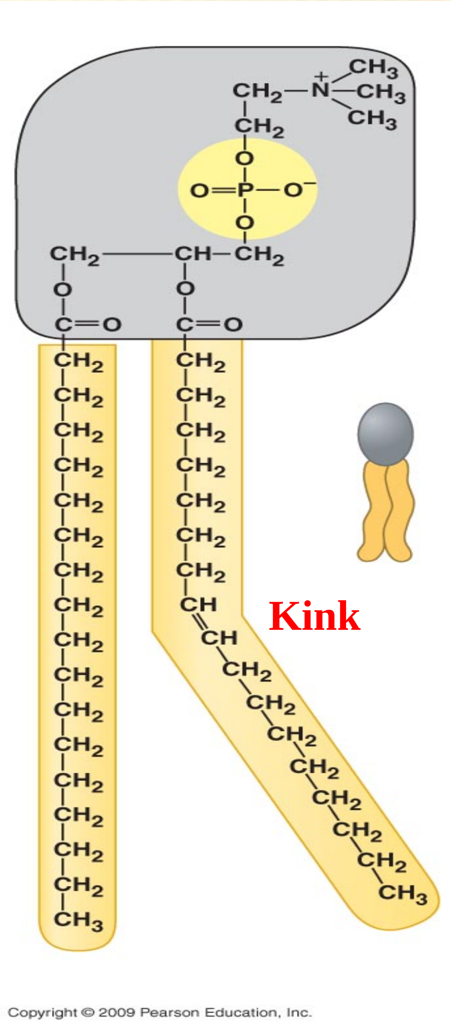
BIOENERGETICS

Transport across membranes

MEMBRANE STRUCTURE AND FUNCTION

Membranes are a fluid mosaic of phospholipids and proteins

- **Membranes are composed of phospholipids bilayer and proteins**
- **Many phospholipids are made from unsaturated fatty acids that have kinks in their tails that keep the membrane fluid phospholipid Contains 2 fatty acid chains that are nonpolar**
- **Are nonpolar and Head is polar & contains a –PO4 group & glycerol**



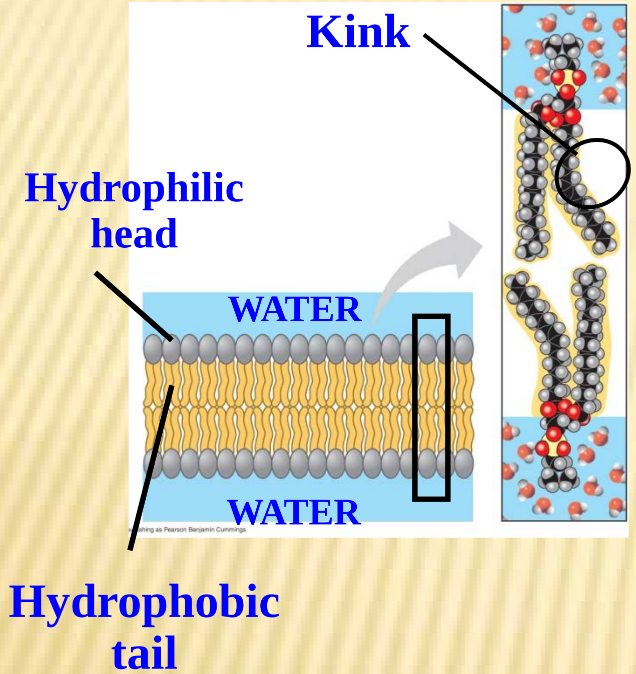
Membranes are a fluid mosaic of phospholipids and proteins

Membranes are commonly described as a fluid mosaic

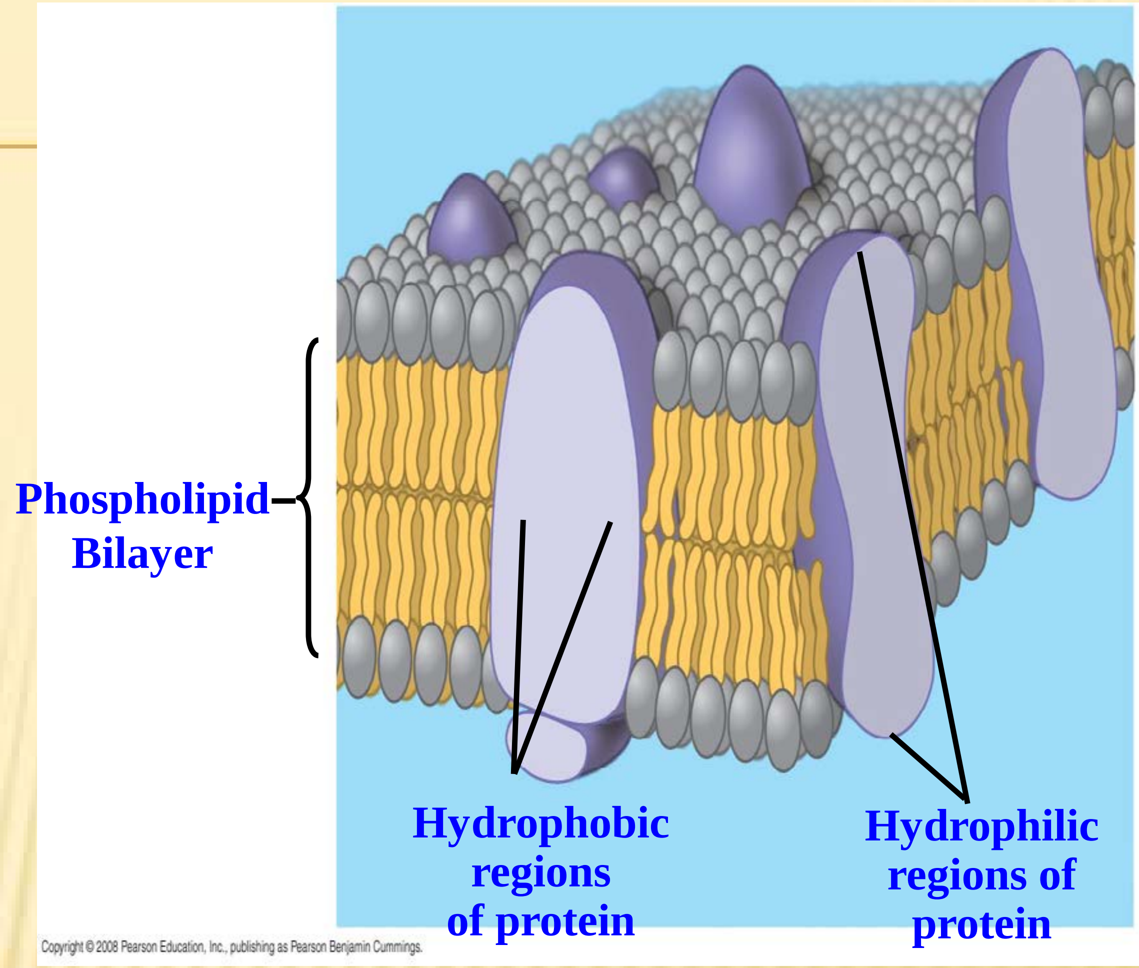
FLUID- because individual phospholipids and proteins can move side-to-side within the layer, like it's a liquid.

The fluidity of the membrane is aided by cholesterol wedged into the bilayer to help keep it liquid at lower temperatures.

MOSAIC- because of the pattern produced by the scattered protein molecules embedded in the phospholipids when the membrane is viewed from above.



Phospholipid bilayer (cross section)

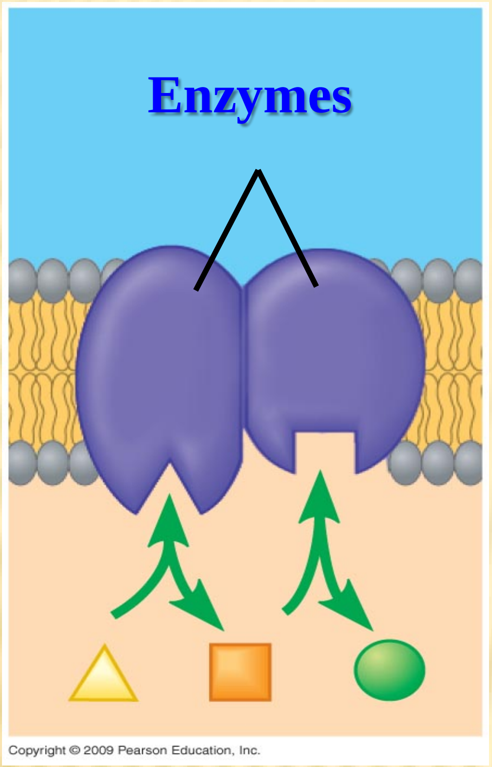


The fluid mosaic model for membranes

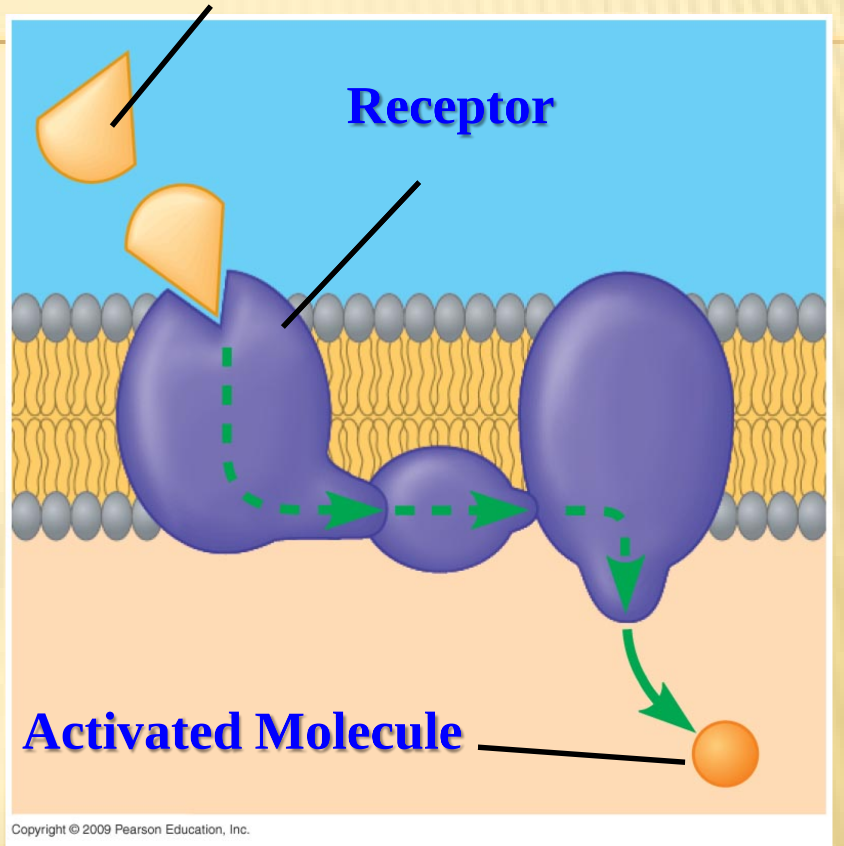
Functions of Plasma Membrane

Many membrane proteins function as

- **Enzymatic activity**
- **Transport**
- **Bind cells together (junctions)**
- **Protective barrier**
- **Regulate transport in & out of cell (selectively permeable)**
- **Allow cell recognition**
- **Signal transduction**



Enzyme activity



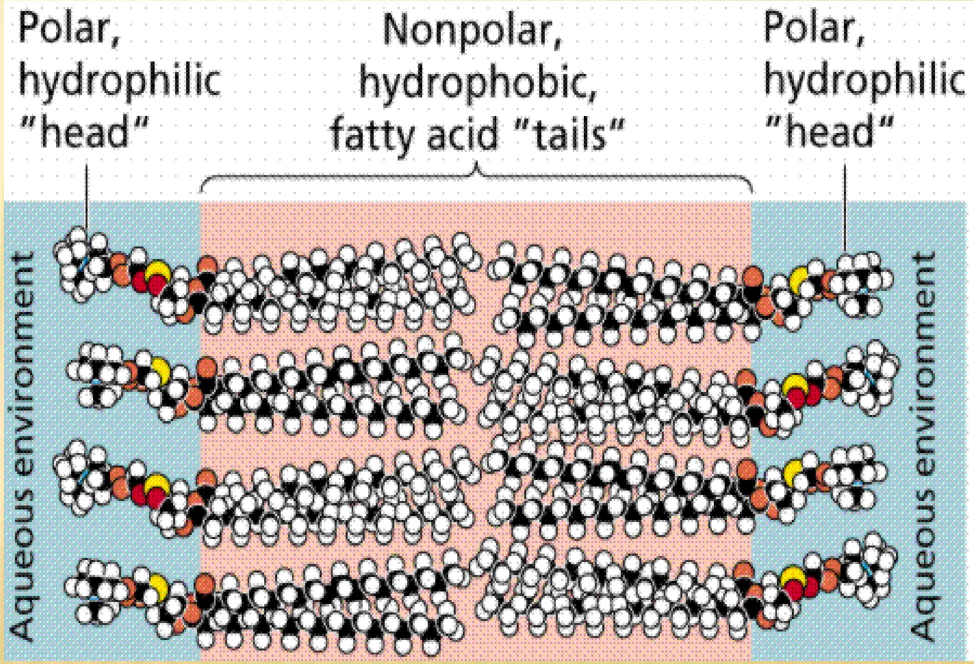
Signal transduction

Membranes are a fluid mosaic of phospholipids and proteins

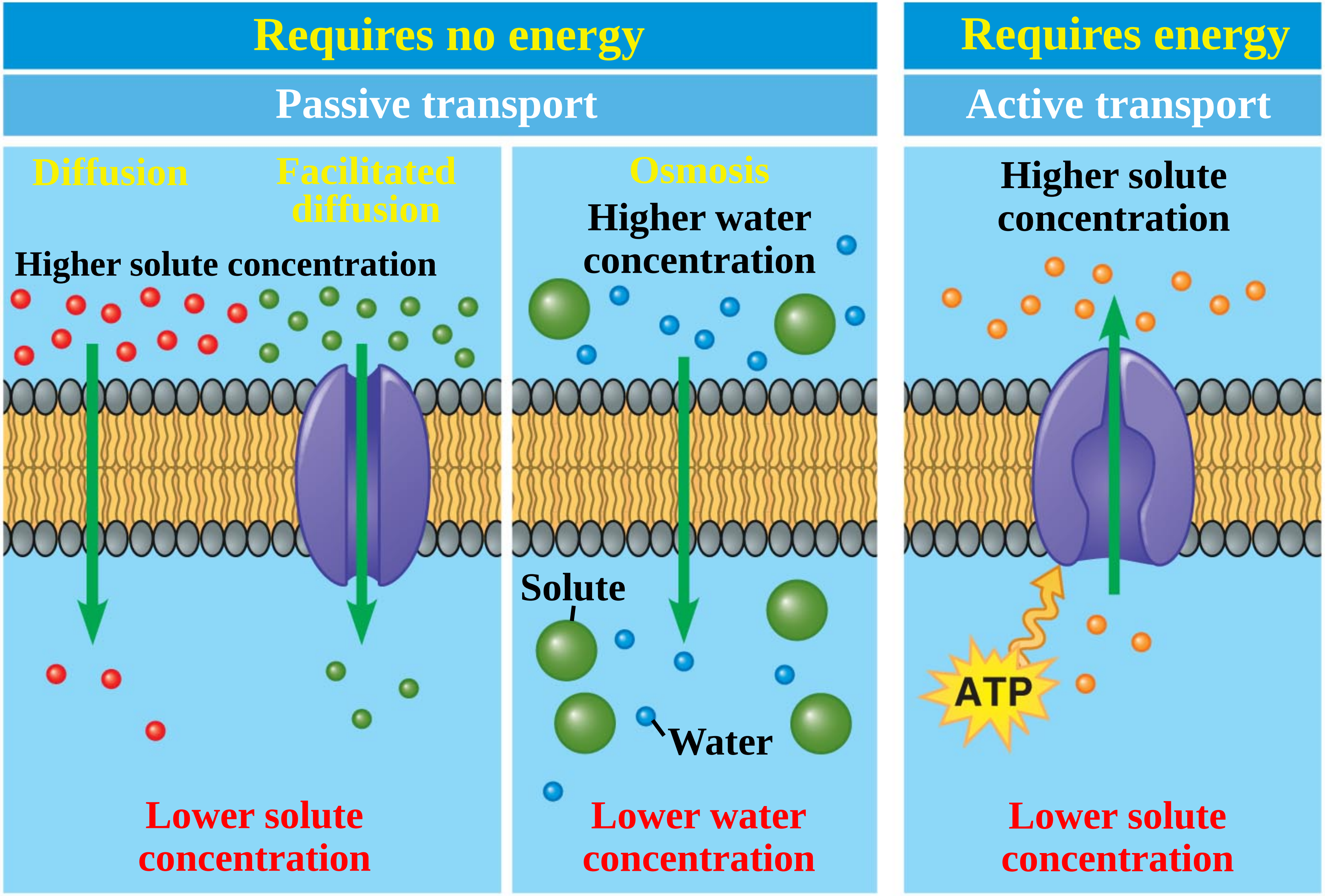
– Because membranes allow some substances to cross or be transported more easily than others, they exhibit selective permeability.

Nonpolar hydrophobic molecules, Materials that are soluble in lipids can pass through the cell membrane easily.

- Small molecules e.g. O_2, CO_2, H_2O move through easily.
- Ions , Polar hydrophilic molecules larger than water (glucose, other sugars and amino acids) do not cross easily on their own.



Types of Transport Across Cell Membranes

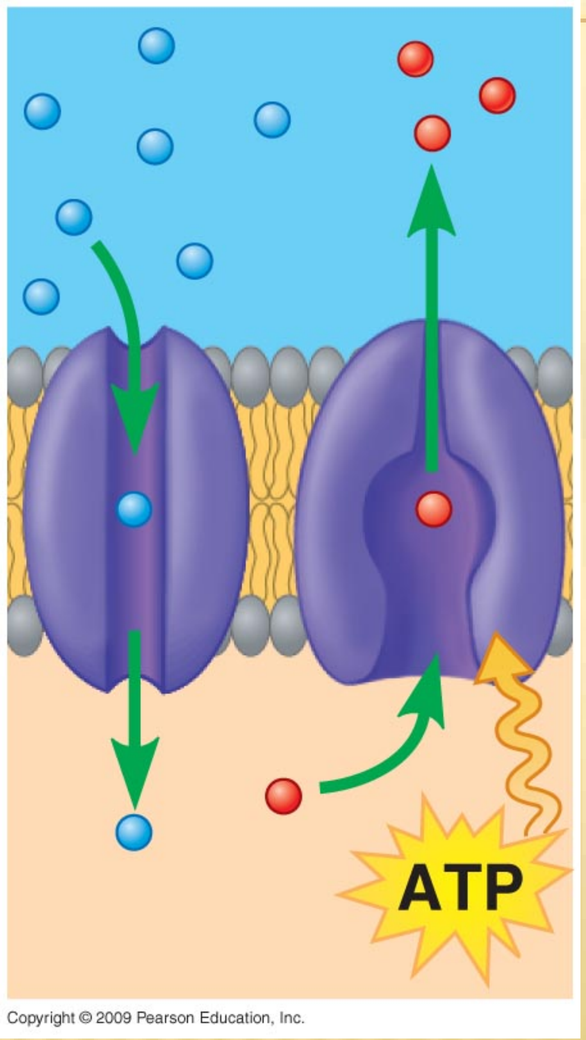

Requires no energy
Requires energy
Passive transport
Active transport
Diffusion
Facilitated diffusion
Higher solute concentration
Osmosis
Higher water concentration
Higher solute concentration
Solute
Water
ATP
Lower solute concentration
Lower water concentration
Lower solute concentration

Concentration Gradient

High
Concentration

Passive
Transport

From a region of
higher to lower
concentration



Active Transport
(against
concentration
gradient)

Low
Concentration

Transport

Passive transport is diffusion across a membrane with no energy investment

- **Diffusion** Net movement of substance down its concentration gradient
  - from region of greater concentration
  - to region of lower concentration
- Does not use direct metabolic energy
- Is a process in which particles spread out evenly in an available space

Passive transport is diffusion across a membrane with no energy investment

- This means that particles diffuse down their **concentration gradient**, molecules move because they have a natural **KINETIC ENERGY**

- Eventually, the particles reach **equilibrium** where the concentration of particles is the same throughout

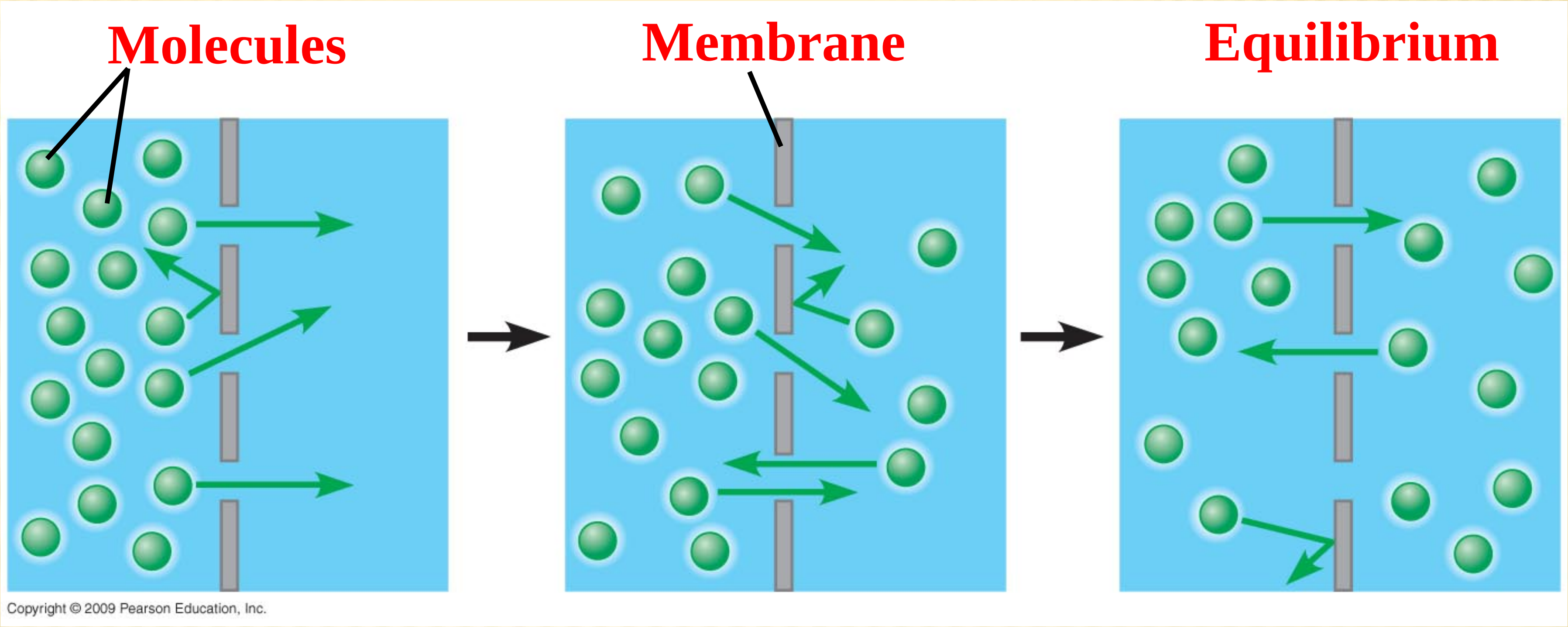
Passive transport is diffusion across a membrane with no energy investment

- **Passive transport**
- **Diffusion across a cell membrane does not require energy, so it is called passive transport**
  - **The concentration gradient itself represents potential energy for diffusion**
  - **Passive transport could be:**

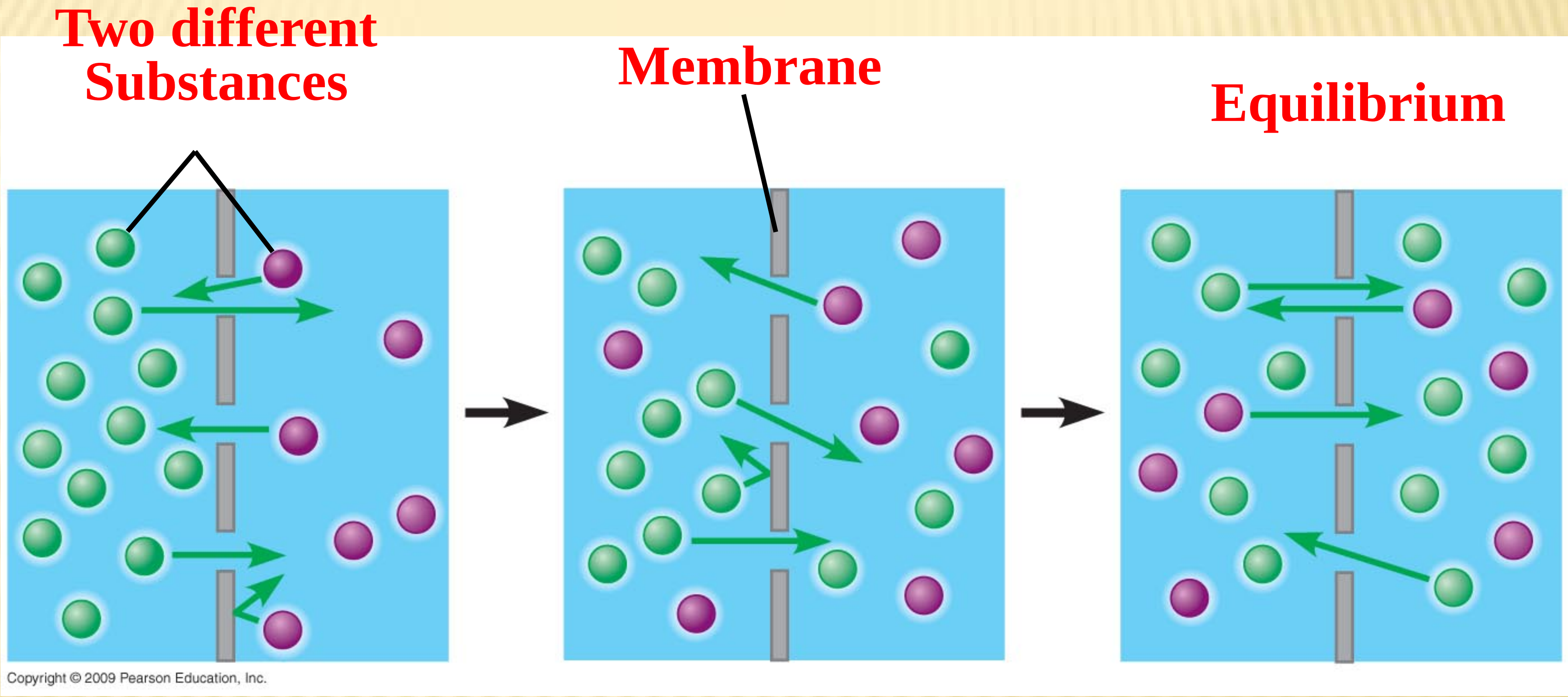
1) **Simple diffusion: Example: Oxygen or water diffusing into a cell and carbon dioxide diffusing out.**
2) **Facilitated diffusion: Uses transport proteins to move high to low concentration**

   Examples: Glucose or amino acids moving from blood into a cell

Passive transport (simple diffusion)

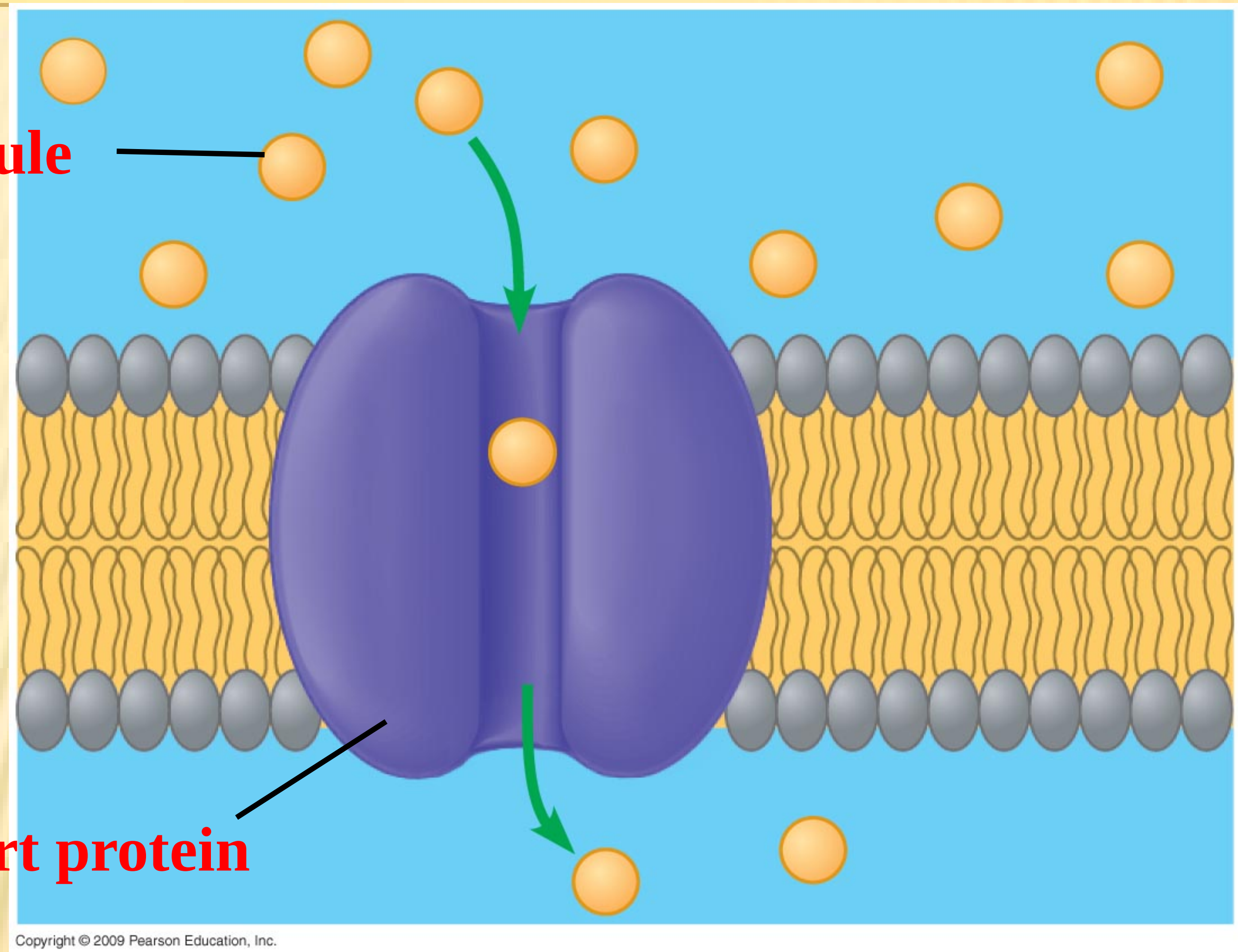


Passive transport of one type of molecule

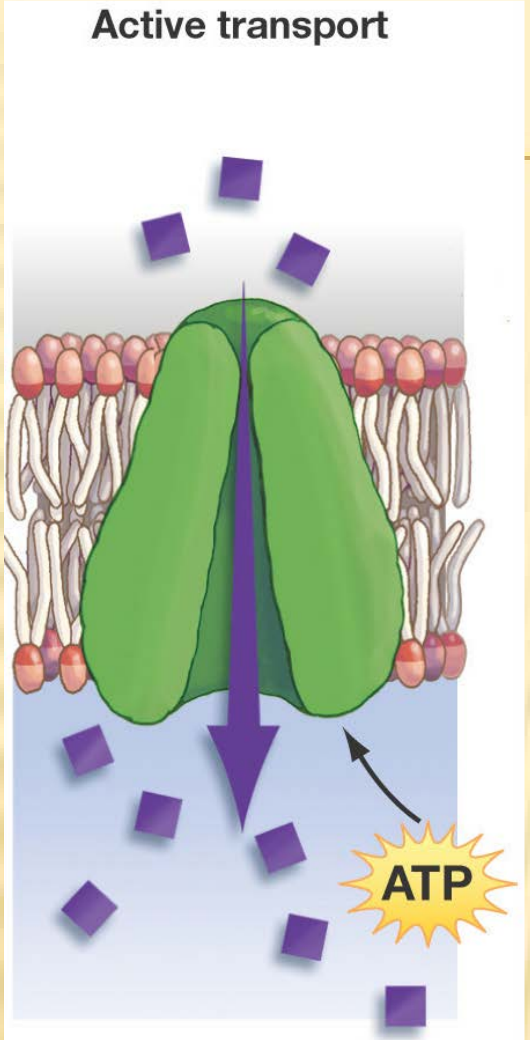


Passive transport of two types of molecules

Passive transport Facilitated diffusion



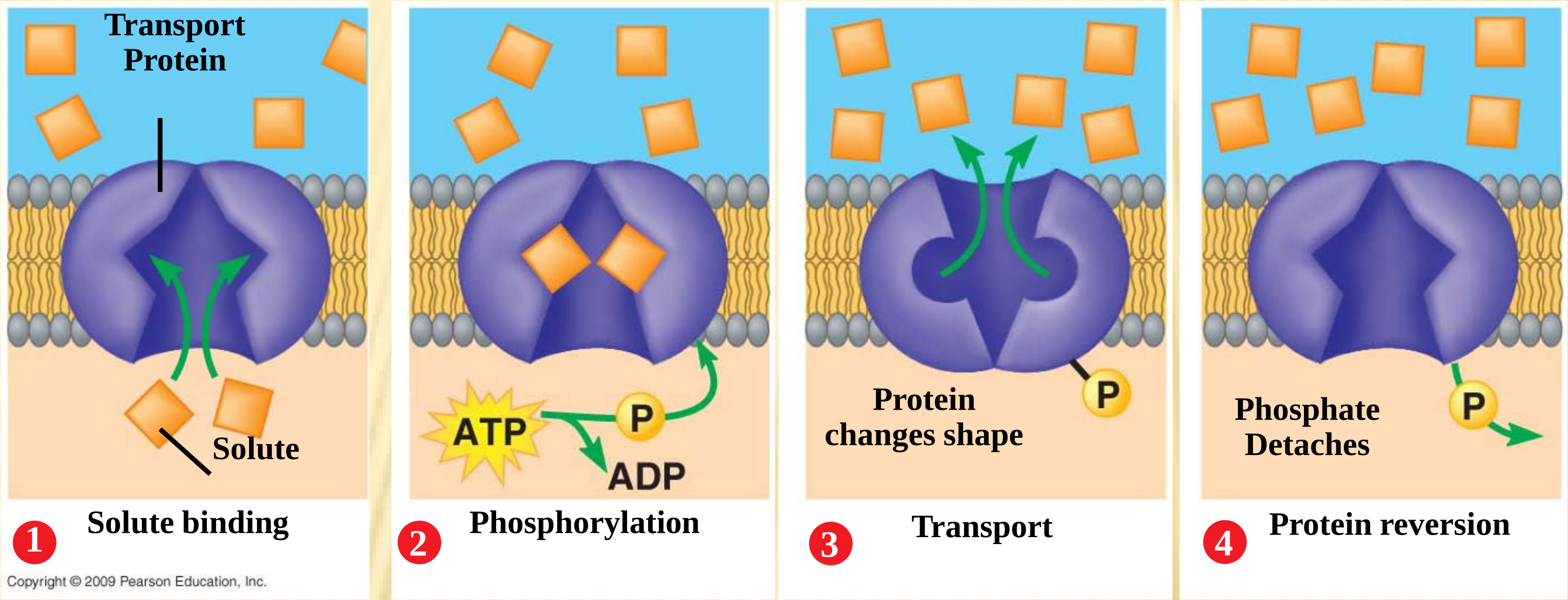
Transport protein providing a channel for the diffusion of a specific solute across a membrane



Molecules again move through a transport protein, but now energy must be expended to move them against their concentration gradient.

Active Transport

- ❖ **Requires energy or ATP**
- ❖ **Moves solute from LOW to HIGH concentration AGAINST concentration gradient.**
- ❖ **The mechanism alters the shape of the membrane protein through phosphorylation using ATP.**



Active transport of a solute across a membrane

Moving the "Big Stuff"

Exocytosis and endocytosis transport large molecules across membranes

- A cell uses two mechanisms for moving large molecules across membranes
  - Exocytosis is used to export bulky molecules, such as proteins or polysaccharides
  - Endocytosis is used to import substances useful to the livelihood of the cell
- In both cases, material to be transported is packaged within a vesicle that fuses with the membrane

- **There are three kinds of endocytosis**

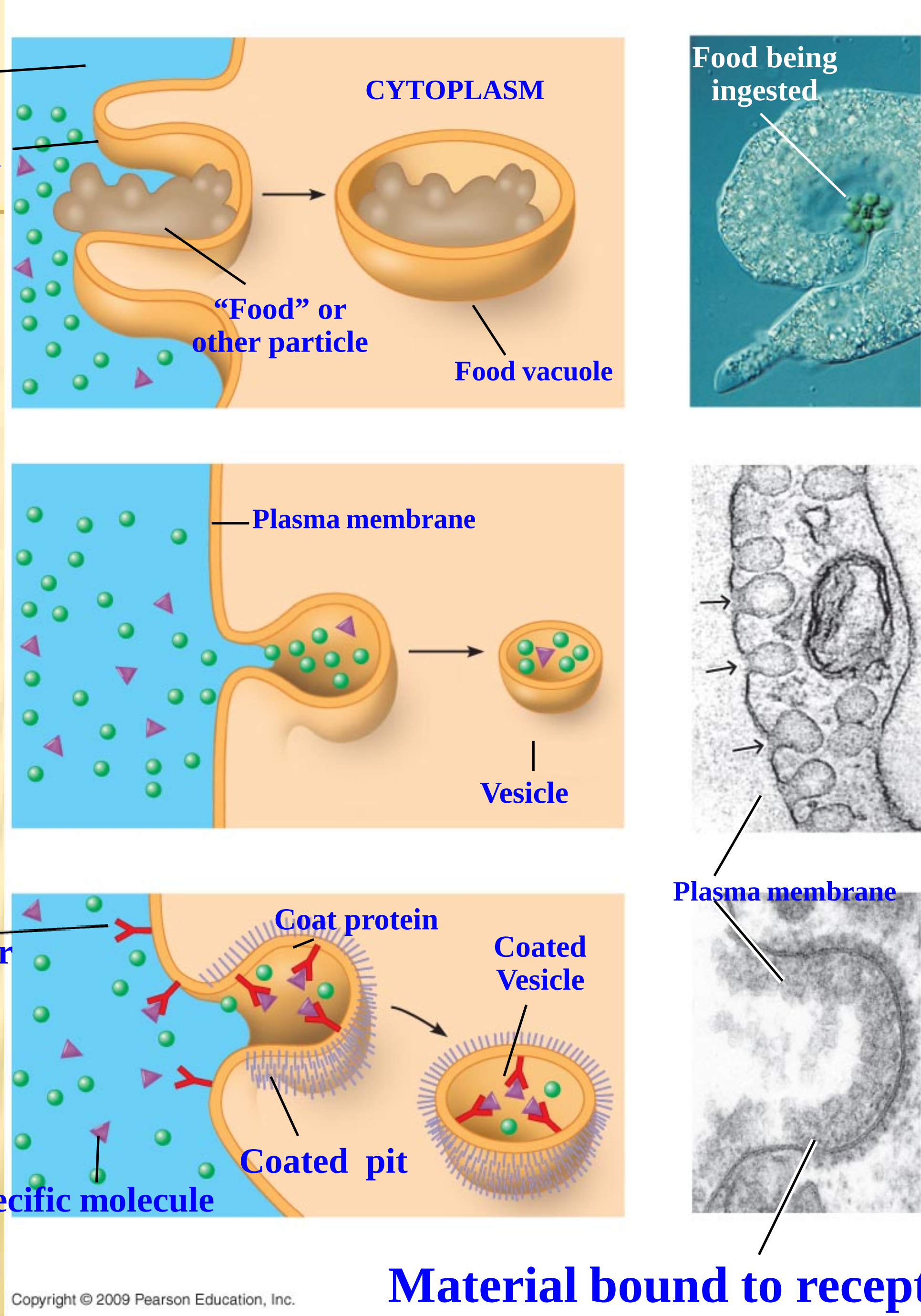
1. **Phagocytosis is the engulfment of a particle by wrapping cell membrane around it, forming a vacuole**
2. **Pinocytosis is the same thing except that fluids are taken into small vesicles**
3. **Receptor-mediated endocytosis is where receptors in a receptor-coated pit interact with a specific protein, initiating formation of a vesicle**

Three kinds of endocytosis

EXTRACELLULAR FLUID

Pseudopodium

Receptor



Phagocytosis

Pinocytosis

Receptor-mediated endoytosis

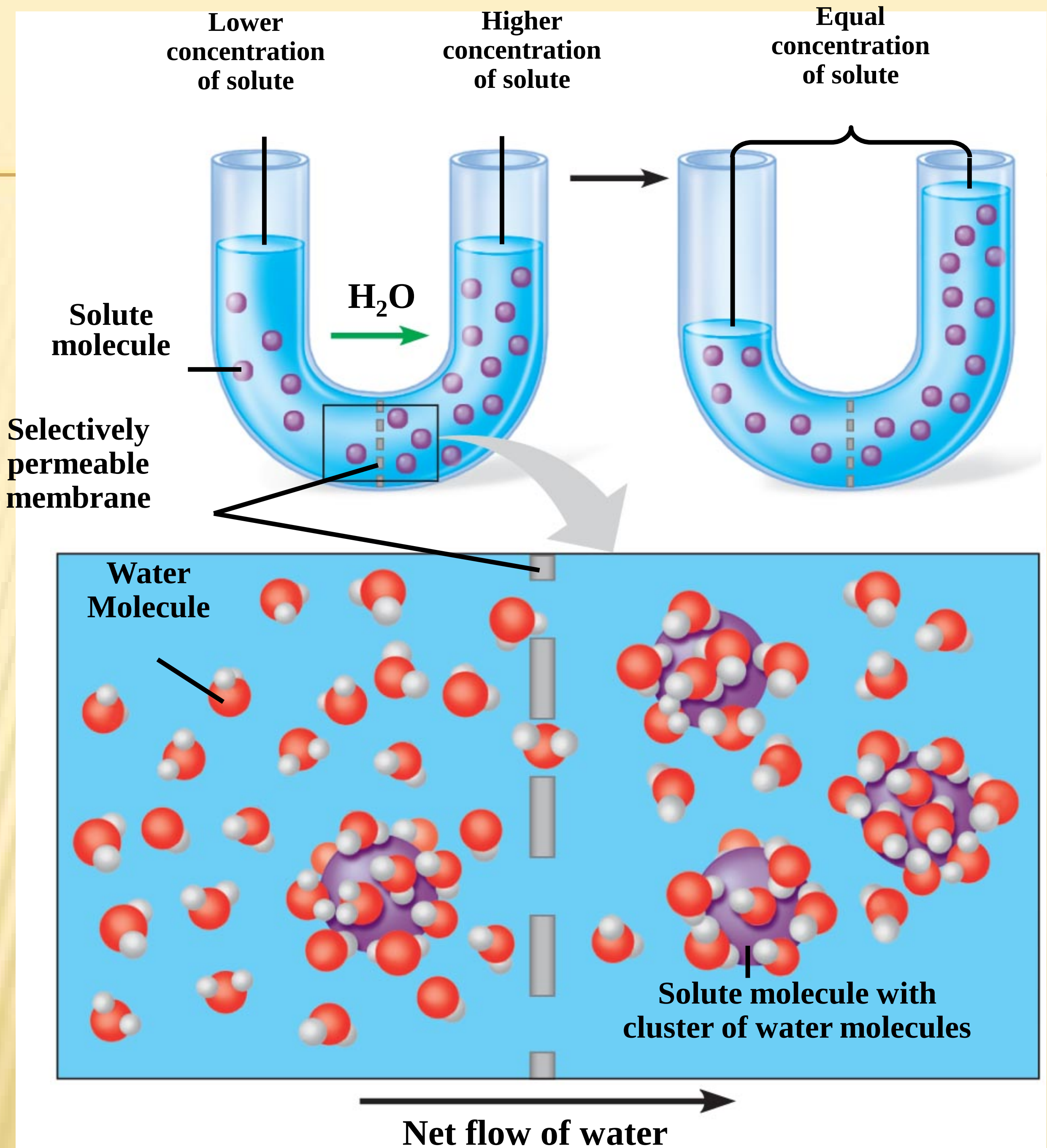
Material bound to receptor proteins

Osmosis: Osmosis is the **diffusion of water across a membrane**

- **Osmosis will move water across a membrane down its concentration gradient until the concentration of solute is equal on both sides of the membrane (equilibrium).**

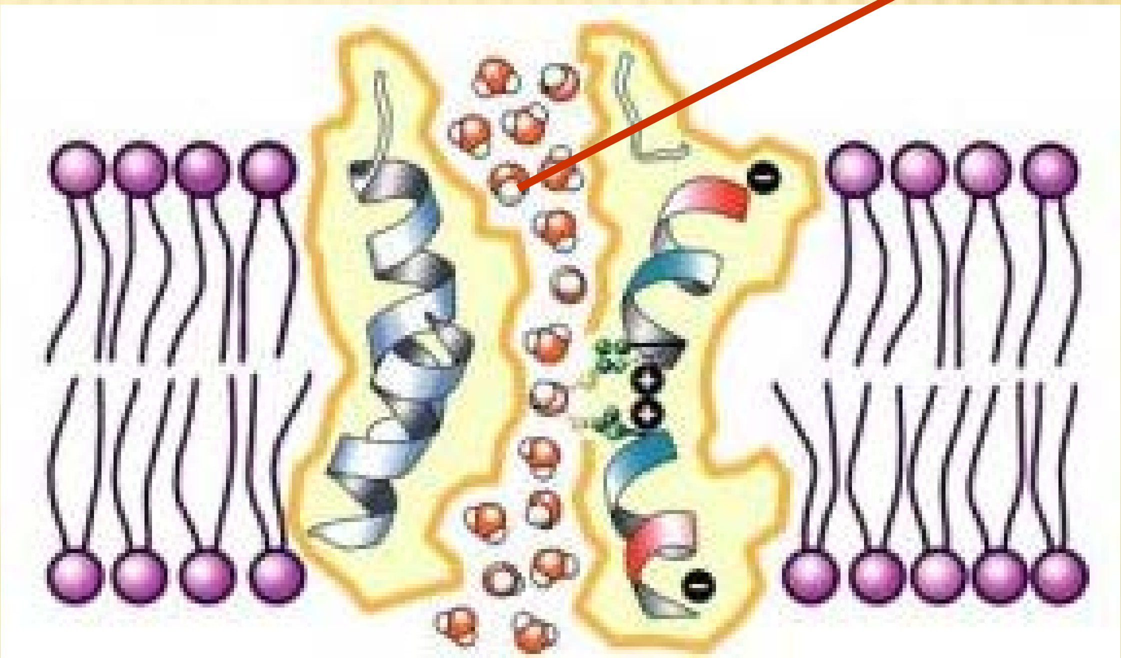
- **Moves from HIGH water potential (low solute) to LOW water potential (high solute)**

Osmosis, **the diffusion of water across a membrane**



Aquaporins

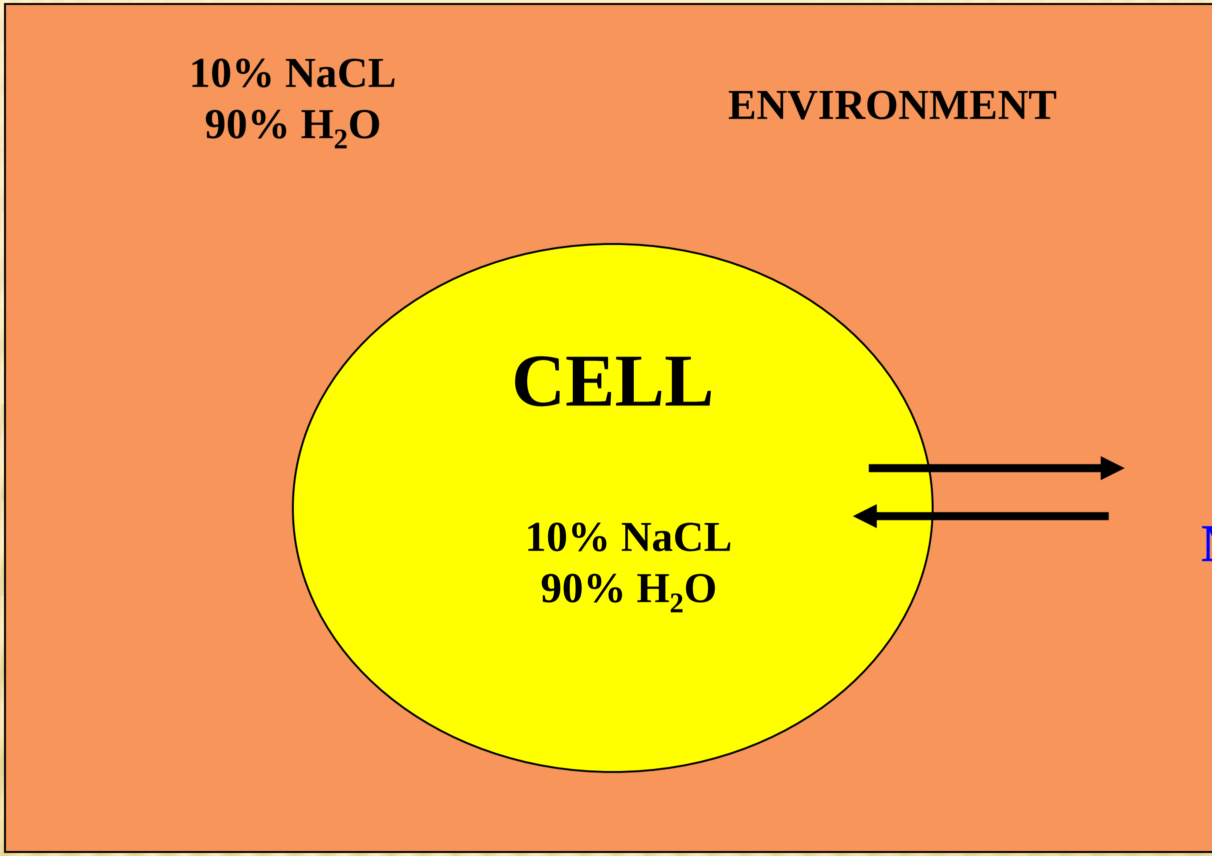
- **Water Channels**
- **Protein pores used during OSMOSIS**



Water balance between cells and their surroundings is crucial to organisms

- **Tonicity** is a term that describes the ability of a solution to cause a cell to gain or lose water
  - Tonicity is dependent on the concentration of a non-penetrating solute on both sides of the membrane
    - **Isotonic** indicates that the concentration of a solute is the same on both sides
    - **Hypertonic** indicates that the concentration of solute is higher **outside** the cell
    - **Hypotonic** indicates a higher concentration of solute **inside** the cell

Cell in Isotonic Solution

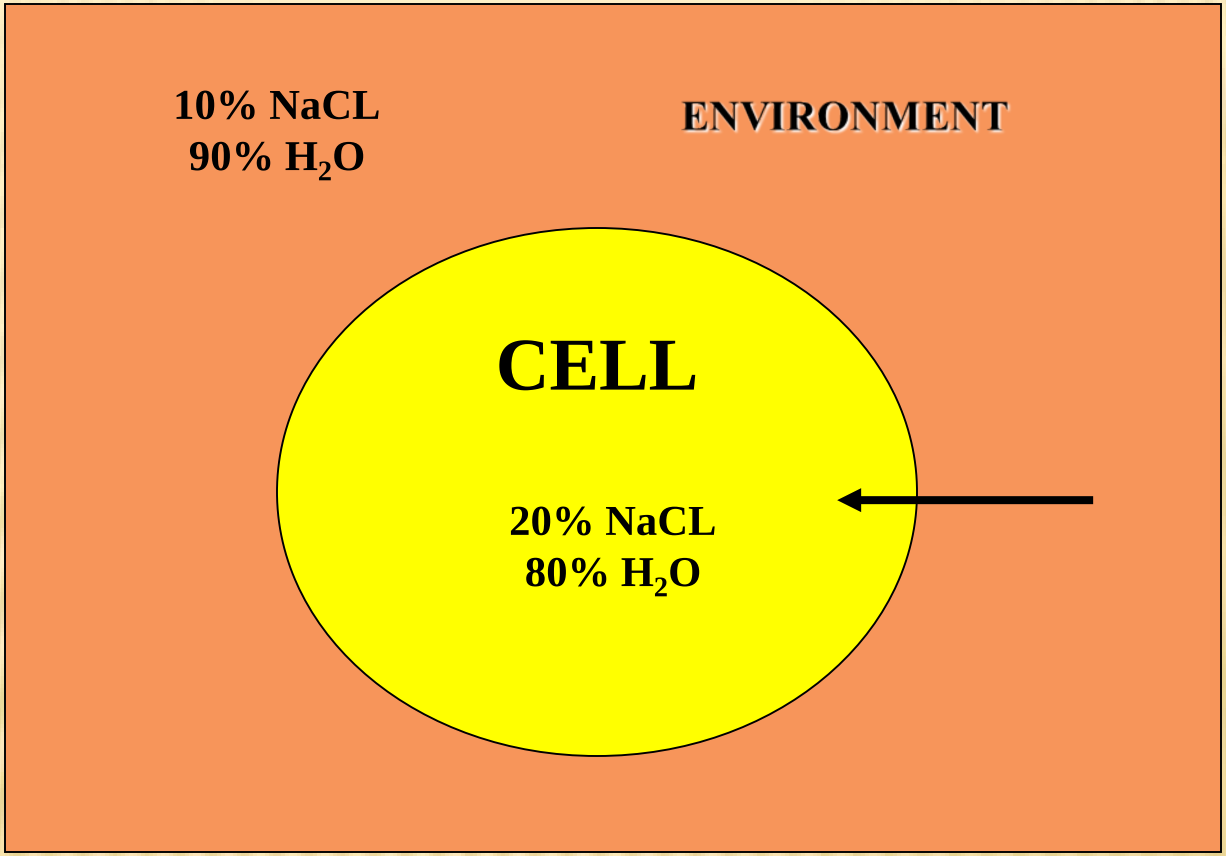


NO NET MOVEMENT

What is the direction of water movement?

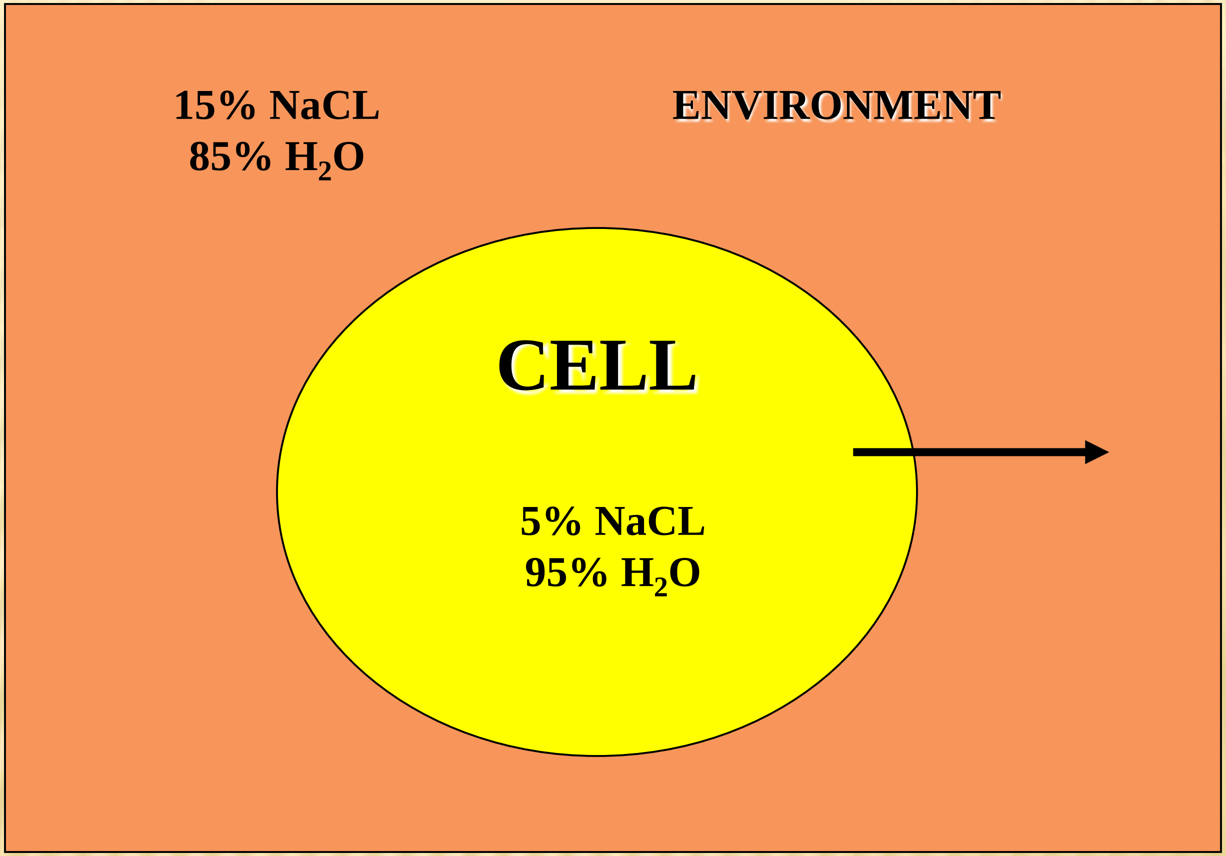
The cell is at ___equilibrium___.

Cell in Hypotonic Solution

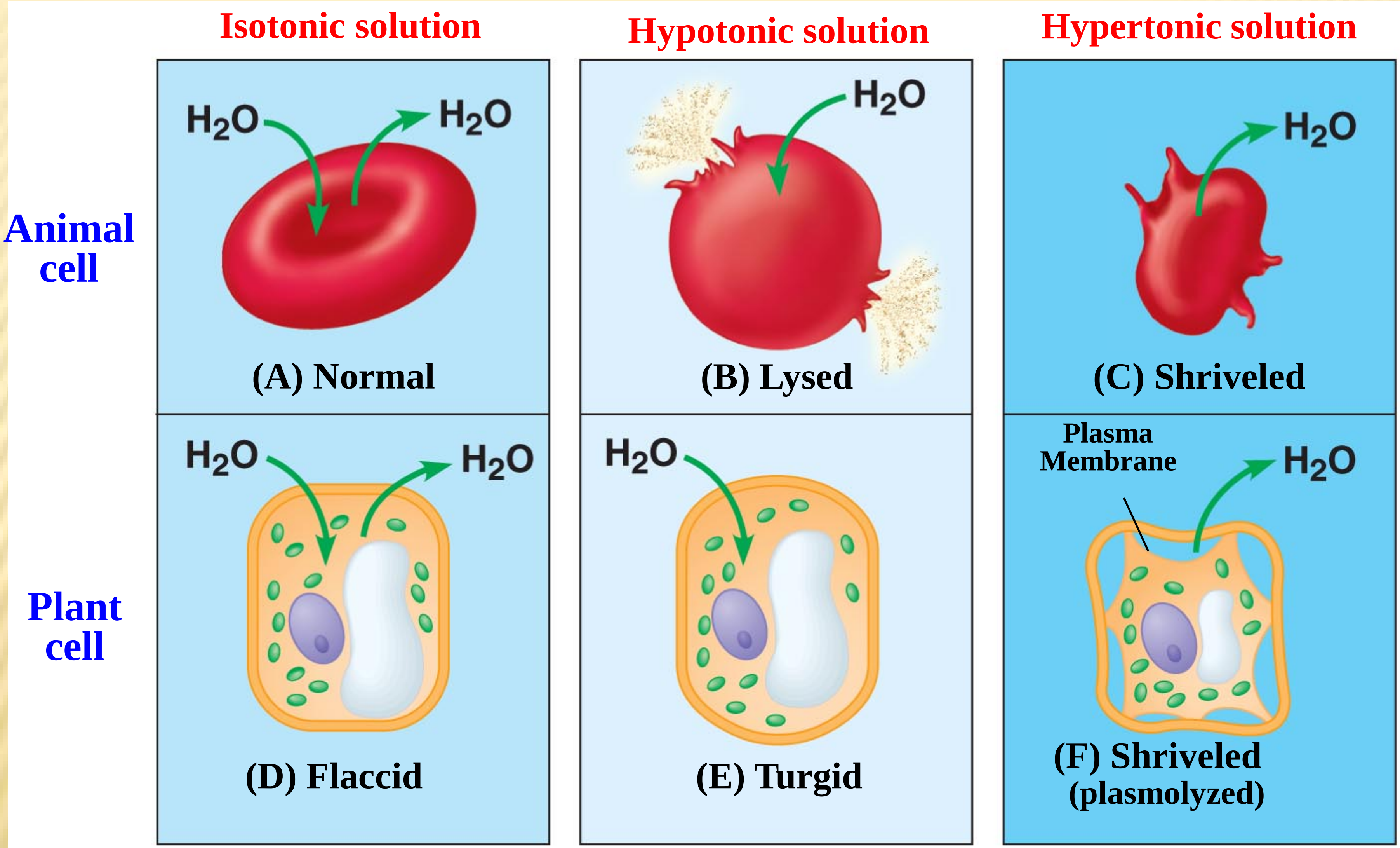


What is the direction of water movement?

Cell in Hypertonic Solution



What is the direction of water movement?



How animal and plant cells behave in different solutions

ENERGY AND THE CELL

Cells transform energy as they perform work

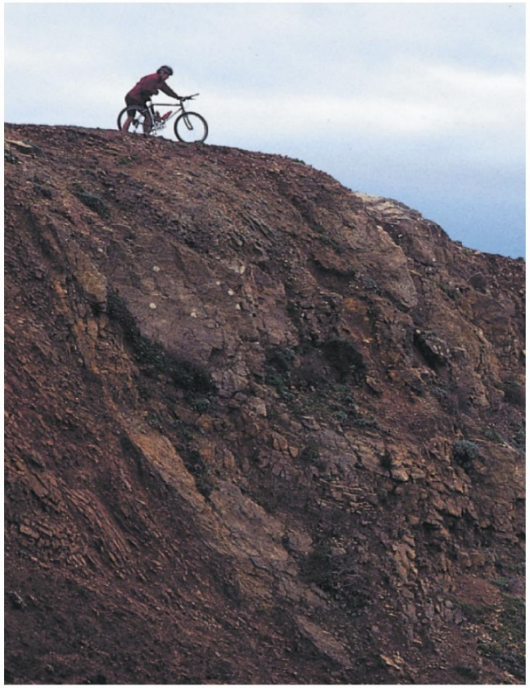
- **Cells are small units, a chemical factory, housing thousands of chemical reactions**
  - **The result of reactions is maintenance of the cell, manufacture of cellular parts and replication**

- **Energy is the capacity to do work and cause change**
  - **There are two kinds of energy**

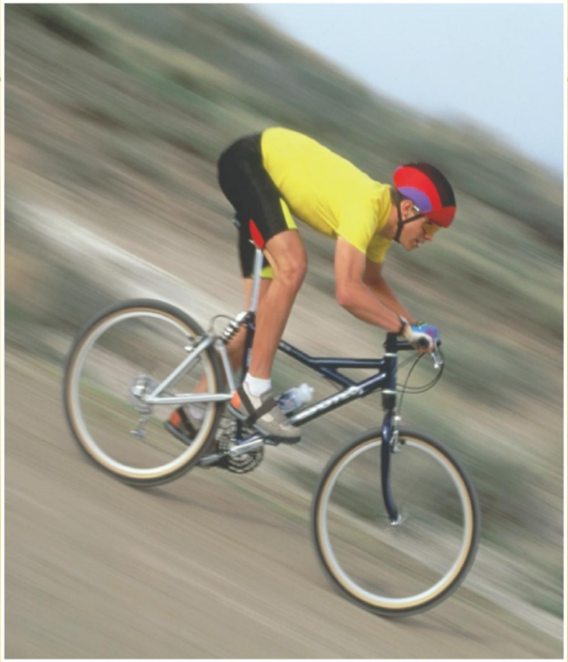
    A. **Kinetic energy is the energy of motion, Heat and light energy are examples**

    B. **Potential energy is energy that an object possesses as a result of its position , includes energy stored in chemical bonds**

Kinetic energy,
the energy of motion



Potential energy,
stored energy as
a result of location
or structure

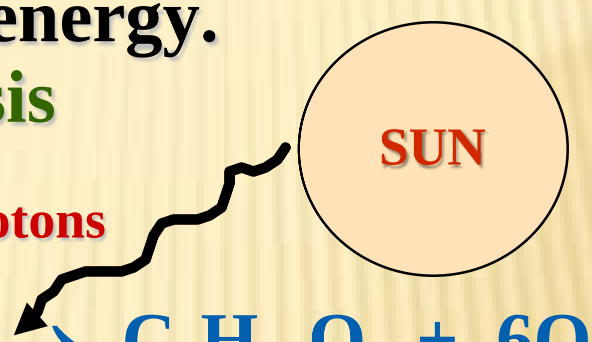


Potential energy being
converted to kinetic
energy

Two Types of Energy Reactions

1.Endergonic Reactions: **Chemical reaction that requires a net input of energy.**

Example: Photosynthesis



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

(glucose)

2.Exergonic Reactions:

Chemical reactions that releases energy

Example: Cellular Respiration

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

Metabolic Reactions of Cells

What is Metabolism?

- The **sum total** of the **chemical activities** of all **cells**.

- *Two Types of Metabolism*

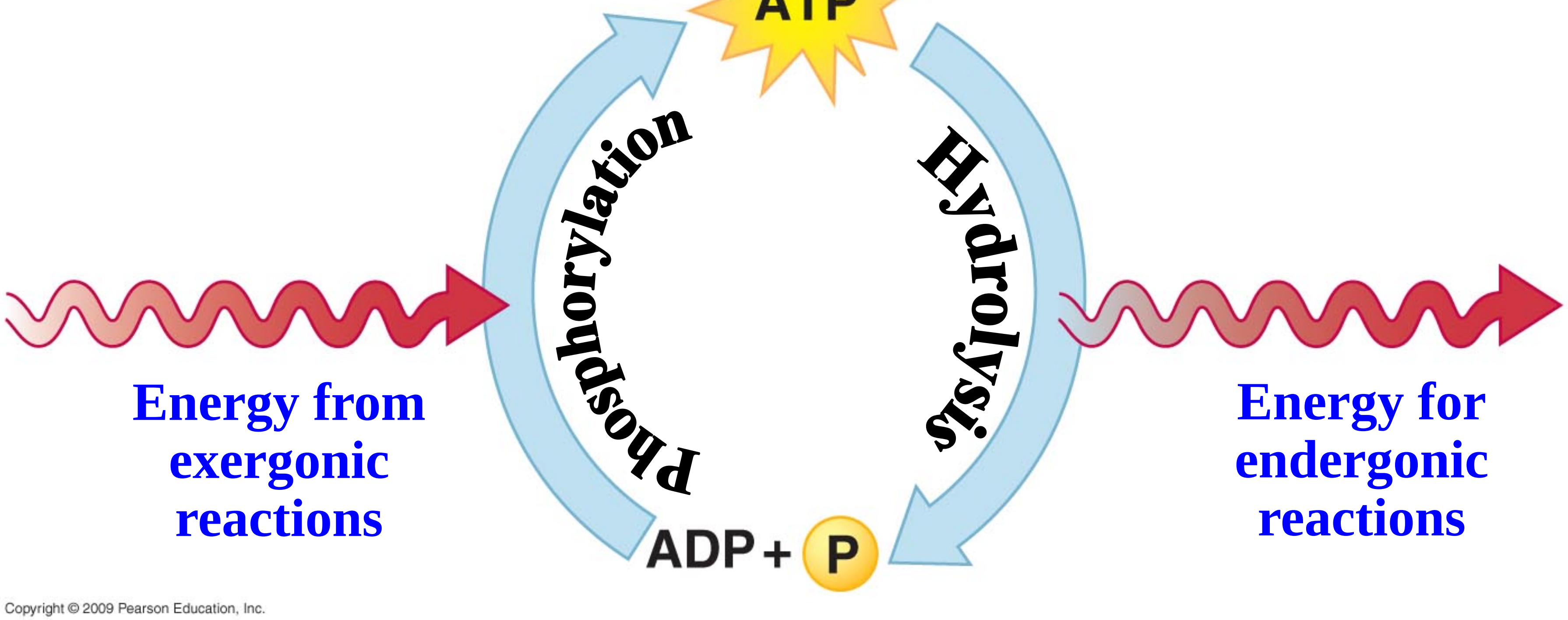
1) **Anabolic Pathways. Metabolic reactions, which consume energy (endergonic), to build complicated molecules from simpler compounds.**

2) **Catabolic Pathways. Metabolic reactions which release energy (exergonic) by breaking down complex molecules in simpler compounds**

Chemical reactions either release or store energy

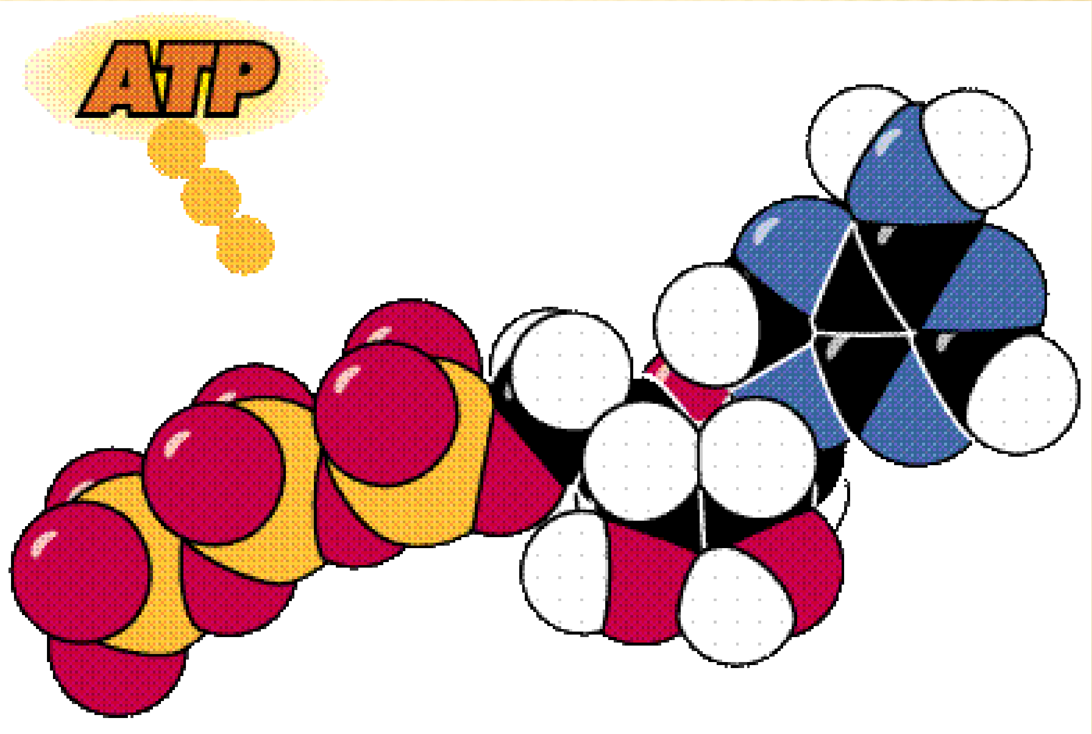
- A cell does three main types of cellular work
  - Chemical work — driving endergonic reactions
  - Transport work — pumping substances across membranes
  - Mechanical work — beating of cilia
- To accomplish work, a cell must manage its energy resources, and it does so by energy coupling — the use of exergonic processes to drive an endergonic one

Phosphorylation is the addition of a phosphate (PO_4^{3-}) group to a protein



The ATP cycle

Cellular Energy - ATP

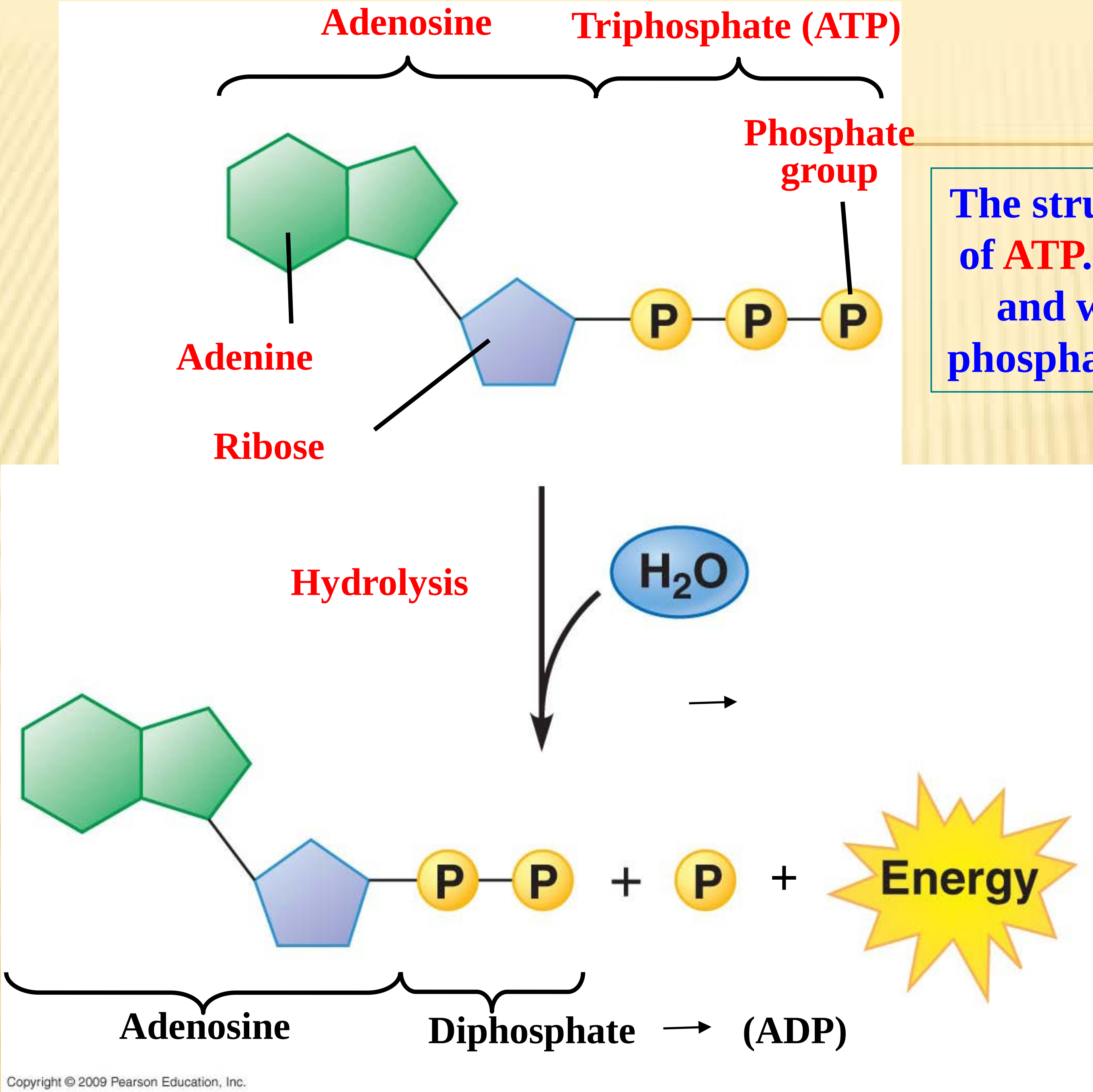


ATP shuttles chemical energy and drives cellular work

- **ATP, adenosine triphosphate, is the energy currency of cells.**
  - **ATP is the immediate source of energy that powers most forms of cellular work.**
  - **It is composed of adenine (a nitrogenous base), ribose (a five-carbon sugar), and three phosphate groups.**

ATP shuttles chemical energy and drives cellular work

- **Hydrolysis of ATP releases energy by transferring its third phosphate from ATP to some other molecule**
  - **The transfer is called phosphorylation**
  - **In the process, ATP energizes molecules**



The structure and hydrolysis of ATP. The reaction of ATP and water yields ADP, a phosphate group, and energy

Enzymes speed up the cell's chemical reactions

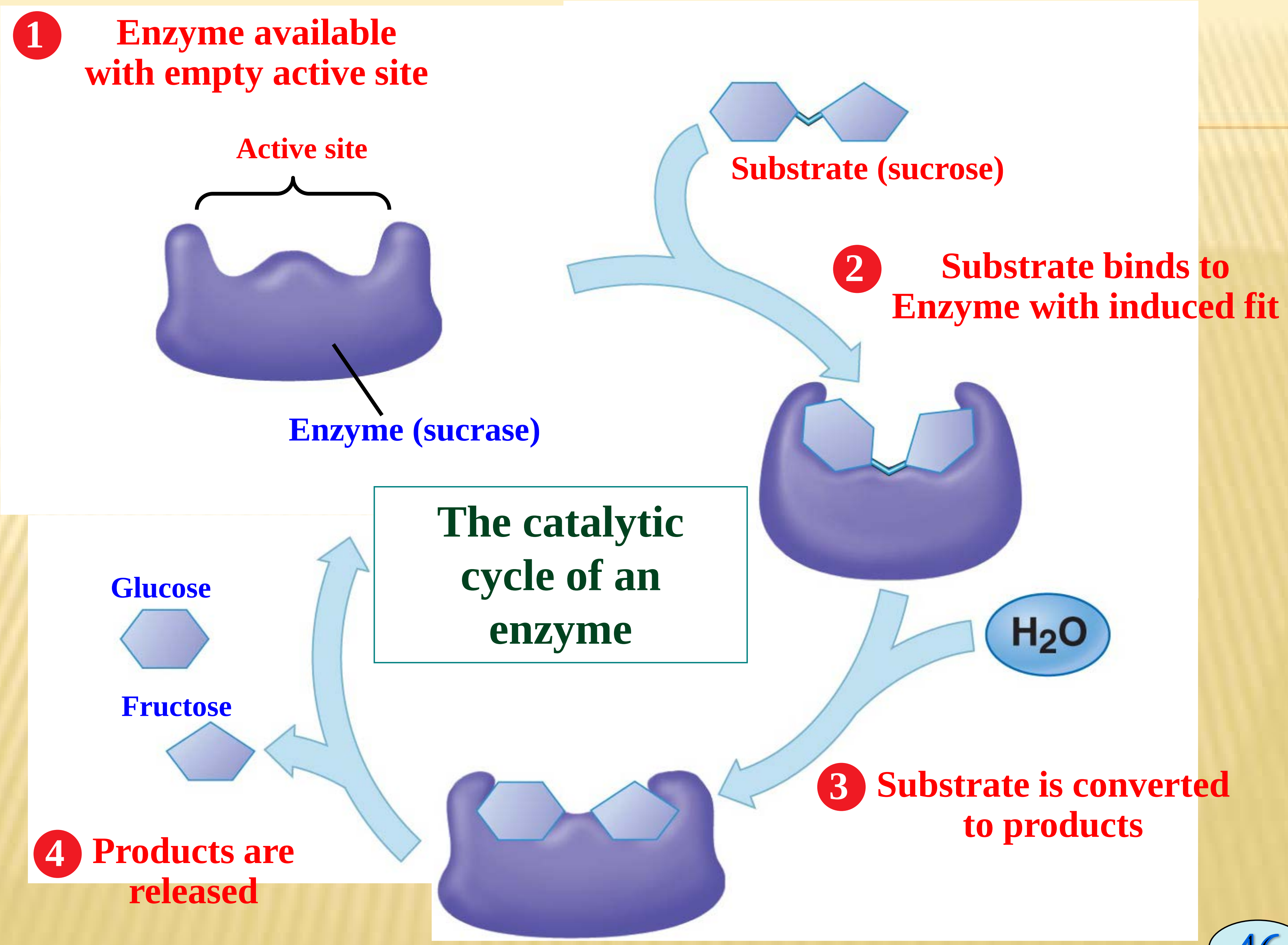
- **The cell uses catalysis to drive (speed up) biological reactions**
  - **Catalysis is accomplished by enzymes, which are proteins that function as biological catalysts**
- **Enzyme increases speed of a chemical reaction without being consumed**
  - **Each enzyme is specific, has a particular target molecule called the substrate**

A specific enzyme catalyzes each cellular reaction

- **Enzymes have unique three-dimensional shapes**

The shape is critical to their role as biological catalysts.

- **As a result of its shape, the enzyme has an active site where the enzyme interacts with the enzyme's substrate.**
- **Consequently, the substrate's chemistry is altered to form the product of the enzyme reaction.**


1 Enzyme available with empty active site
Active site
Enzyme (sucrase)
Substrate (sucrose)
2 Substrate binds to Enzyme with induced fit
The catalytic cycle of an enzyme
H2O
3 Substrate is converted to products
Glucose
Fructose
4 Products are released

A specific enzyme catalyzes each cellular reaction

- For optimum activity, enzymes require certain environmental conditions
  - Temperature is very important, and optimally, human enzymes function best at 37ºC, or body temperature
  - High temperature will denature human enzymes
  - Enzymes also require a pH around neutrality for best results

Enzymes helpers

- **Some enzymes require non-protein helpers**
  - **Cofactors are inorganic, such as zinc, iron, or copper**
  - **Coenzymes are organic molecules and are often vitamins**

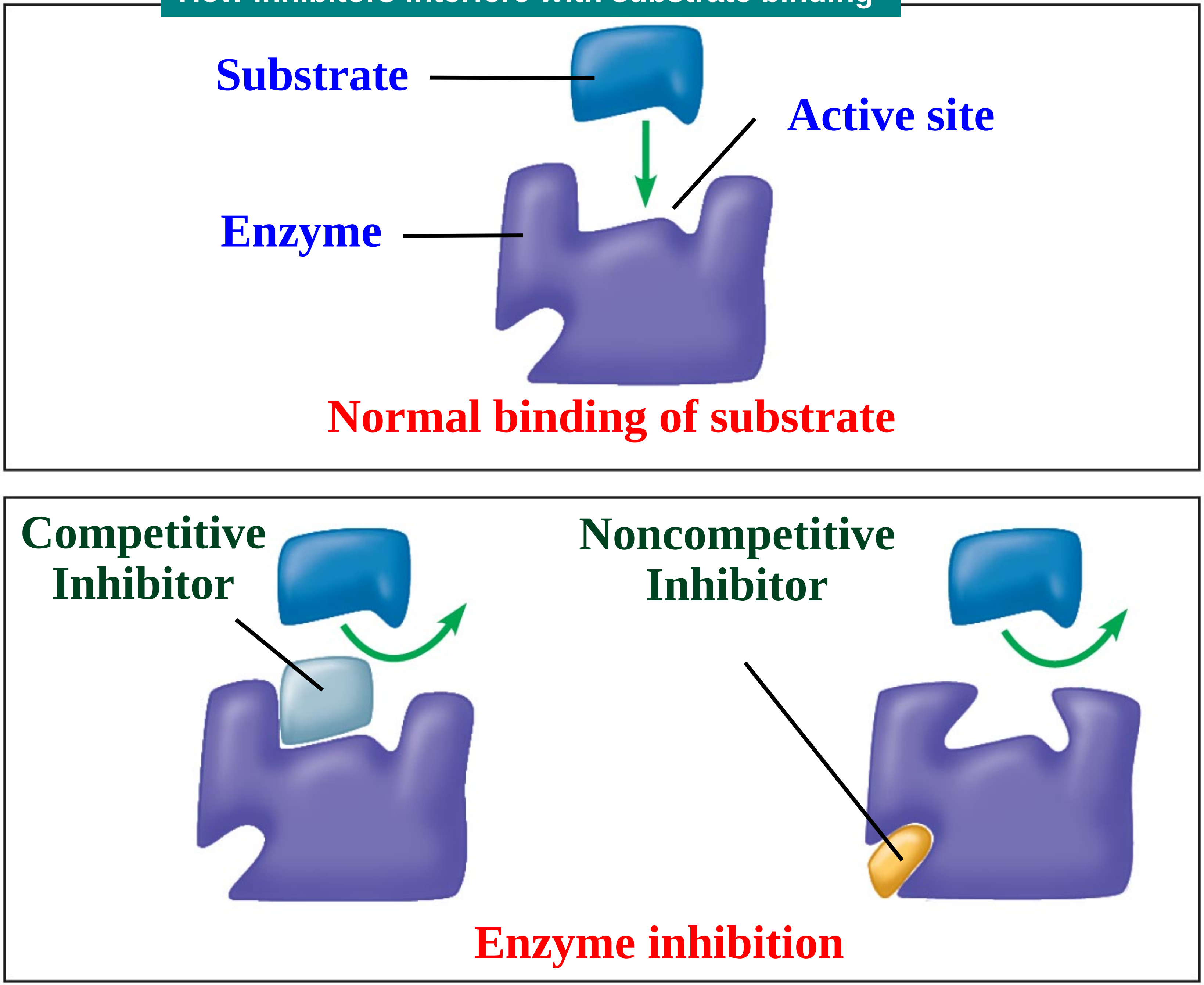
Competitive Inhibitors

- **Inhibitors are chemicals that inhibit an enzyme's activity**
  - **One group inhibits because they compete for the enzyme's active site and thus block substrates from entering the active site**
  - **These are called competitive inhibitors**

Noncompetitive Inhibitors

- Other inhibitors do not act directly with the active site
  - These bind somewhere else and change the shape of the enzyme so that the substrate will no longer fit the active site
  - These are called noncompetitive inhibitors

How inhibitors interfere with substrate binding



Enzyme inhibitors

- Enzyme inhibitors are important in regulating cell metabolism
  - Often the product of a metabolic pathway can serve as an inhibitor of one enzyme in the pathway, a mechanism called **feedback inhibition**
  - The more product formed, the greater the inhibition, and in this way, regulation of the pathway is accomplished

How Cells Harvest Chemical Energy

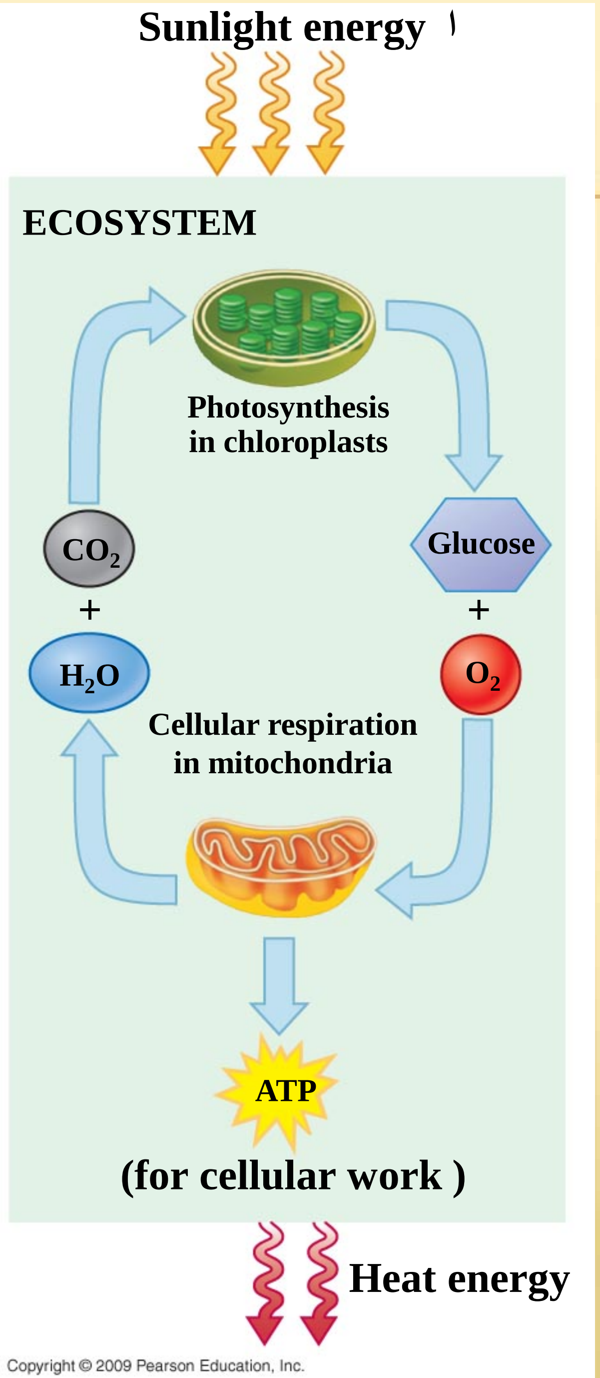
Harvest chemical energy (ATP)

- Energy is necessary for life processes. These include growth, transport, manufacture, movement, reproduction, and others.
- Energy that supports life on Earth is captured from sun rays reaching Earth through plant, algae, protist, and bacterial photosynthesis.
- All of our cells harvest chemical energy (ATP) from our food by a process called cellular respiration

Photosynthesis and cellular respiration provide energy for life

- Energy in sunlight is used in photosynthesis to make glucose from CO_2 and H_2O with release of O_2
- Other organisms use the O_2 and energy in sugar and release CO_2 and H_2O (cellular respiration)
- Together, these two processes are responsible for the majority of life on Earth

The connection between photosynthesis and cellular respiration

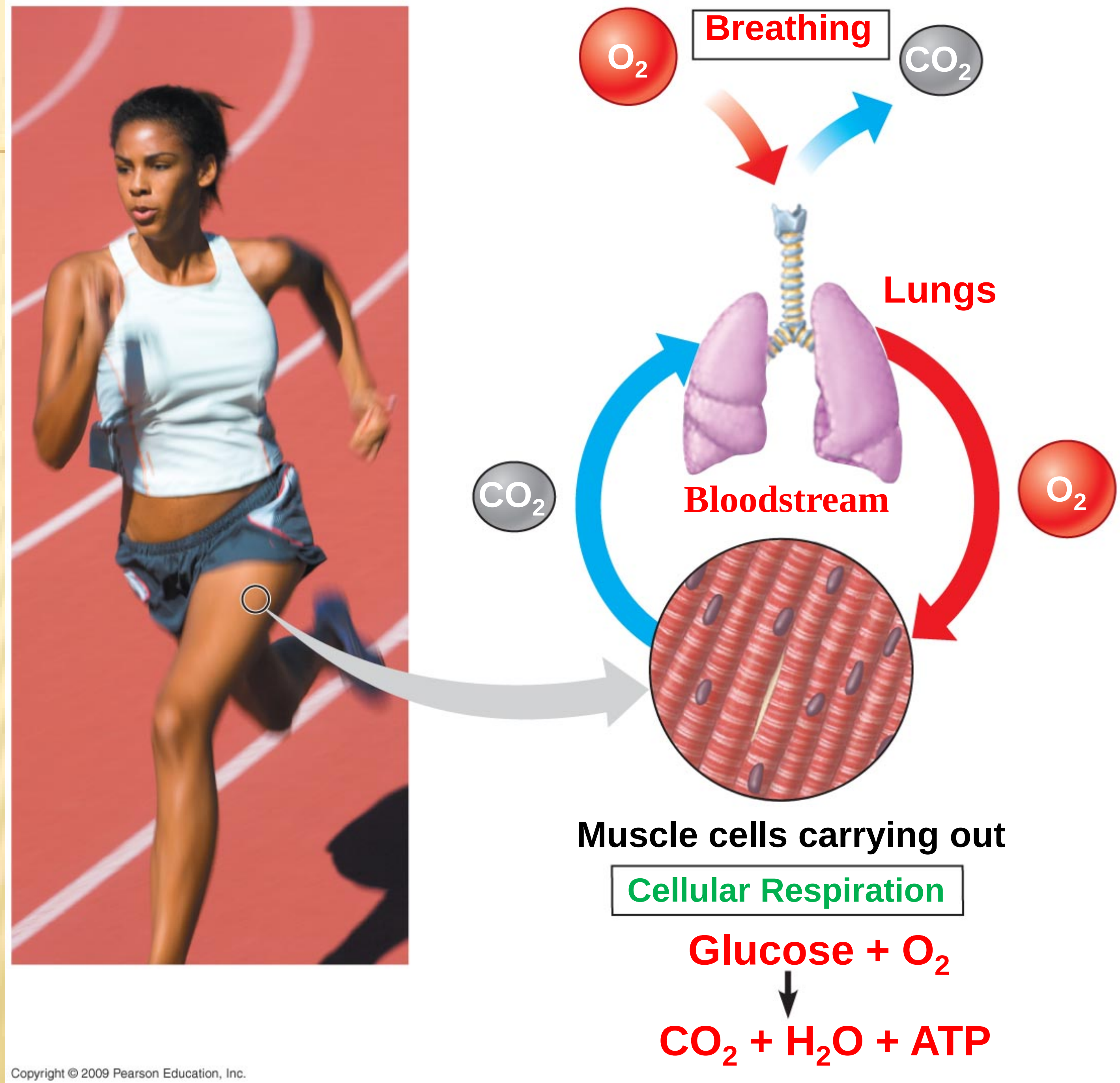


INTRODUCTION TO CELLULAR RESPIRATION

Breathing supplies oxygen to our cells for use in cellular respiration and removes carbon dioxide

- **Breathing and cellular respiration are closely related**
  - **Breathing** is necessary for exchange of CO_2 produced during cellular respiration for atmospheric O_2
  - **Cellular respiration** uses O_2 to help harvest energy from glucose and produces CO_2 in the process

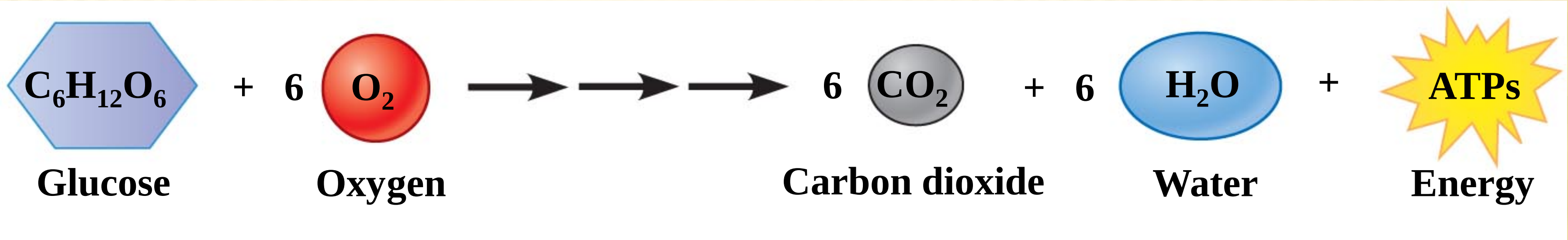
The connection between breathing and cellular respiration



Cellular respiration banks energy in ATP molecules

- **Cellular respiration is an exergonic process that transfers energy stored in glucose bonds to ATP**
  - **Cellular respiration produces 38 ATP molecules from each glucose molecule**
  - **Other foods (protein and lipid) can be used as a source of energy as well**

Summary equation for cellular respiration



How do cells extract energy in chemical bonds in the organic molecules (food)

How do cells extract energy in chemical bonds in organic molecules

- **The energy necessary for life is contained in the arrangement of electrons in chemical bonds in organic molecules**
- **When the carbon-hydrogen bonds of glucose are broken, electrons are transferred to oxygen**
  - **Oxygen has a strong tendency to attract electrons**

How do cells extract energy in chemical bonds in organic molecules

- **A cellular respiration equation is helpful to show the changes in hydrogen atom distribution**
  - **Glucose loses its hydrogen atoms and is ultimately converted to CO_2**
  - **At the same time, O_2 gains hydrogen atoms and is converted to H_2O**
    - **Loss of electrons is called oxidation**
    - **Gain of electrons is called reduction**

Rearrangement of hydrogen atoms (with their electrons) in the redox reactions (Reduction & Oxidation) of cellular respiration

Loss of hydrogen atoms (oxidation)

$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O + \text{Energy}$$

Glucose

(38 ATP)

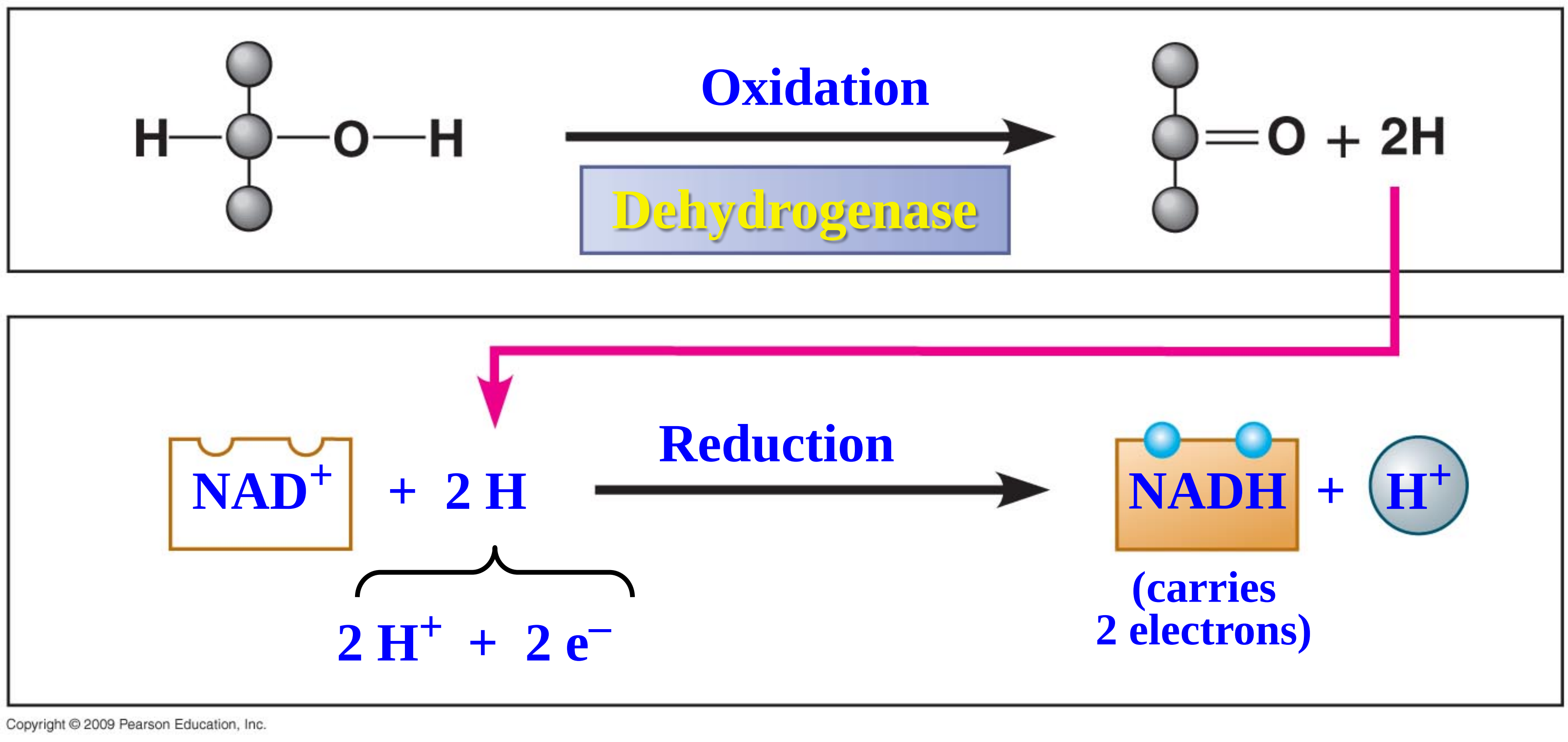
Gain of hydrogen atoms (reduction)

Redox (Reduction & Oxidation) reactions

How do cells extract energy in chemical bonds in organic molecules

- **Enzymes are necessary to oxidize glucose and other foods**
  - **The enzyme that removes hydrogen from an organic molecule is called dehydrogenase**
  - **Dehydrogenase requires a coenzyme called NAD^+ (nicotinamide adenine dinucleotide) to shuttle electrons**
  - **NAD^+ can become reduced when it accepts electrons and oxidized when it gives them up**

A pair of redox reactions, occurring simultaneously

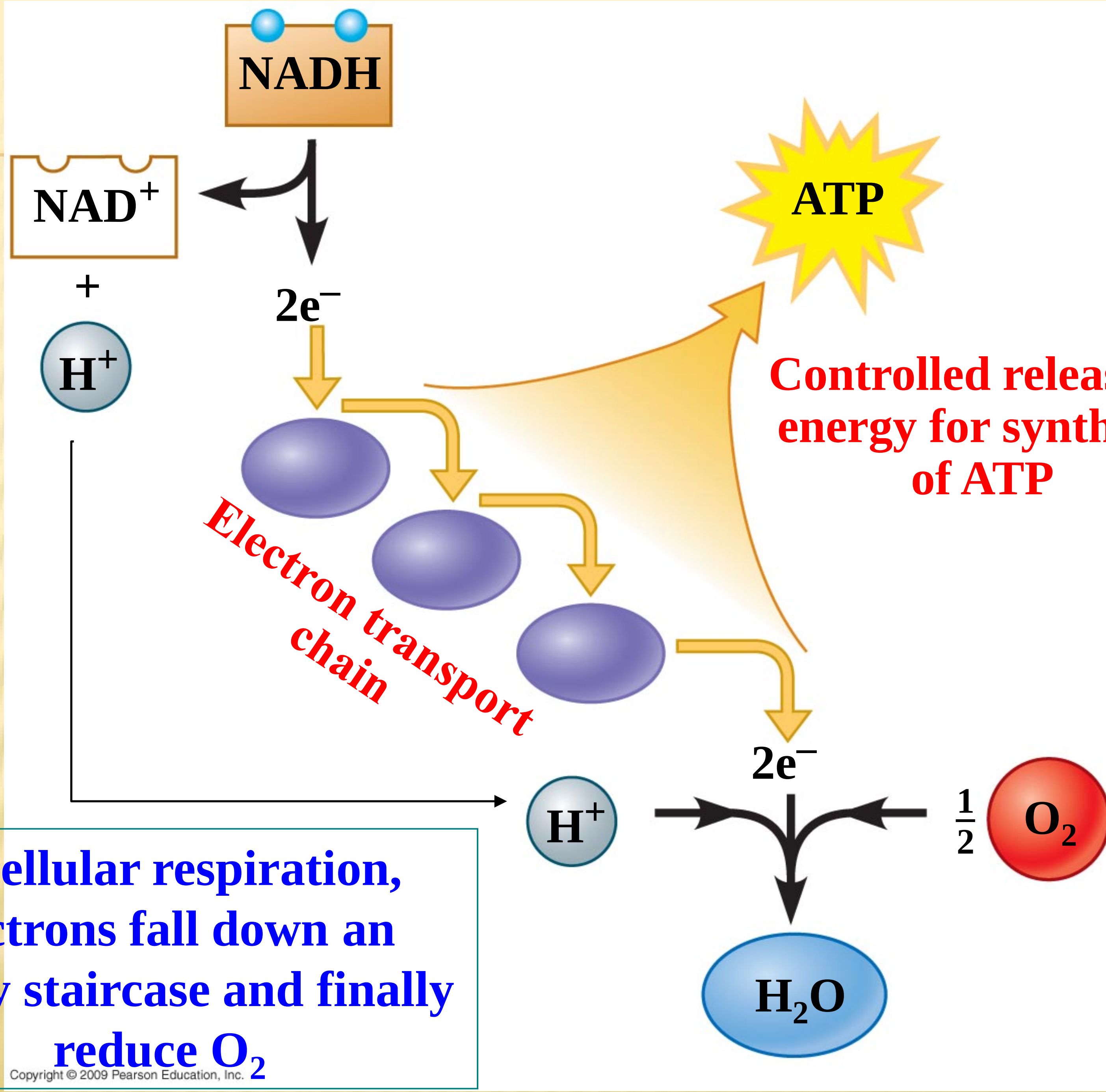


Cells tap energy from electrons "falling" from organic fuels to oxygen

- **The transfer of electrons to NAD^+ results in the formation of NADH, the reduced form of NAD^+**
  - **In this situation, NAD^+ is called an electron acceptor, but it eventually becomes oxidized (loses an electron) and is then called an electron donor**

Cells tap energy from electrons “falling” from organic fuels to oxygen

- There are other electron “carrier” molecules that function like NAD^+
  – They form a staircase where the electrons pass from one to the next down the staircase
  – These electron carriers collectively are called the **electron transport chain**, and as electrons are transported down the chain, ATP is generated



In cellular respiration, electrons fall down an energy staircase and finally reduce O_2

Stages of Aerobic Cellular Respiration

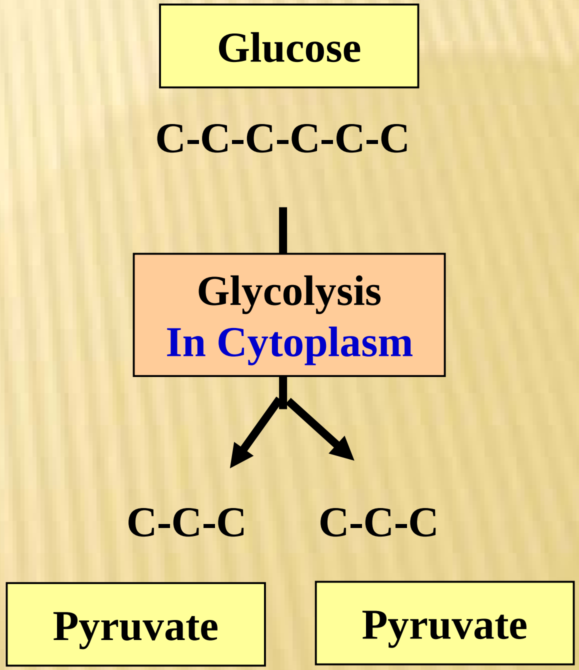
What are the Stages of Cellular Respiration?

1. Glycolysis occurs in the Cytoplasm

2. The Krebs Cycle or citric acid cycle occurs in the mitochondria matrix

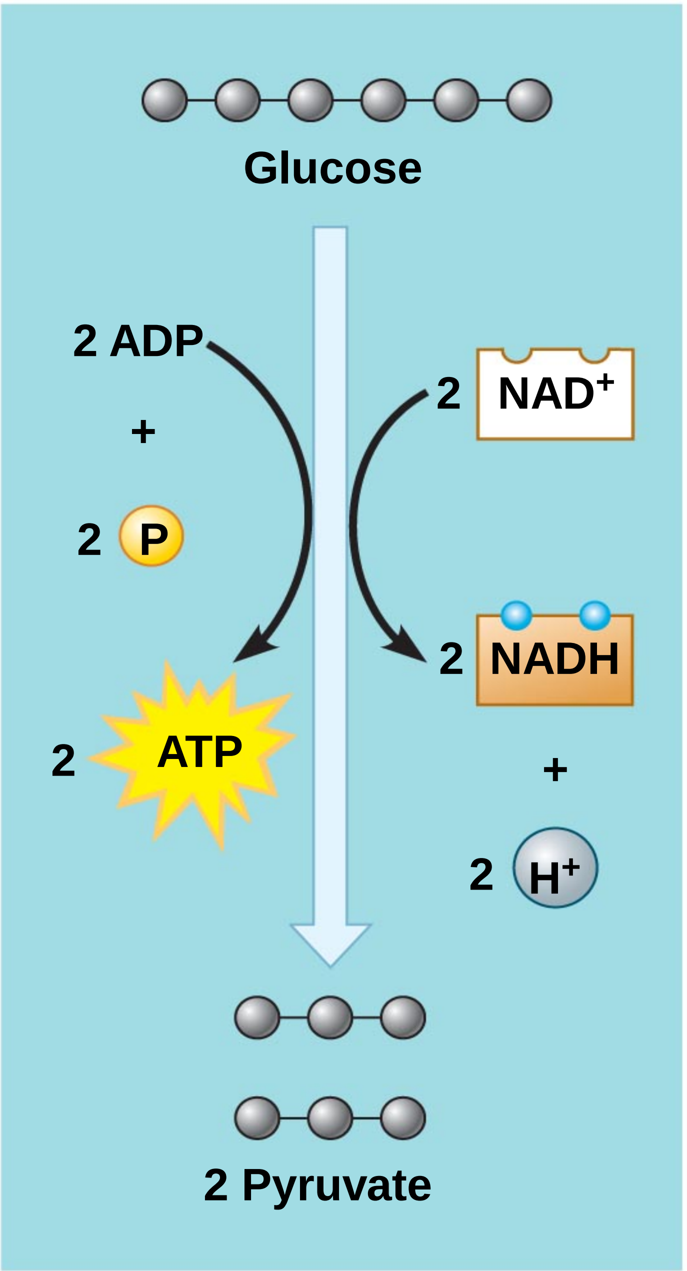
3. Oxidation phosphorylation or The Electron Transport Chain occurs in the mitochondria inner membrane

- **Stage 1: Glycolysis**
  - **Glycolysis begins respiration by breaking glucose, a six-carbon molecule, into two molecules of a three-carbon compound called pyruvate**
  - **This stage occurs in the cytoplasm**



Glycolysis harvests chemical energy by oxidizing glucose to pyruvate

- In glycolysis, a single molecule of glucose is enzymatically cut in half through a series of steps to produce two molecules of pyruvate
  - In the process, two molecules of NAD^+ are reduced to two molecules of NADH
  - At the same time, two molecules of ATP are produced by substrate-level phosphorylation



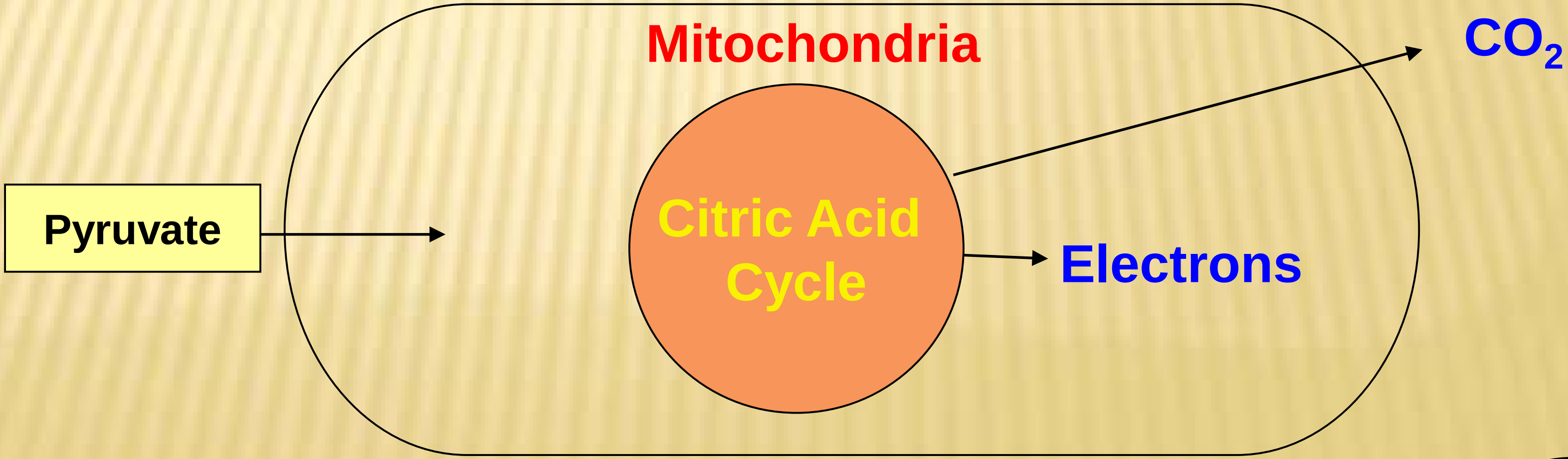
An overview of glycolysis

Stage 2: The citric acid cycle (Krebs Cycle) A Little Krebs Cycle History

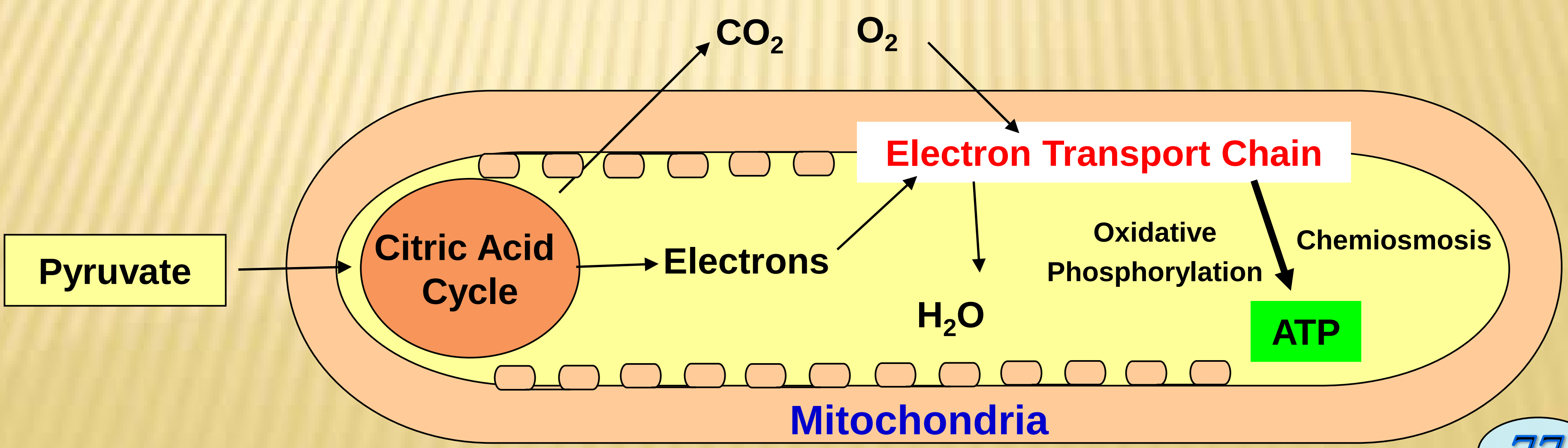
- Discovered by Hans Krebs in 1937
- He received the Nobel Prize in physiology or medicine in 1953 for his discovery

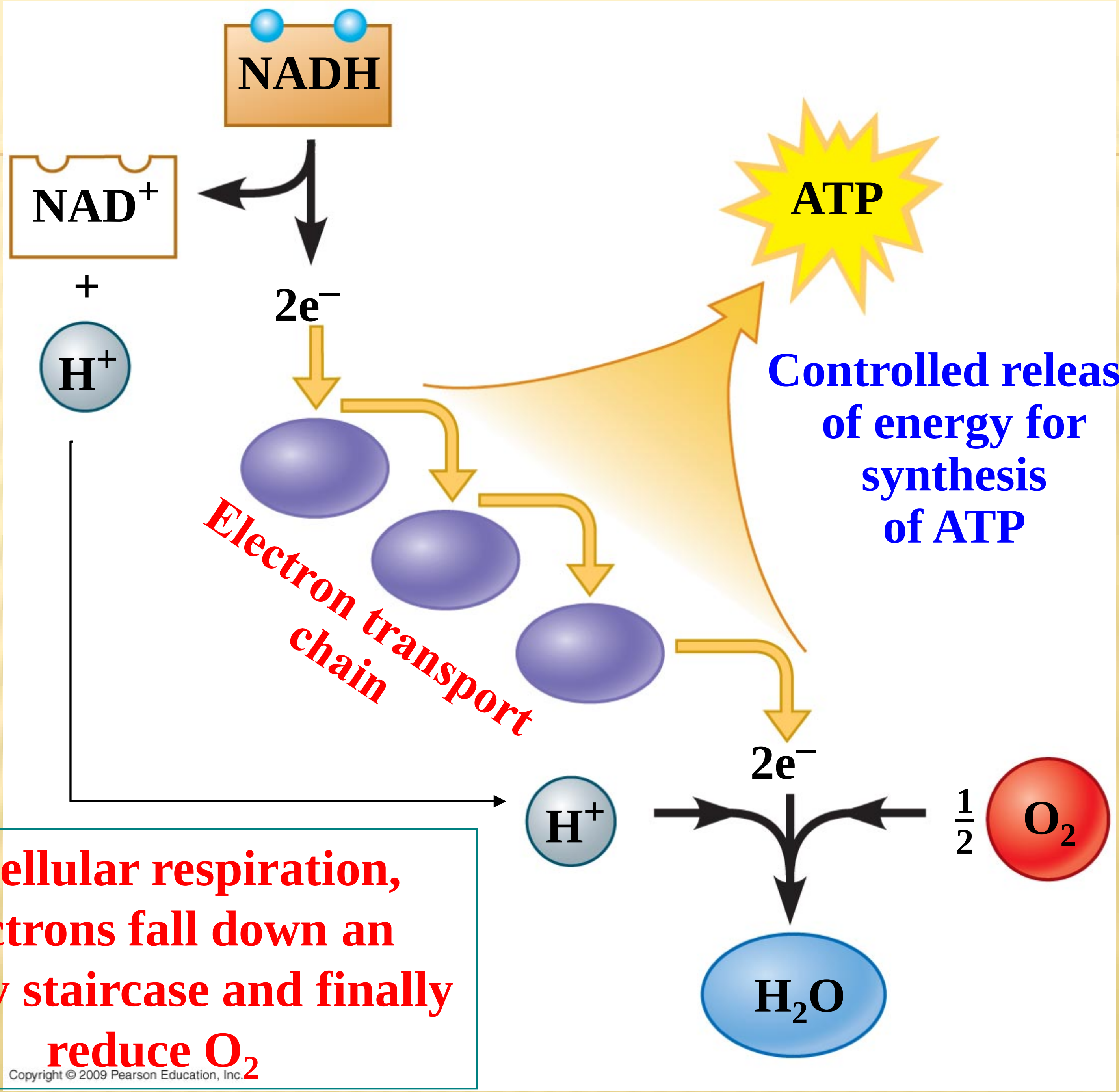
Overview Stage 2: The citric acid cycle

- **Stage 2: The citric acid cycle**
  - The citric acid cycle breaks down pyruvate into carbon dioxide and supplies the third stage **Oxidative phosphorylation** with electrons
  - This stage, **The citric acid cycle,** occurs in the mitochondria matrix
  - **For each Glucose molecule, the Krebs Cycle produces 6NADH, 2$FADH_2$, 4CO_2, and 2ATP**



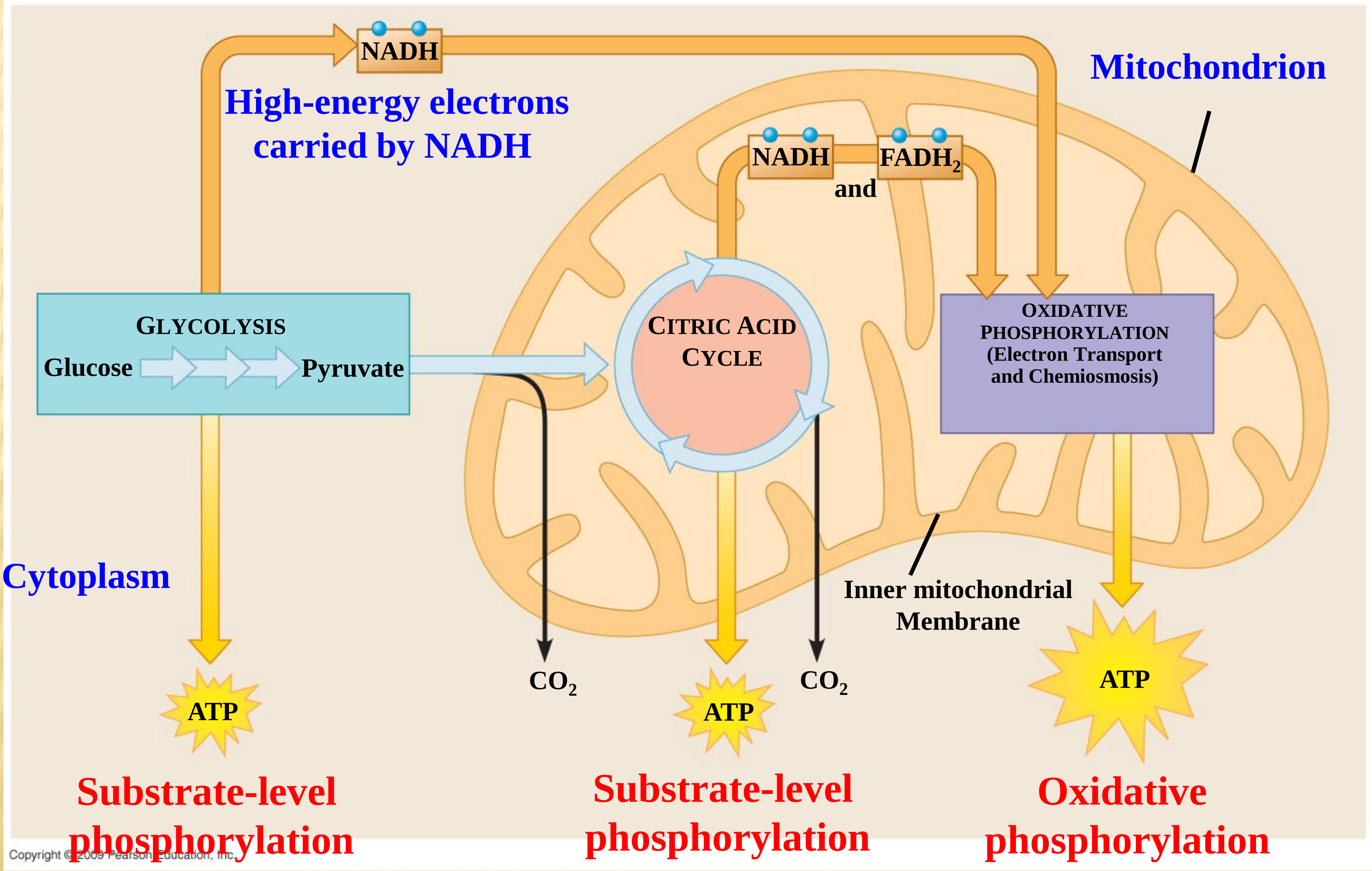
- **Stage 3: Oxidative phosphorylation**
  - At this stage, electrons are shuttled through the electron transport chain
  - As a result, ATP is generated through oxidative phosphorylation
  - (oxidation of NADH to NAD and phosphorylation of ADP to ATP)
  - This stage Occurs Across Inner Mitochondrial membrane





In cellular respiration, electrons fall down an energy staircase and finally reduce O_2

An overview of cellular respiration



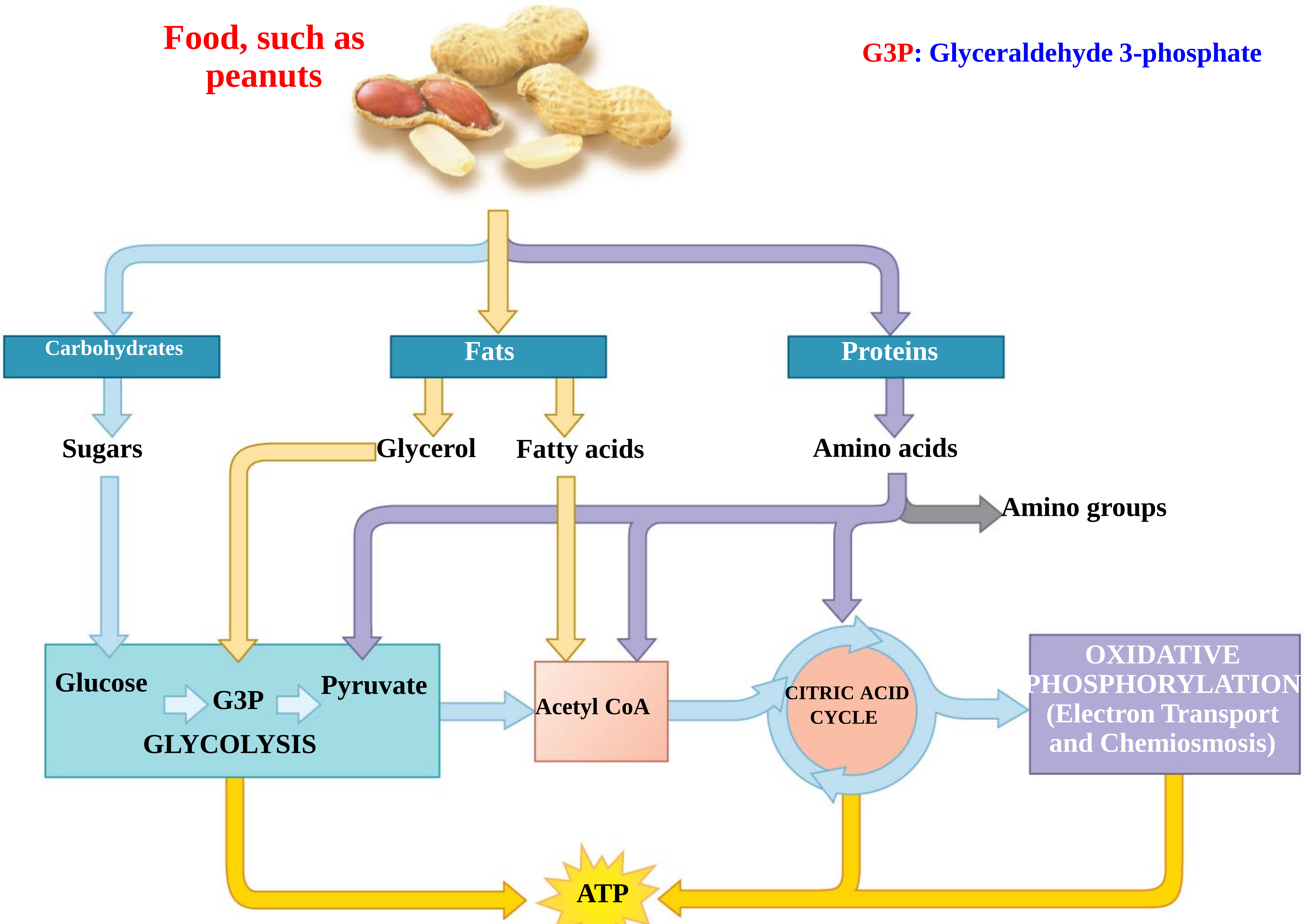
INTERCONNECTIONS BETWEEN MOLECULAR BREAKDOWN AND SYNTHESIS

How do cells extract energy in chemical bonds in organic molecules

- **Although glucose is considered to be the primary source of sugar for respiration and fermentation, there are actually three sources of molecules for generation of ATP**
  - **Carbohydrates (disaccharides)**
  - **Proteins (after conversion to amino acids)**
  - **Fats**

Catabolism of Various Food Molecules

- **Other organic molecules used for fuel.**
- **Fats: glycerols and fatty acids both oxidized as fuel**
- **Proteins: amino acids undergo deamination. Carbon skeletons converted to intermediates of aerobic respiration**



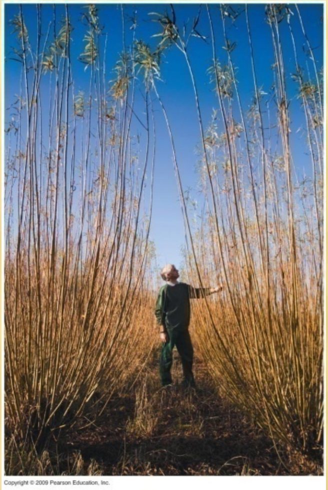
Pathways that break down various food molecules

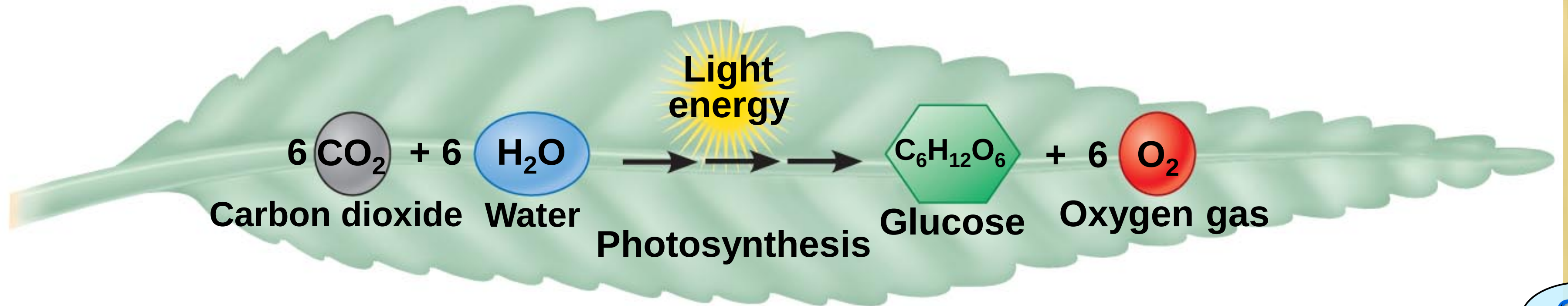
Photosynthesis:

Using Light to Make Food

An overview of photosynthesis

- Plants use water and atmospheric carbon dioxide to produce a simple sugar and liberate oxygen
  - Earth's plants produce 160 billion metric tons of sugar each year through photosynthesis, a process that converts solar energy to chemical energy
  - Sugar is food for humans and for animals that we consume





Photosynthesis

- **Photosynthesis occurs in chloroplasts located in mesophyll cells inside the leaf**
- **Light energy is converted to chemical energy (carbohydrates)**
- **Hydrogens from water reduce carbon**
- **Oxygen from water is oxidized, forming molecular oxygen**

Photosynthesis occurs in chloroplasts in plant cells

- **Chloroplasts are the major sites of photosynthesis in green plants**
  - **Chlorophyll, an important light absorbing pigment in chloroplasts, is responsible for the green color of plants**
  - **Chlorophyll plays a central role in converting solar energy to chemical energy**

Photosynthesis occurs in chloroplasts in plant cells

- Chloroplasts are concentrated in the cells of the mesophyll, the green tissue in the interior of the leaf
- Stomata are tiny pores in the leaf that allow carbon dioxide to enter and oxygen to exit
- Veins in the leaf deliver water absorbed by roots

Autotrophs are the producers of the biosphere

- **Autotrophs are living things that are able to make their own food without using organic molecules derived from any other living thing**
  - **Autotrophs that use the energy of light to produce organic molecules are called photoautotrophs**
  - **Most plants, algae and other protists, and some prokaryotes are photoautotrophs**

Kelp, a large algae

Autotrophs are the producers of the biosphere

- **The ability to photosynthesize is directly related to the structure of chloroplasts**
  - **Chloroplasts are organelles consisting of photosynthetic pigments, enzymes, and other molecules grouped together in membranes**

Micrograph of Cyanobacteria (photosynthetic bacteria)

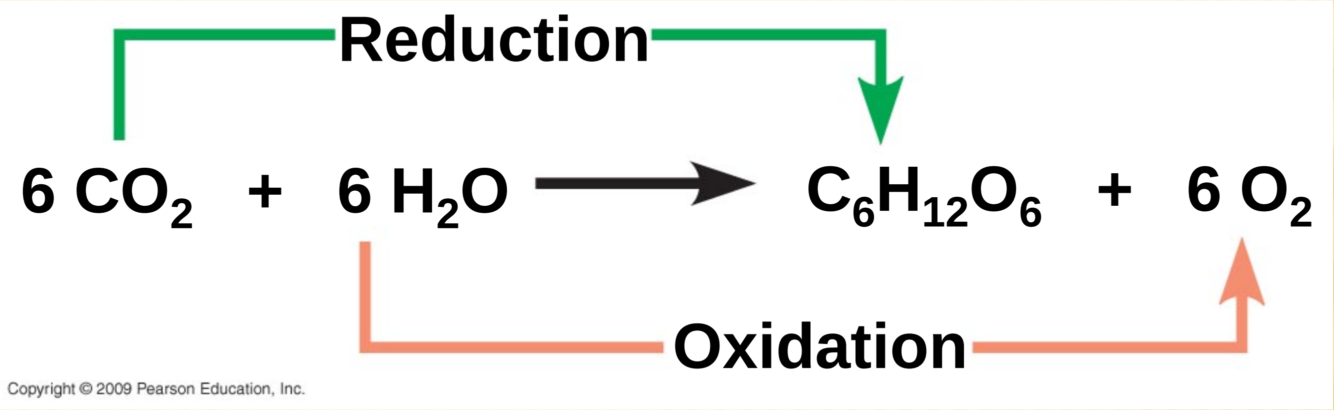
Photosynthesis is a redox process, as is cellular respiration

- Photosynthesis, like respiration, is a redox (oxidation-reduction) process
  - Water molecules are split apart by oxidation, which means that they lose electrons along with hydrogen ions (H^+)
  - Then CO_2 is reduced to sugar as electrons and hydrogen ions are added to it

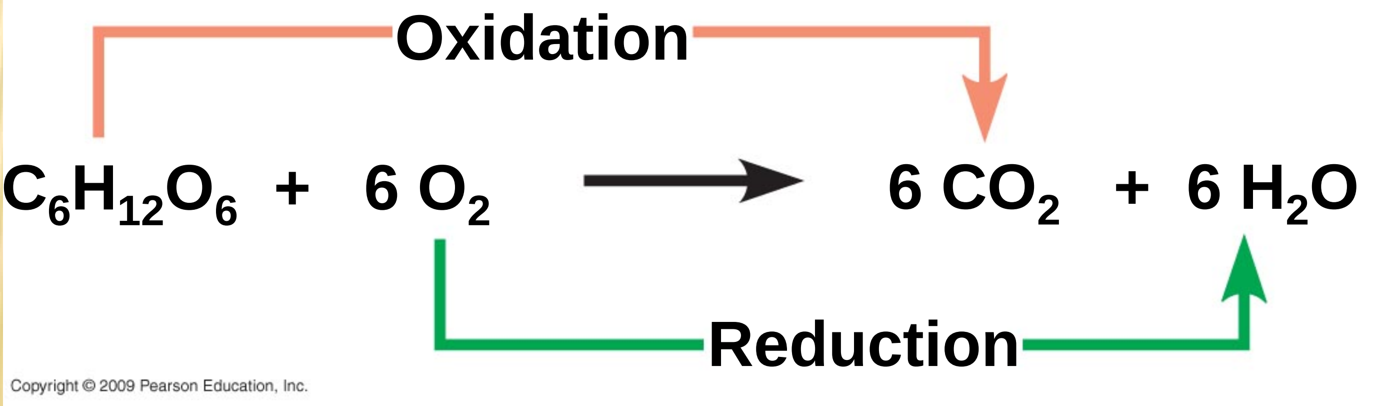
Photosynthesis is a redox process, as is cellular respiration

- Recall that cellular respiration uses redox reactions to harvest the chemical energy stored in a glucose molecule
  - This is accomplished by oxidizing the sugar and reducing O_2 to H_2O
  - The electrons lose potential as they travel down an energy hill, the electron transport system
  - In contrast, the food-producing redox reactions of photosynthesis reverse the flow and involve an uphill climb

Photosynthesis (uses light energy)



Cellular respiration (releases chemical energy)



Photosynthesis Reactions

1. Light-dependent reactions

- **light energizes water electrons that generate ATP and NADPH**

2. Carbon fixation reactions

- **use energy of ATP and NADPH to fix CO_2 into carbohydrate**

Overview: The two stages of photosynthesis are linked by ATP and NADPH

- **Actually, photosynthesis occurs in two metabolic stages**

First stage

- **One stage involves the light reactions**
- **In the light reactions, light energy is converted in the thylakoid membranes to chemical energy and O_2**
- **Water is split to provide the O_2 as well as electrons**

Overview: The two stages of photosynthesis are linked by ATP and NADPH

- H^+ ions reduce $NADP^+$ to NADPH, which is an electron carrier similar to NADH
  - NADPH is temporarily stored and then shuttled into the Calvin cycle where it is used to make sugar
  - Finally, the light reactions generate ATP

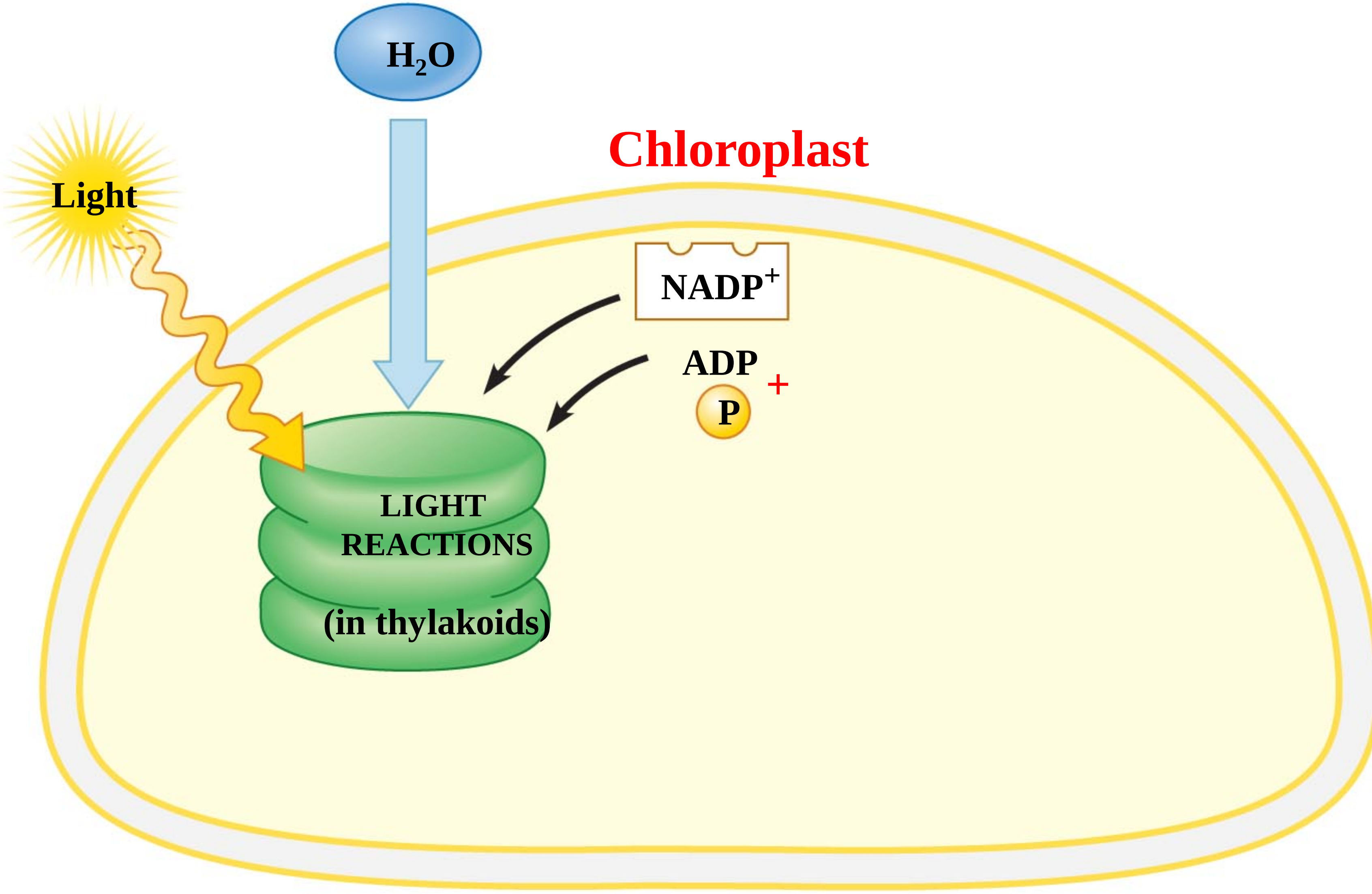
Overview: The two stages of photosynthesis are linked by ATP and NADPH

Second stage

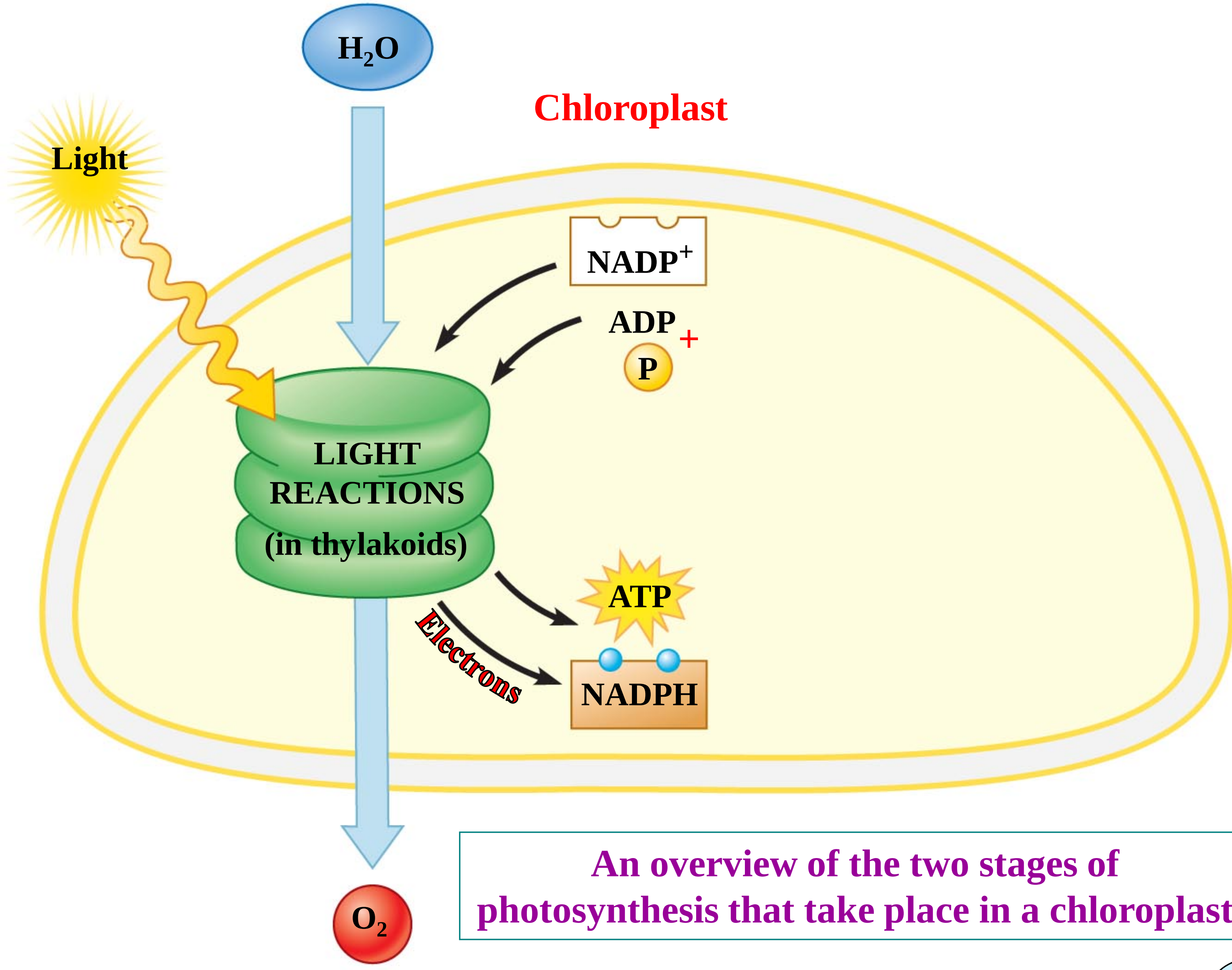
- The second stage is the Calvin cycle, which occurs in the stroma of the chloroplast
  - It is a cyclic series of reactions that builds sugar molecules from CO_2 and the products of the light reactions
  - During the Calvin cycle, CO_2 is incorporated into organic compounds, a process called carbon fixation

Overview: The two stages of photosynthesis are linked by ATP and NADPH

- NADPH produced by the light reactions provides the electrons for reducing carbon in the Calvin cycle
  - ATP from the light reactions provides chemical energy for the Calvin cycle
  - The Calvin cycle is often called the dark (or light-independent) reactions

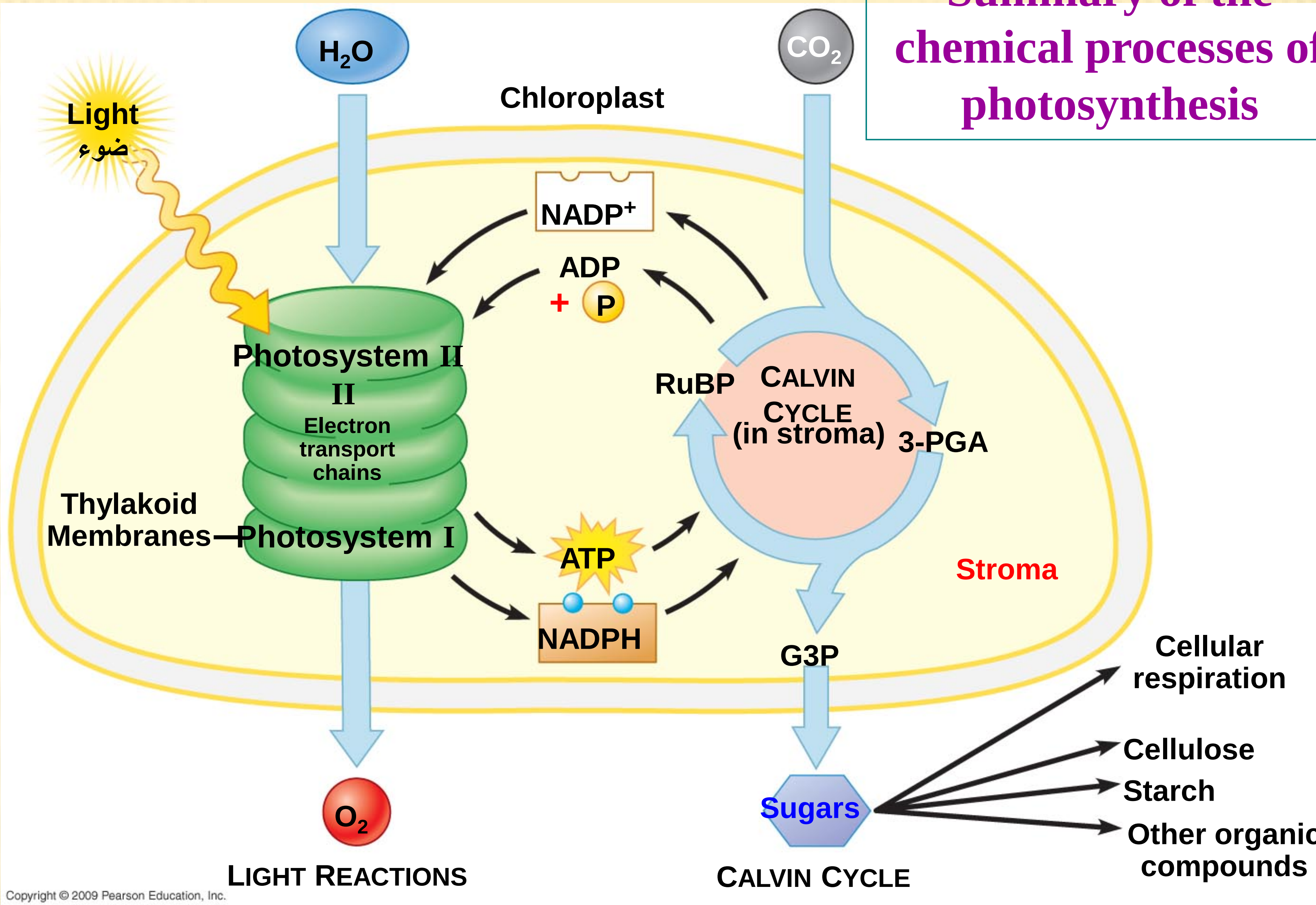


An overview of the two stages of photosynthesis that take place in a chloroplast



An overview of the two stages of photosynthesis that take place in a chloroplast

Summary of the chemical processes of photosynthesis



Review: Photosynthesis uses light energy, CO_2, and H_2O to make food molecules

- The chloroplast, which integrates the two stages of photosynthesis, makes sugar from CO_2
  - All but a few microscopic organisms depend on the food-making machinery of photosynthesis
  - Plants make more food than they actually need and stockpile it as starch in roots, tubers, and fruits

PHOTOSYNTHESIS,
SOLAR RADIATION,
AND EARTH'S ATMOSPHERE

CONNECTION: Photosynthesis moderates global warming

- **The greenhouse effect results from solar energy warming our planet**
  - **Gases in the atmosphere (often called greenhouse gases), including CO_2, reflect heat back to Earth, keeping the planet warm and supporting life**
  - **However, as we increase the level of greenhouse gases, Earth's temperature rises above normal, initiating problems**

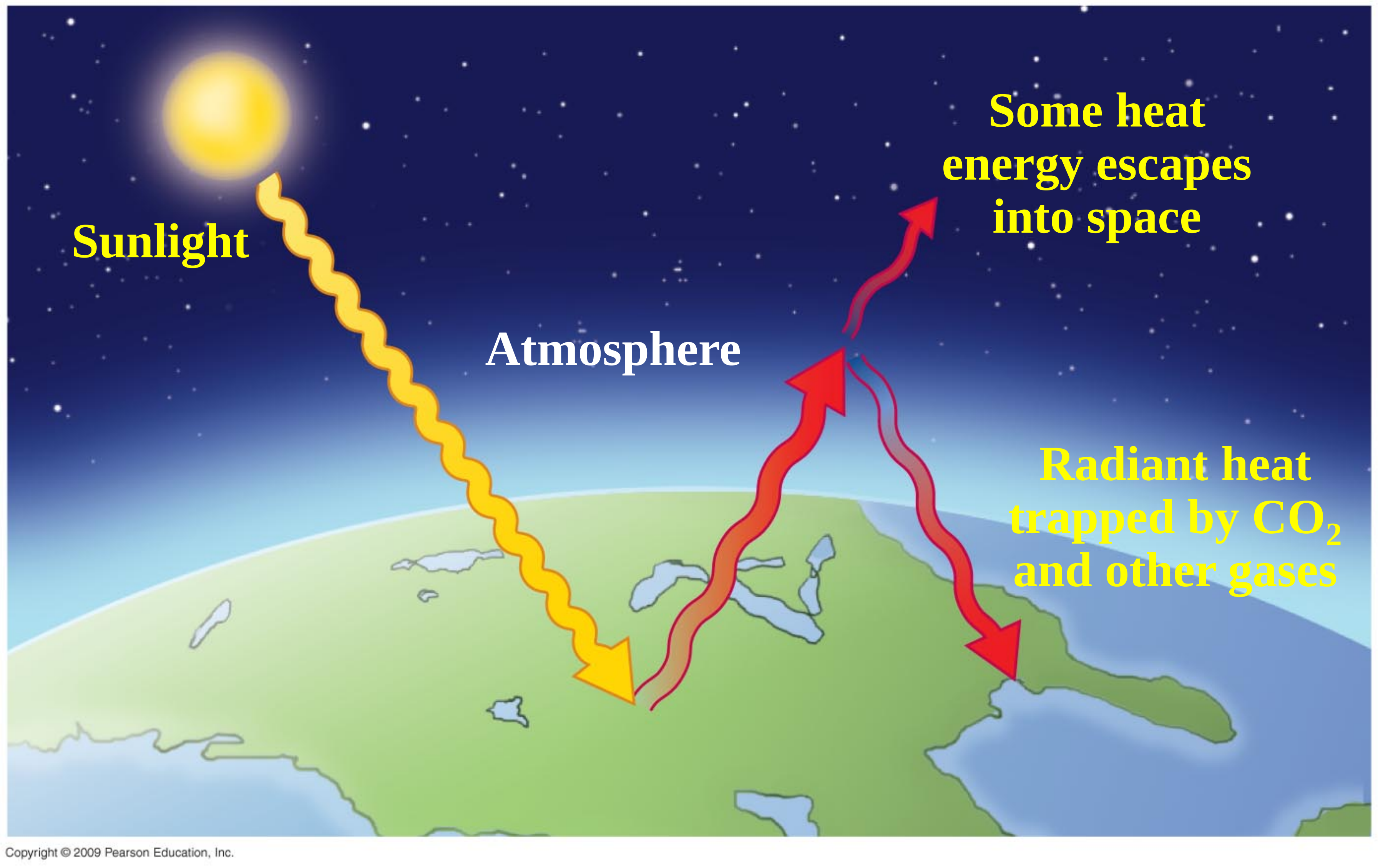
7.13 CONNECTION: Photosynthesis moderates global warming

- Increasing concentrations of greenhouse gases lead to global warming, a slow but steady rise in Earth's surface temperature
  - The extraordinary rise in CO_2 is mostly due to the combustion of carbon-based fossil fuels
  - The consequences of continued rise will cause melting of polar ice, changing weather patterns, and spread of tropical disease

7.13 CONNECTION: Photosynthesis moderates global warming

- Perhaps photosynthesis can mitigate the increase in atmospheric CO_2
  - However, there is increasing widespread **deforestation**, which aggravates the global warming problem

Plants growing in a greenhouse

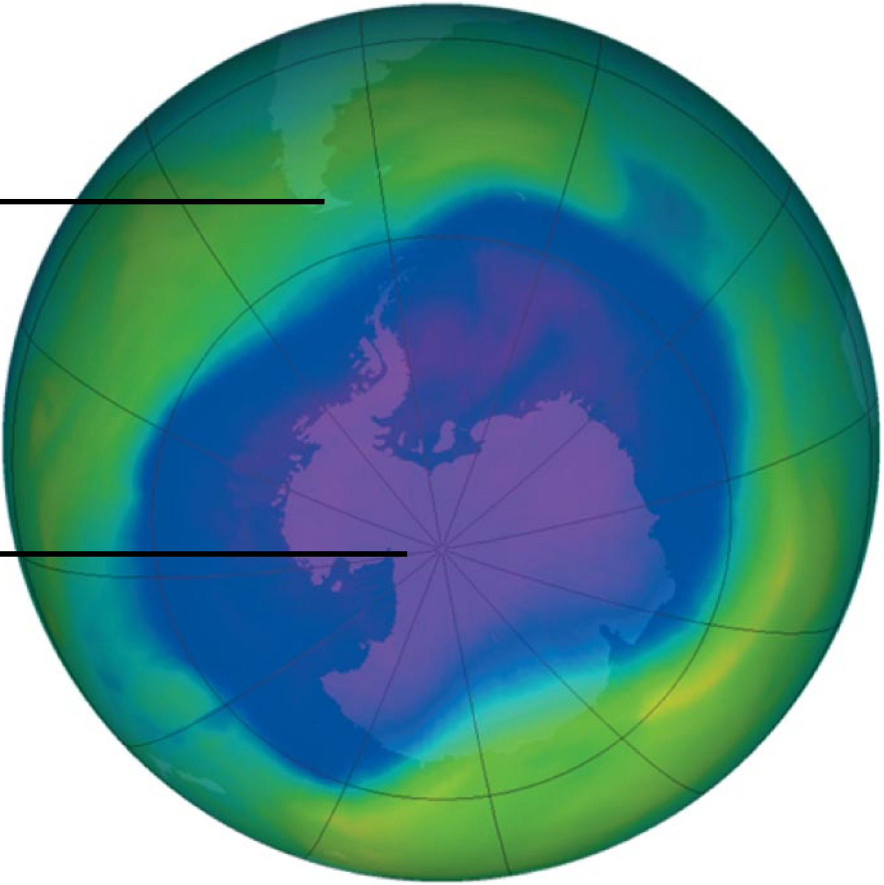


CO_2 in the atmosphere and global warming

7.14 TALKING ABOUT SCIENCE: Mario Molina talks about Earth's protective ozone layer

- Dr. Mario Molina at the University of California, San Diego, received a Nobel Prize for research on damage to the ozone layer
  - Ozone provides a protective layer (the ozone layer) in our atmosphere to filter out powerful ultraviolet radiation
  - Dr. Molina showed that industrial chemicals called chlorofluorocarbons (CFCs), deplete the ozone layer

Mario Molina



The ozone hole in the Southern Hemisphere, spring 2006