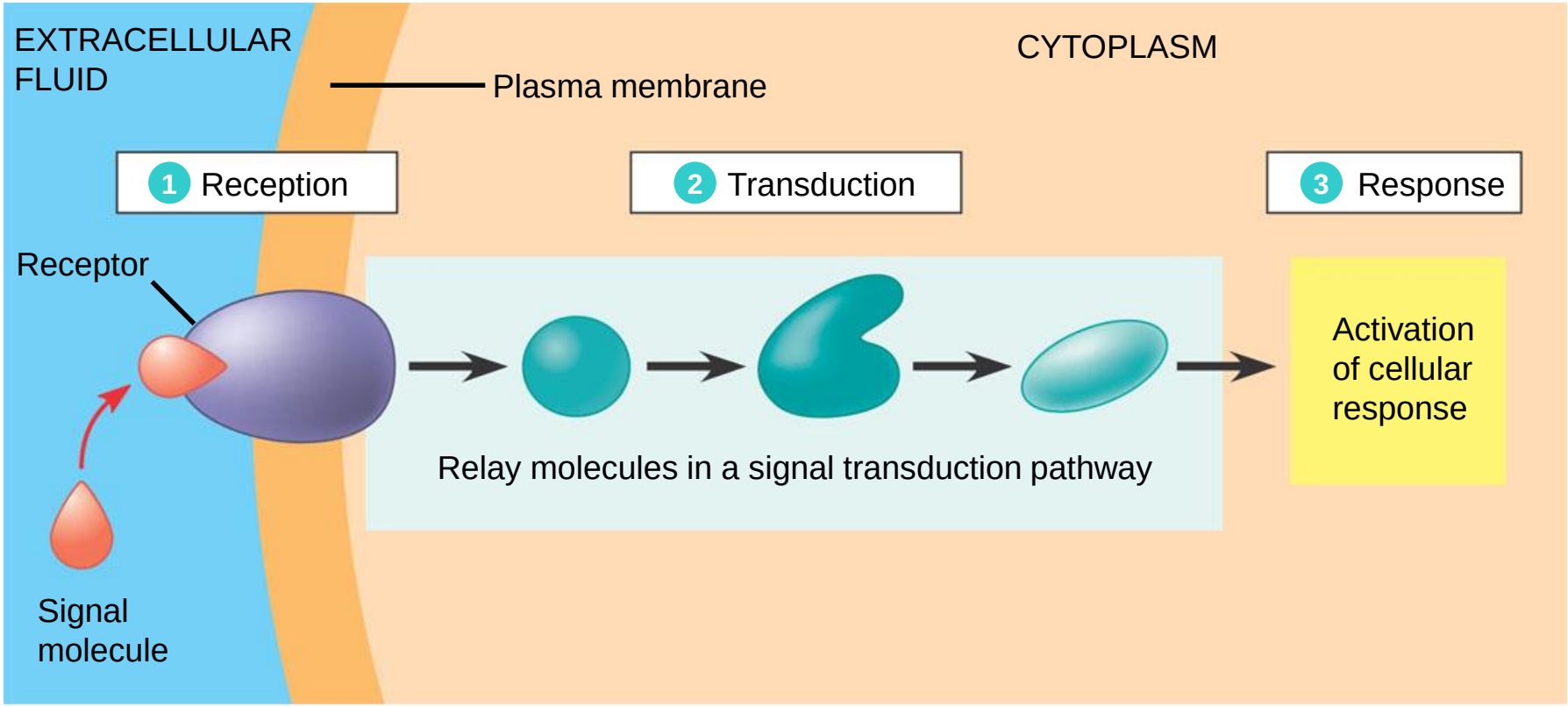
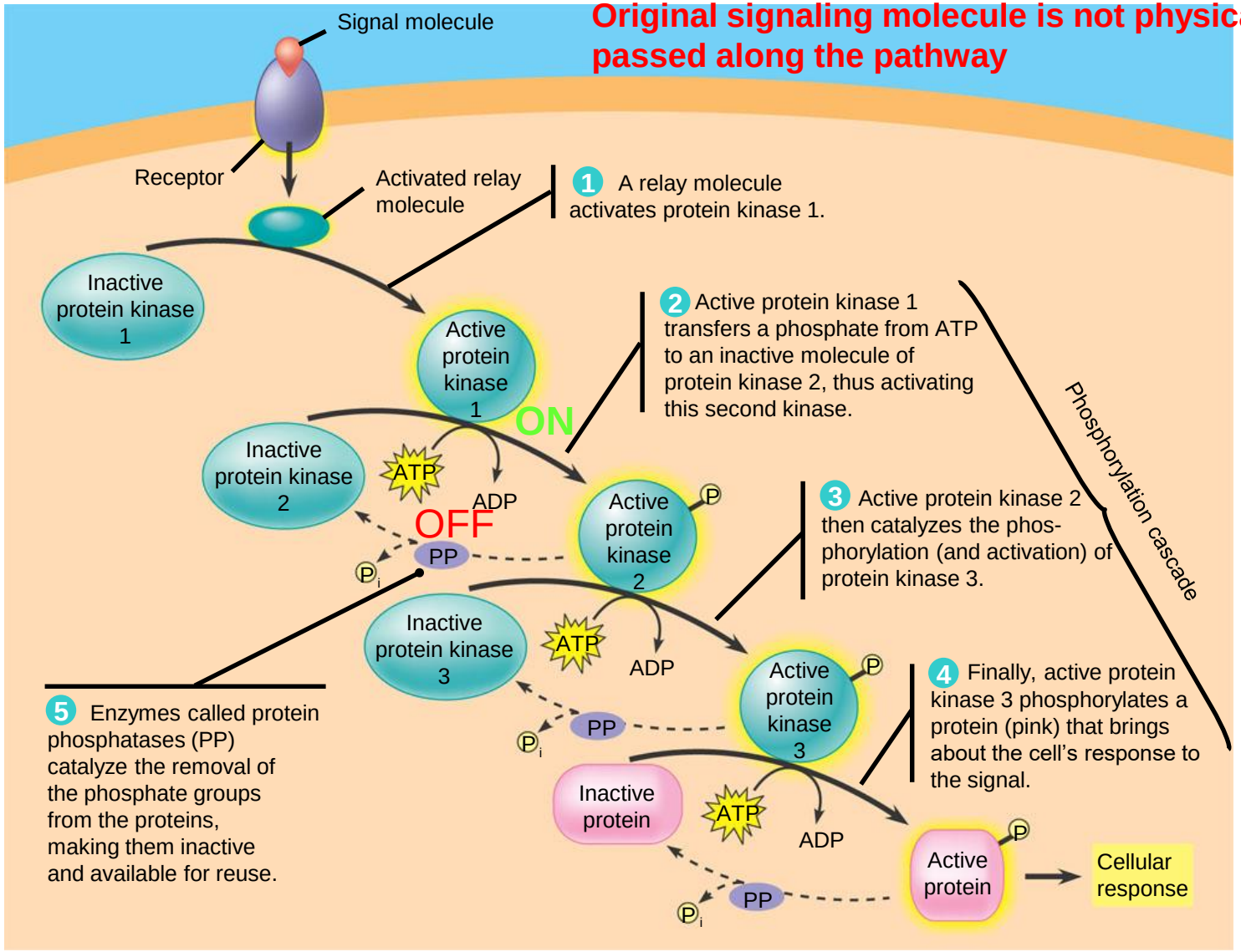
Signal Transduction

Overview of cell signaling: Signaling pathway: Cellular Internet



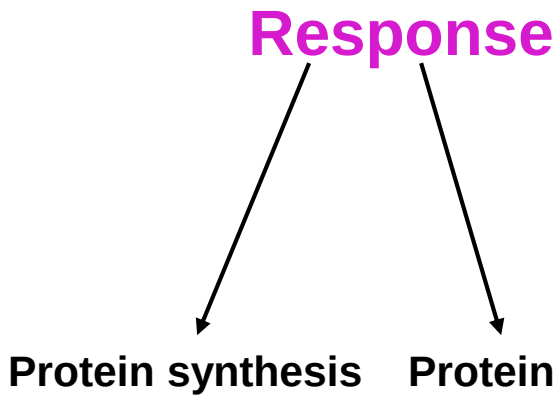
Signal from the environment: Like odor, touch, pathogen infection, Injury, smell, taste

A phosphorylation cascade



Advantages of cascade?

Nearly 2% (~1000-2000) of total protein producing genes in the cell are kinase genes



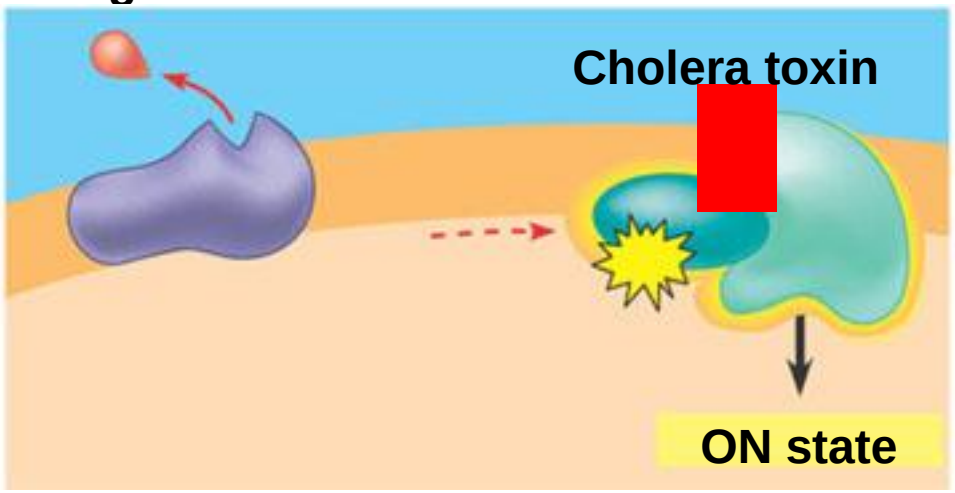
Coordinating a cell's response coming from the different sources of the same or same signal conveying different responses or messages. Ex: glycogen break down is by Glucon and Epinephrine signals.

Two cells that respond differently to the **same signal differ in one or more of the proteins that handle the respond to the signal**

-Specificity of the cell signaling and coordination of the response

Epinephrine on liver response is glycogen breakdown to glucose whereas on heart its role is muscle contraction so increase the heartbeat.

Signal termination:



Harmful effect

Chemically modifies G protein coupled receptors involved regulation of salt and water secretion: **Diarrhea due to Cholera toxin**

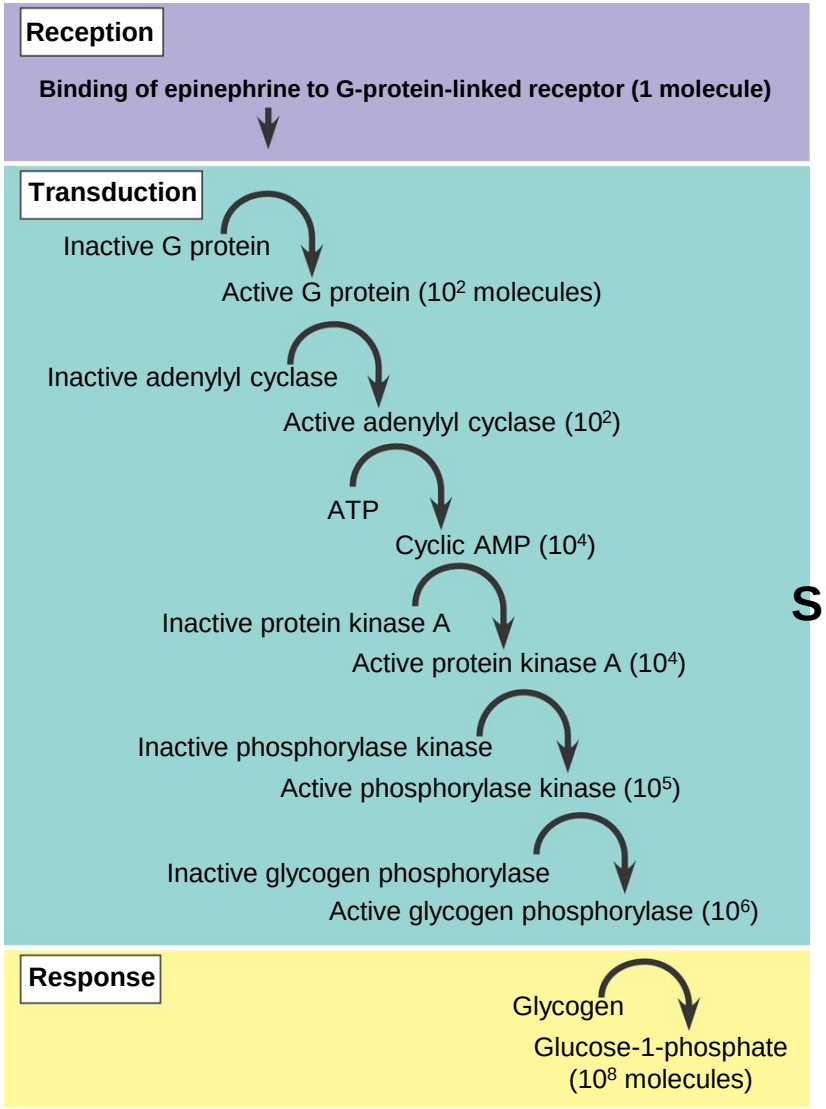
Prolonging the signal for treating disorder:

-Viagra used for treatment of erectile dysfunction in males.

-Relieving chest pain

Cytoplasmic response to a signal: the stimulation of glycogen breakdown by Epinephrine hormone (Scale Up)

How do you convey a message to 1 crore people?



Signal amplification

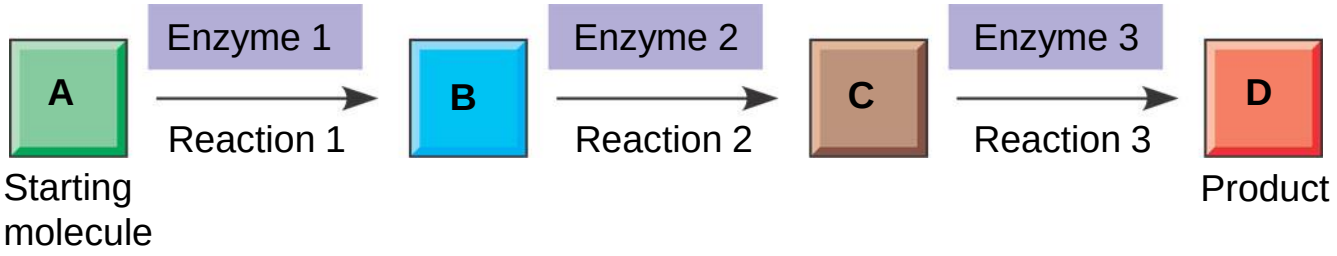
Thus, one copy of epinephrine can release 10^{31} molecules of Glucose from Glycogen

How does the human body get energy to do work?

The human body consists of 10^{14} cells (~ 100 trillion cells)!

Metabolism

Totality of an organism's **chemical reactions** is called Metabolism



Sugars are converted to amino acids, amino acids are incorporated into protein when needed. Also, proteins can be breakdown into amino acids then converted into sugars for energy production.

Catabolism

- Catabolic pathways
  - Break down complex molecules into simpler compounds

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

Anabolism

- Anabolic pathways
  - Build complicated molecules from simpler ones

$6CO_2 + 12\ H_2O + Light\ Energy \Rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$

Bioenergetics is the study of how organisms manage their energy resources

The Laws of Energy Transformation

- Thermodynamics

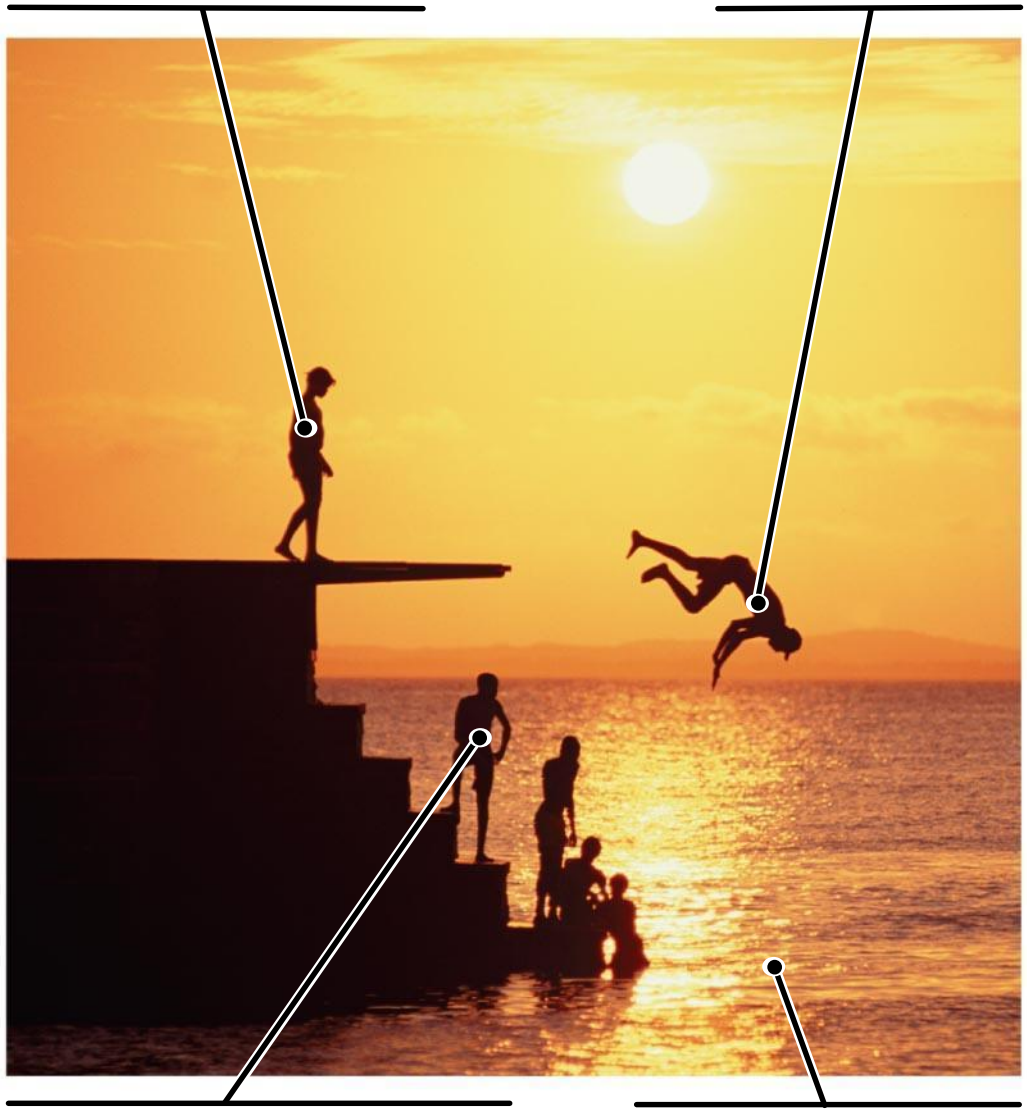
The First Law of Thermodynamics

- According to the first law of thermodynamics
  - Energy can be transferred and transformed
  - Energy cannot be created or destroyed

- According to the second law of thermodynamics
  - Every energy transfer or transformation increases the entropy of the universe
  - Every energy process there is a loss of usable energy which increase the disorder of the surroundings

Kinetic energy
Heat (thermal energy)
Potential energy
Chemical energy

Fig. 8-2



Reaction is spontaneous or not?

Do not confuse spontaneous with speed

Fast: Explosion

Slow: Carbon decay

$$^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + e^{-} + \bar{\nu}_e$$

Living System Free energy

- The change in free energy, ΔG during a biological process
  - Is related directly to the enthalpy change (ΔH) and the change in entropy and temperature in Kelvin

$$\Delta G = \Delta H - T\Delta S$$

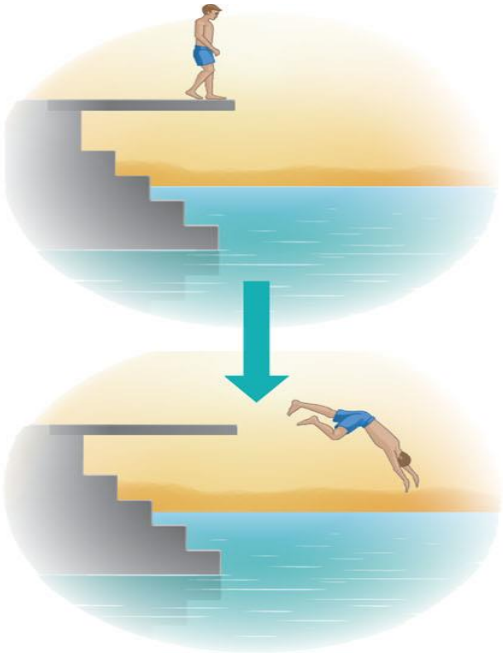
ΔH: Change in system's enthalpy
ΔS: Change in system's entropy

$$\Delta G = \downarrow \Delta H - \uparrow T\Delta S = \text{Spontaneous}$$

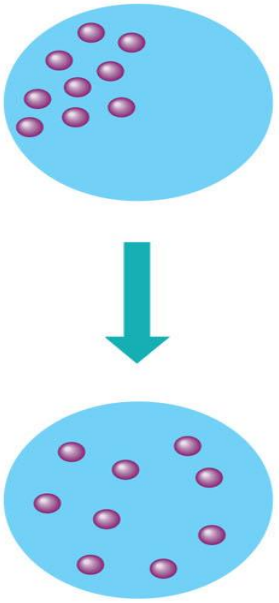
- At maximum stability
  - The system is at equilibrium

In a **spontaneously change**
- The free energy of the system decreases ($\Delta G<0$)
- The system becomes more stable
- The released free energy can be harnessed to do work

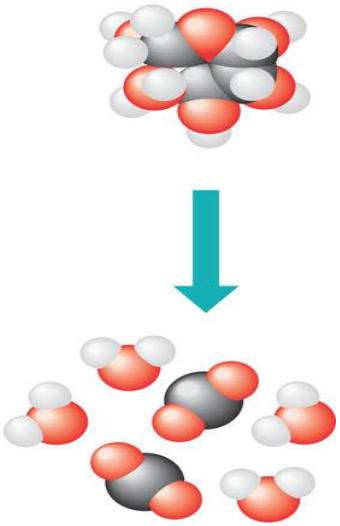
- Less free energy (lower *G*)
- More stable
- Less work capacity



(a) Gravitational motion. Objects move spontaneously from a higher altitude to a lower one.



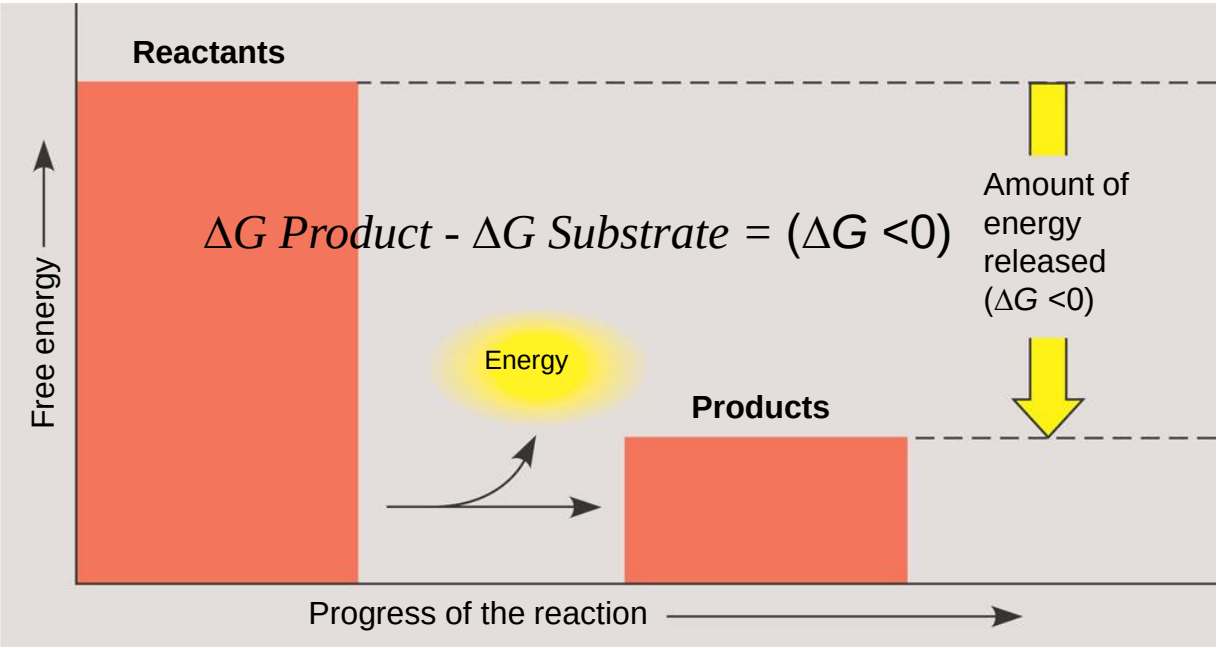
(b) Diffusion. Molecules in a drop of dye diffuse until they are randomly dispersed.



(c) Chemical reaction. In a cell, a sugar molecule is broken down into simpler molecules.

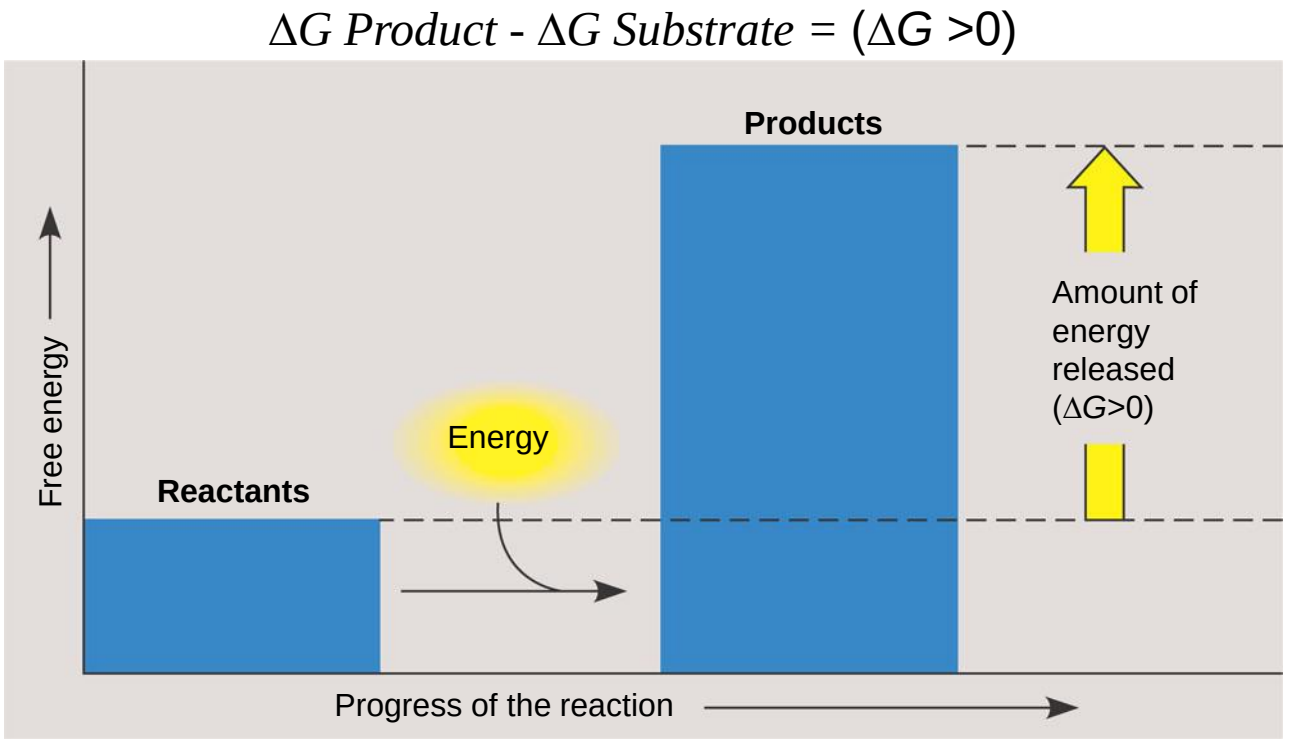
Exergonic (Exothermic) and Endergonic (Endothermic) Reactions

- An exergonic reaction
  - Proceeds with a net release of free energy and is spontaneous



(a) Exergonic reaction: energy released

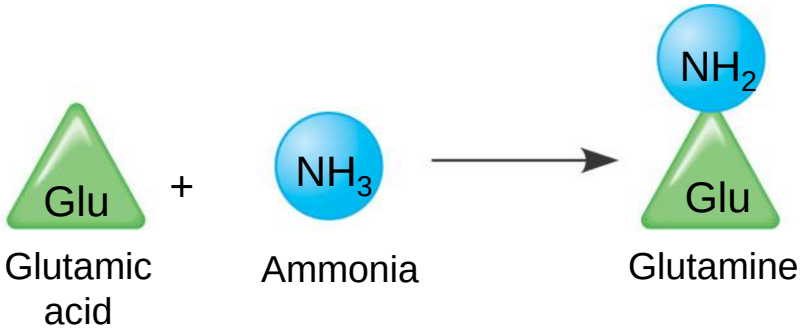
- An endergonic reaction
  - Is one that absorbs free energy from its surroundings and is nonspontaneous



(b) Endergonic reaction: energy required

Energy coupling using ATP hydrolysis

Endergonic reaction: ΔG is positive, reaction is not spontaneous



ΔG = +3.4 kcal/mol

Exergonic reaction: ΔG is negative, reaction is spontaneous

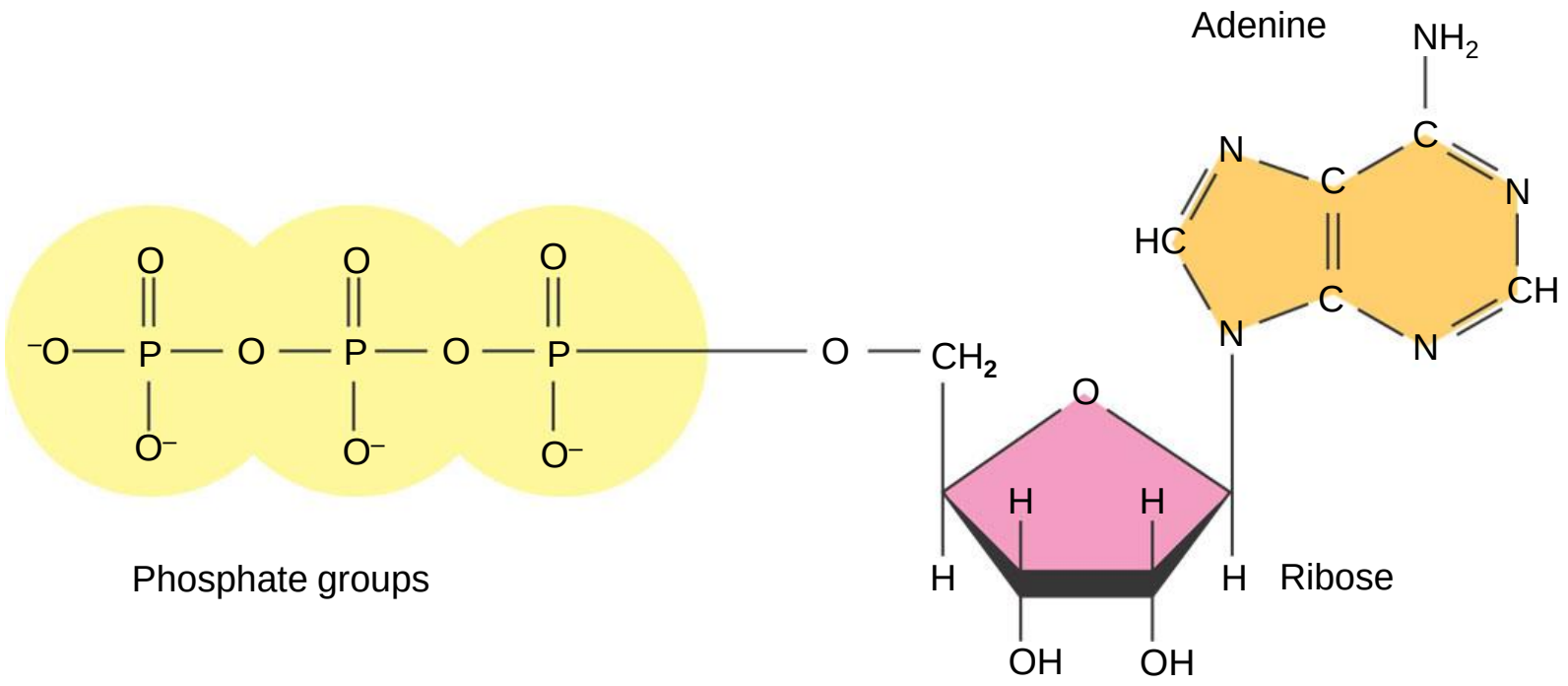
ΔG = –7.3 kcal/mol

Coupled reactions: Overall ΔG is negative; together, reactions are spontaneous

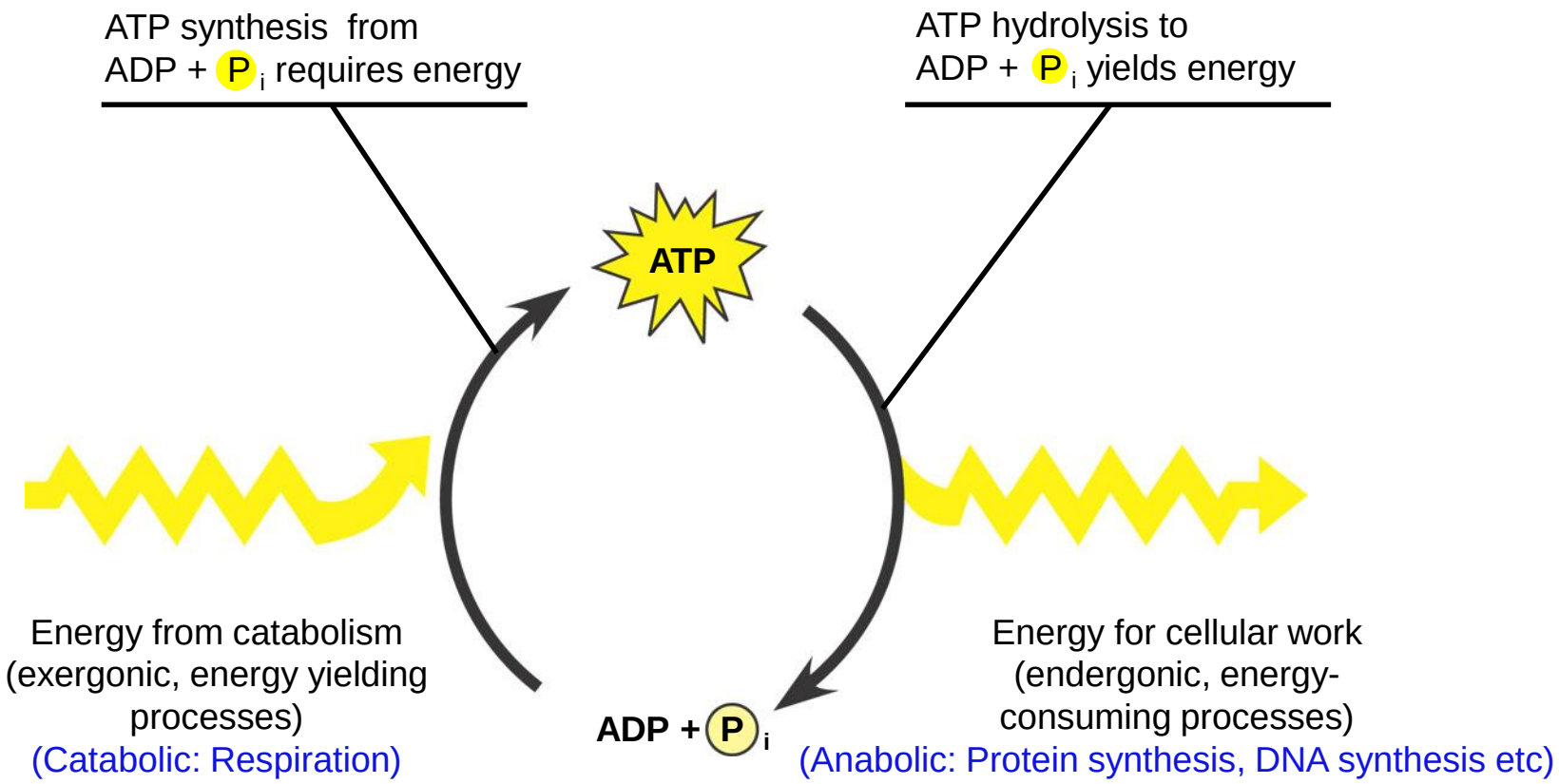
ΔG = –3.9 kcal/mol

The use of an exergonic process to drive an endergonic one.
Most energy coupling in cells is mediated by ATP, and some extent GTP

The structure of adenosine triphosphate (ATP)

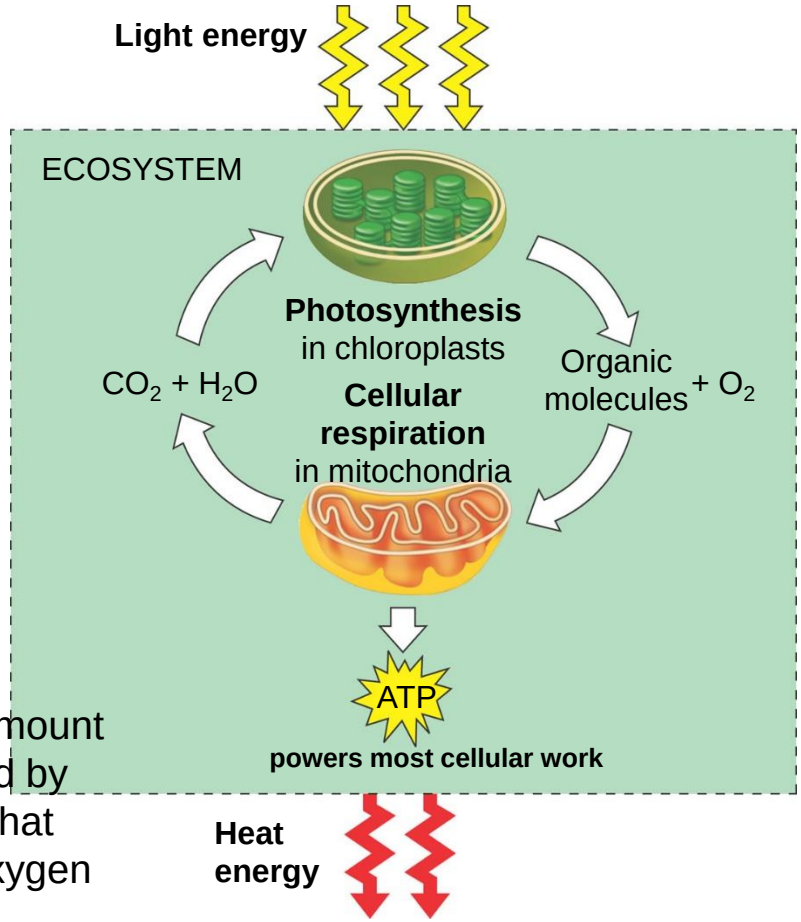


The ATP cycle



Energy

– Flows into an ecosystem as sunlight and leaves as heat



•"On an average, one tree produces nearly 260 pounds of oxygen each year. Two mature trees can provide enough oxygen for a family of four.“

"One acre of trees annually consumes the amount of carbon dioxide equivalent to that produced by **driving an average car for 26,000 miles**. That same acre of trees also produces enough oxygen for 18 people to breathe for a year."
- New York Times

The breakdown of organic molecules is exergonic

Catabolic Pathways and Production of ATP

Cellular respiration

- Is the most prevalent and efficient catabolic pathway
- Consumes oxygen and organic molecules such as glucose: Aerobic respiration
- Yields ATP

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

Catabolic pathways do not directly moves **the flagella, pump solutes across the membrane, polymerize the polymers**. Catabolism is linked to work by a **chemical drive shaft like ATP**. It's like using **money as a currency** for buying and selling.

Redox Reactions: Oxidation and Reduction

How do the catabolic pathways that decompose glucose or **other organic fuels to yield energy?**

- Catabolic pathways yield energy
  - Due to the transfer of electrons

The Principle of Redox

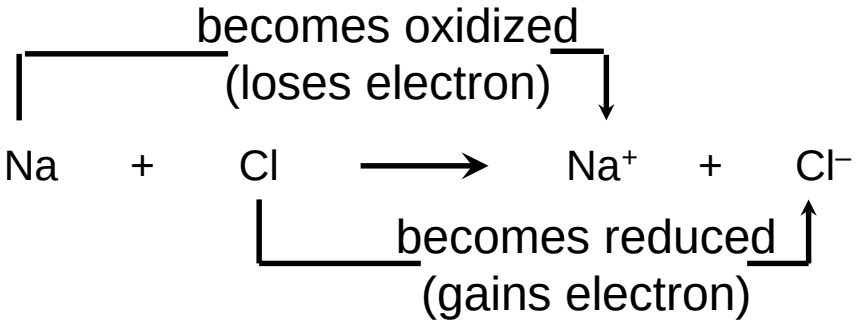
- Redox reactions
  - Transfer electrons from one reactant to another by oxidation and reduction

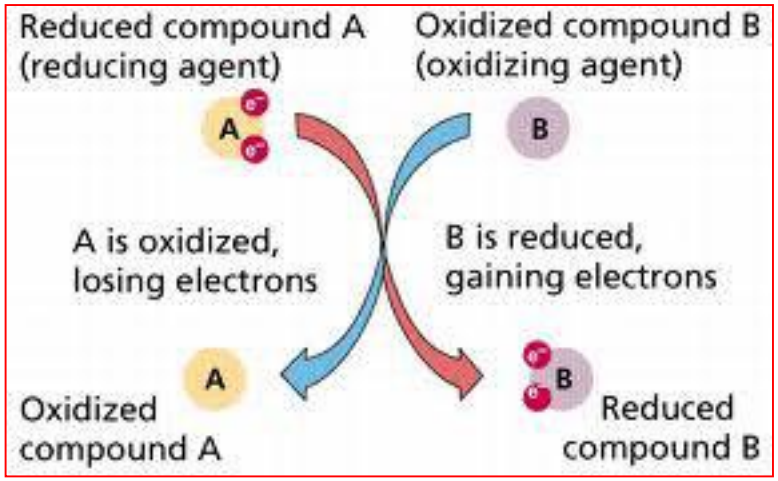
In oxidation

– A substance loses electrons, or is oxidized

In reduction

– A substance gains electrons, or is reduced



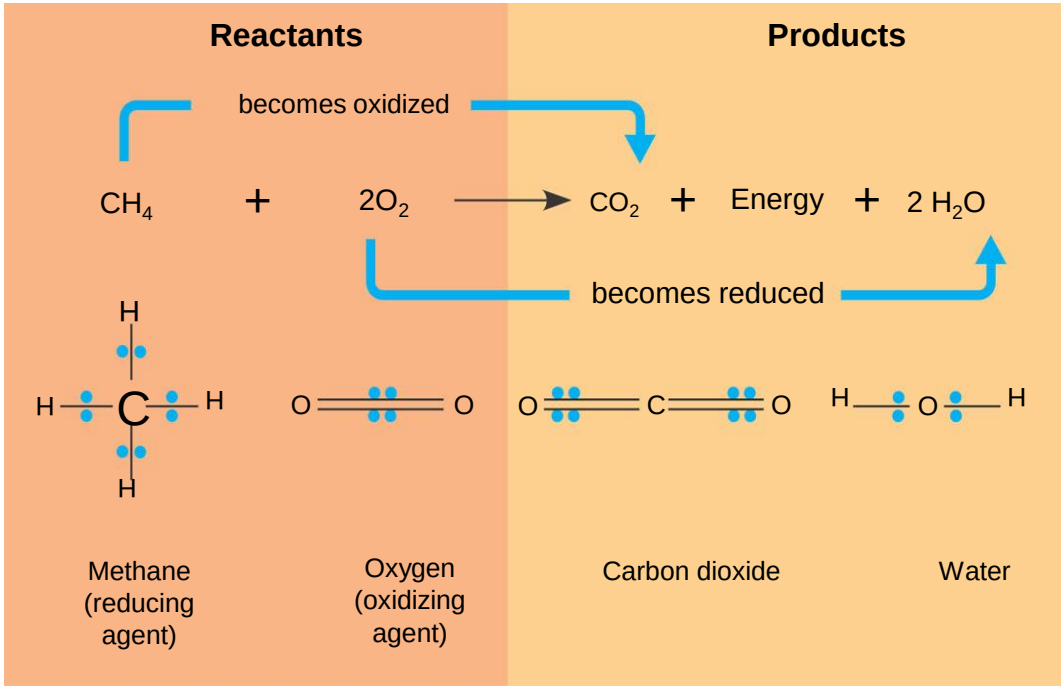


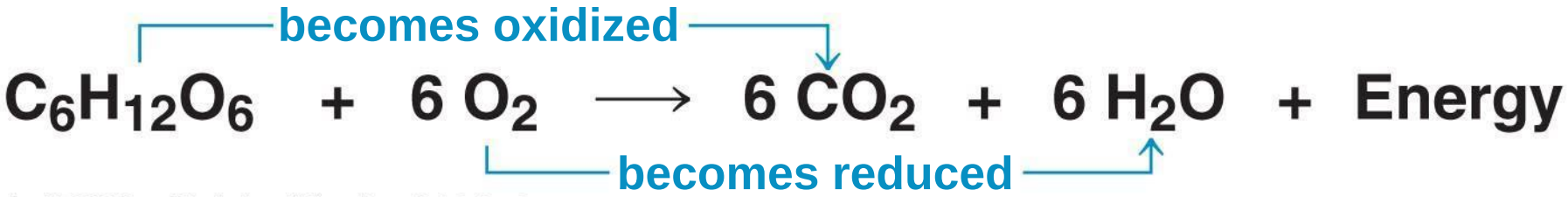
Oxygen is the quintessential oxidizer.

$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$

Some redox reactions

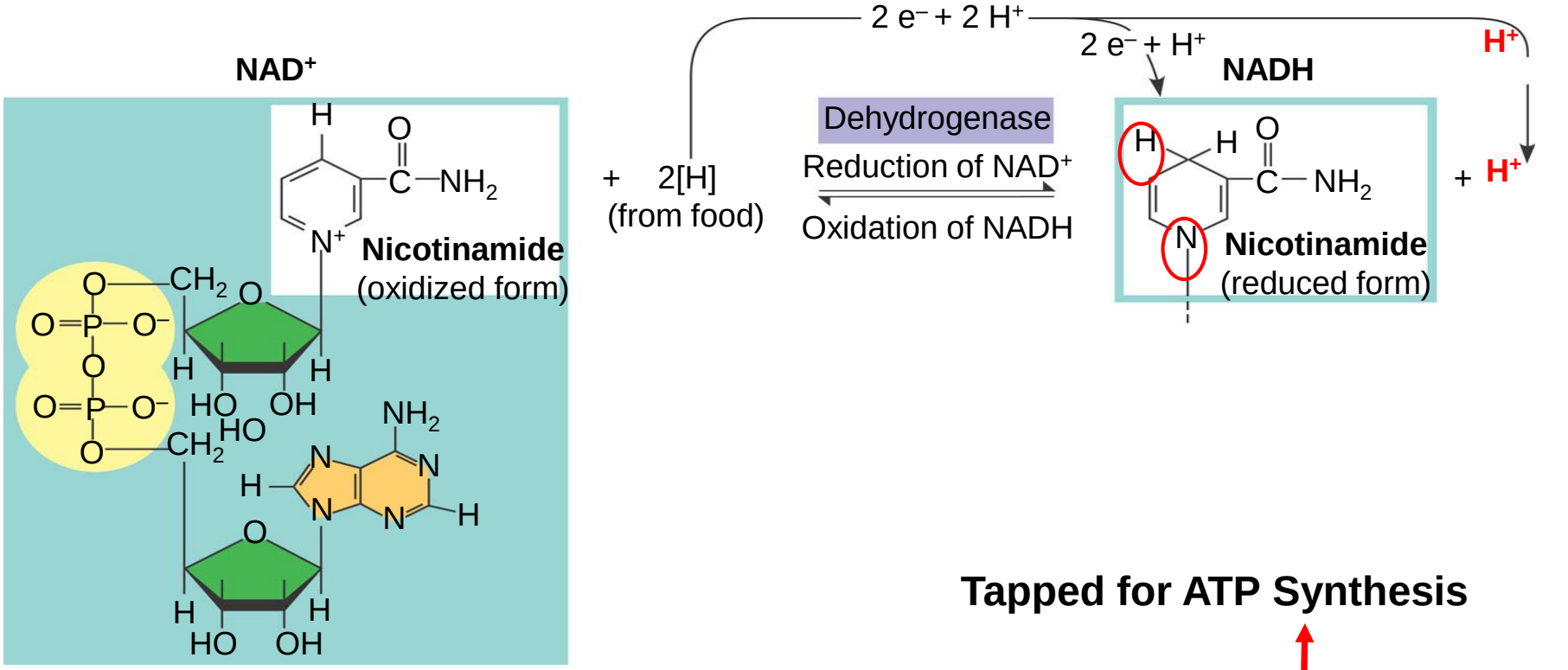
- Do not completely exchange electrons
- Change the degree of electron sharing in covalent bonds





Electrons from organic compounds

– Are usually first transferred to NAD^+, a coenzyme



Tapped for ATP Synthesis

Glucose

Dehydrogenase

$$H-C-OH + NAD^+ \longrightarrow C=O + NADH + H^+$$

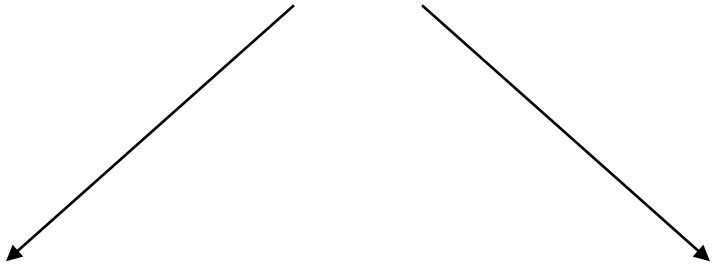
Carbon Dioxide

The Stages of Cellular Respiration

Respiration is a cumulative function of three metabolic stages

- Glycolysis
- The citric acid cycle
- Oxidative phosphorylation

How is the energy currency, ATP, made in the cell?
In other words, how ADP is converted to ATP?

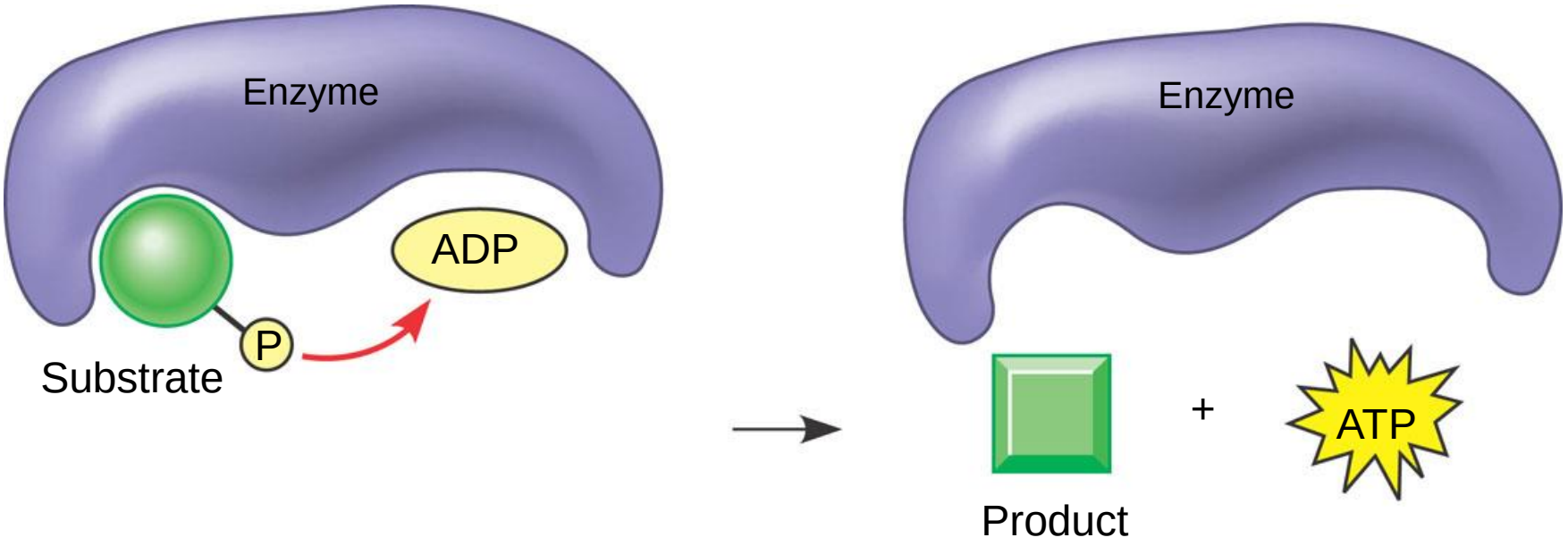


Substrate-level phosphorylation
SLP

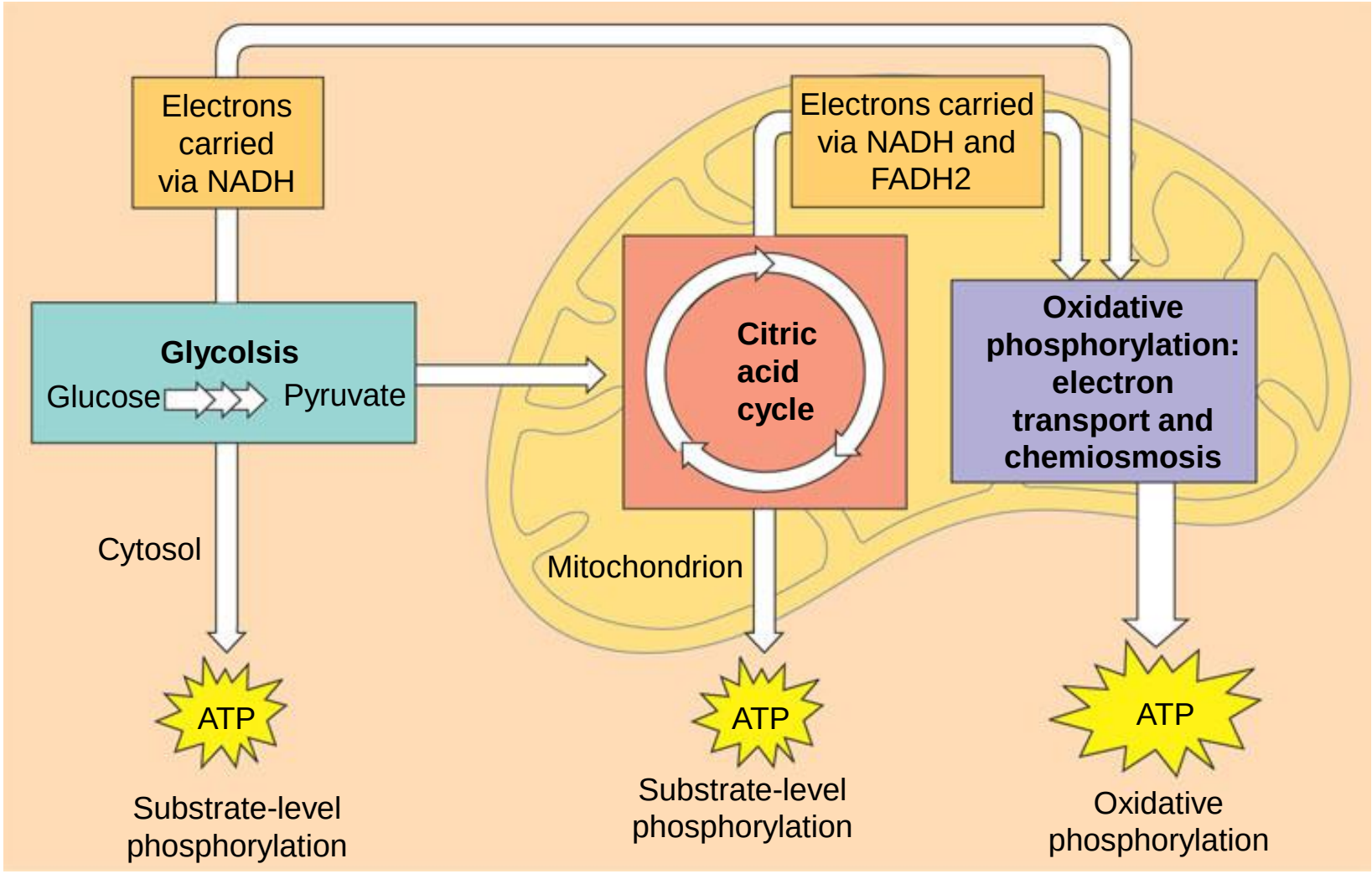
Electron-transport phosphorylation
ETP

Glycolysis and the citric acid cycle

– SLP: Generate ATP



An overview of cellular respiration



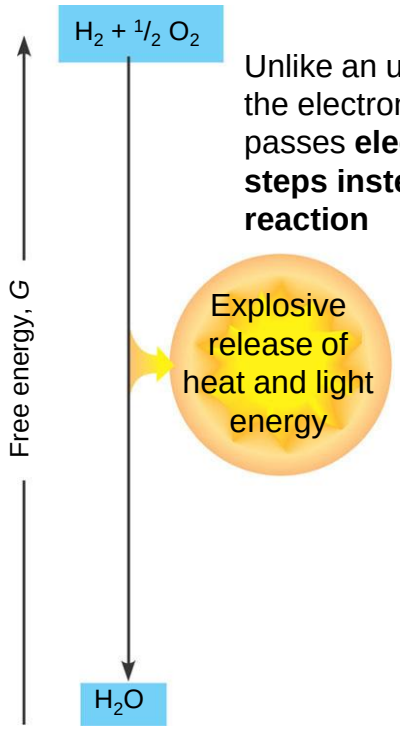
Glycolysis (Sugar-splitting) consists of two major phases

How is the energy currency, ATP, made in the cell?

In other words, how is ADP converted to ATP?

Stepwise energy harvest via NAD+ and the electron Transport chain

Downhill route: Glucose to NADH to Electron transport chain to O2.

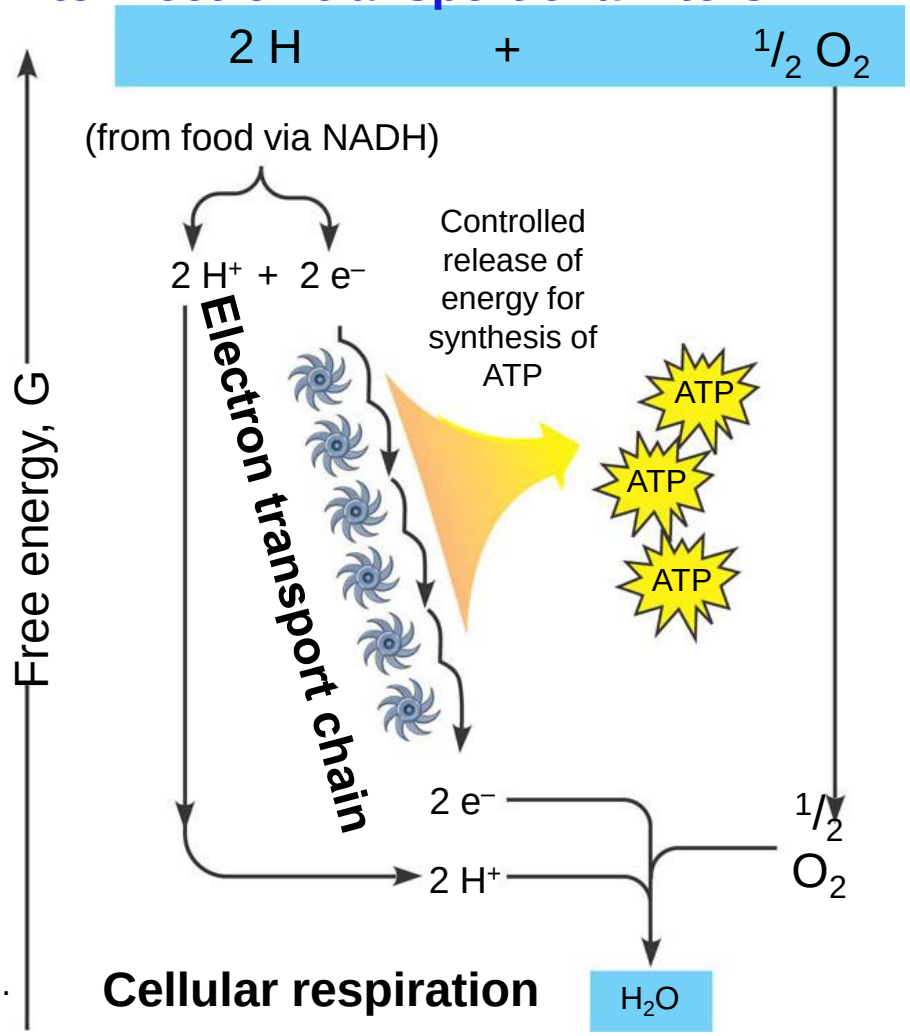


Unlike an uncontrolled reaction, the electron transport chain passes **electrons in a series of steps instead of one explosive reaction**

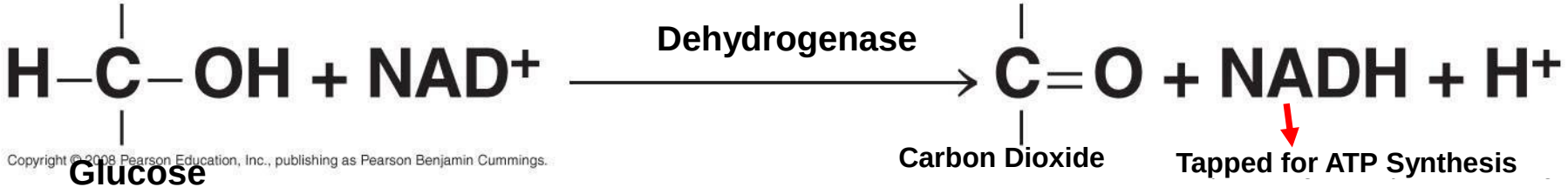
Explosive release of heat and light energy

Uncontrolled Reaction (Space Shuttle fuel)

Electron transfer from NADH to oxygen is an exergonic reaction with a free energy of -53 kcal/mol.

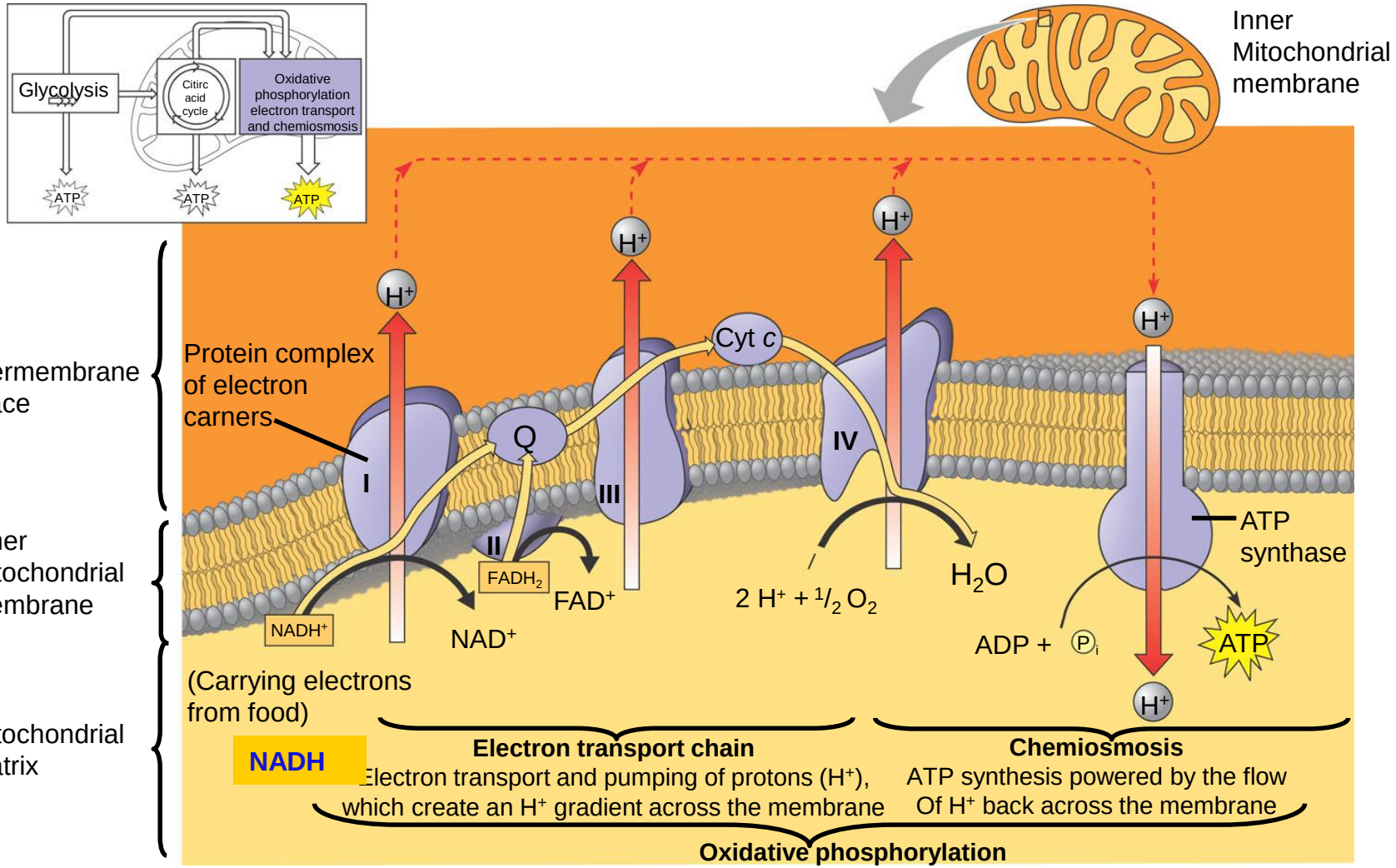


Cellular respiration



Electron transport phosphorylation, ETP: (Oxidative phosphorylation)

chemiosmosis couples electron transport to ATP synthesis



-Water formation
-ATP production

Glucose to NADH to electron transport chain to proton-motive force to ATP

Photosynthesis

The Process That Feeds the Biosphere

Autotrophs

Plants and other autotrophs
Are the producers of the biosphere

Heterotrophs

Obtain their organic material from other organisms
Are the consumers of the biosphere

Plants are photoautotrophs

– They use the energy of sunlight to make organic molecules from water and carbon dioxide

Respiration v/s Photosynthesis

Respiration Reaction:

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

Photosynthesis Reaction:

$6CO_2 + 12\ H_2O$ + Light Energy => $C_6H_{12}O_6 + 6O_2 + 6H_2O$

Net Reaction:

$6CO_2 + 6\ H_2O$ + Light Energy => $C_6H_{12}O_6 + 6O_2$

Basic Reaction:

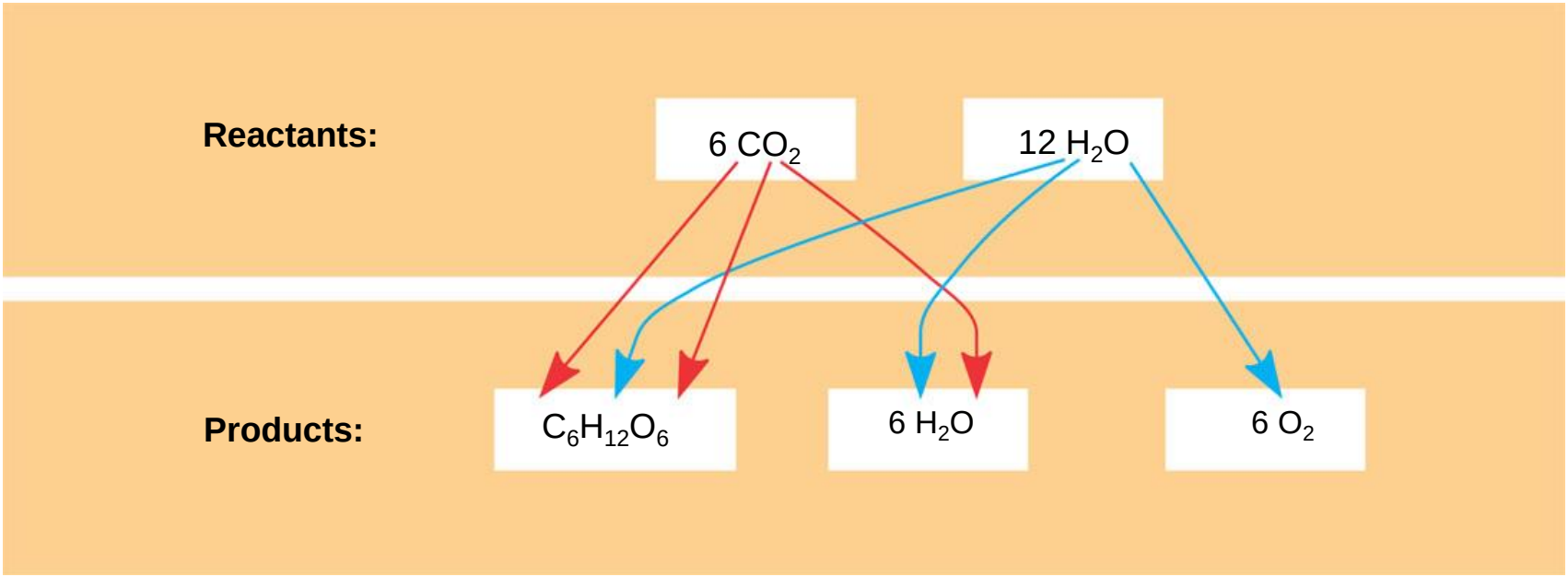
$CO_2 + H_2O$ => $[CH_2O] + O_2$

Comes from splitting of H_2O

Chloroplasts split water into

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

Photosynthesis is a redox process in which H_2O



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