Energy Transformation

Metabolism = total chemical reactions in cells.

metabole = change

Metabolism is concerned with managing the material and energy resources of the cell

-Catabolism

-Anabolism

-Catabolism is the degradative process to harvest energy from breaking down the macromolecules to simpler compounds.

Cellular respiration is the main process to convert potential energy stored in macromolecules into available energy for cellular work.

-Anabolism consumes energy to build or synthesize complicated molecule from simpler ones

Cells use energy from catabolism to drive reactions in anabolism.

Energy = capacity to do work or capacity to cause specific changes

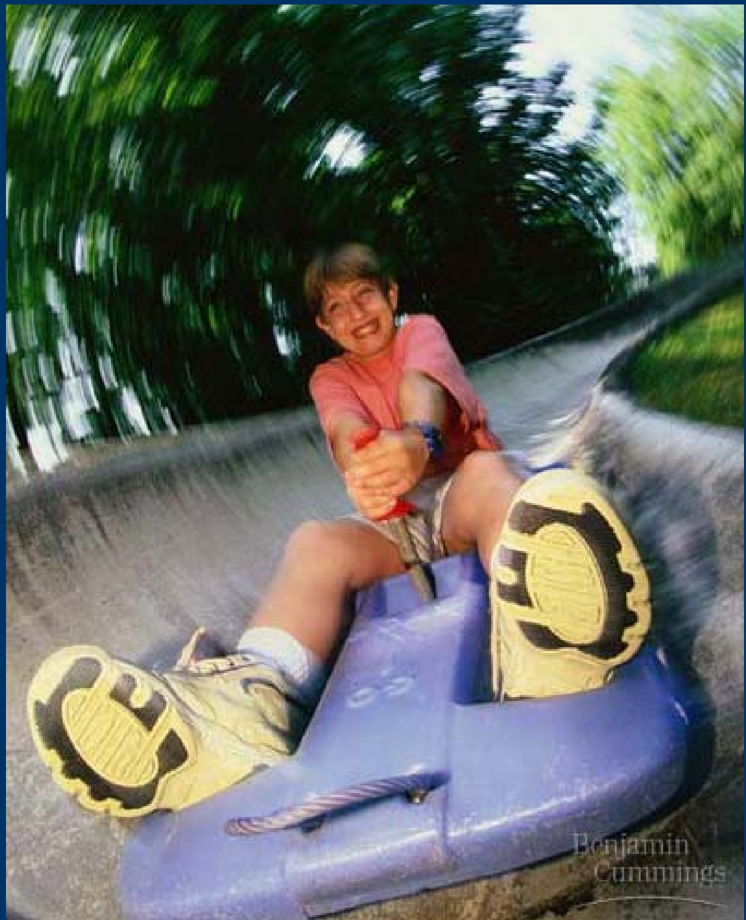
-non biological systems use HEAT to perform work, but

-biological systems use CHEMICAL ENERGY to do work

2 stages of energy -potential energy = stored energy

-kinetics energy = the energy of motion

Sliding down converts potential energy to kinetics energy



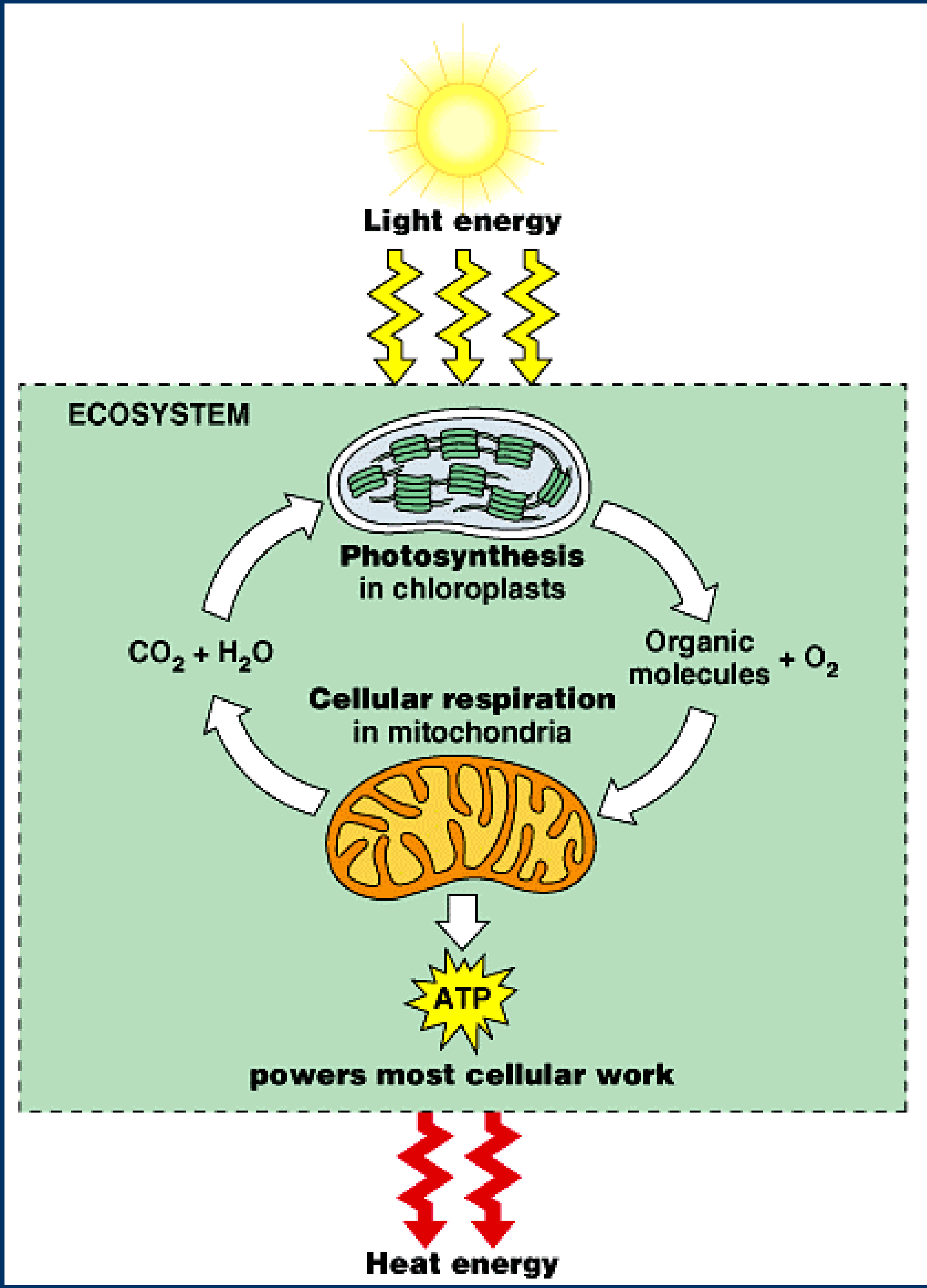
In living cells, chemical energy is a potential energy stored in a molecule resulting from the arrangement of atoms in that molecules.

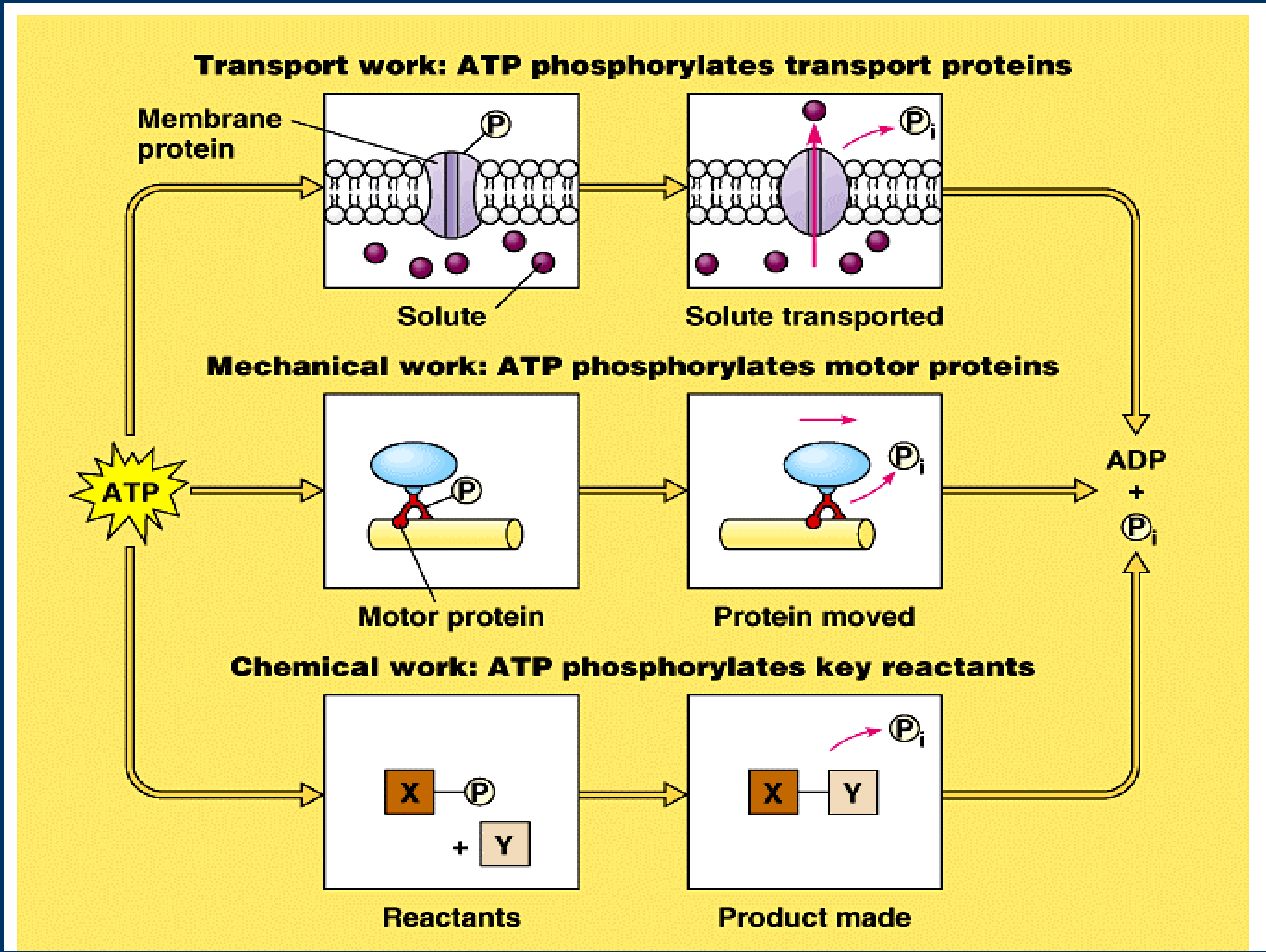
Catabolic pathways rearrange the molecular structure of nutrients e.g. breaking down glucose to CO_2 and water.

As a result, the potential energy in those nutrients is converted to kinetic energy to cause specific changes in cells.

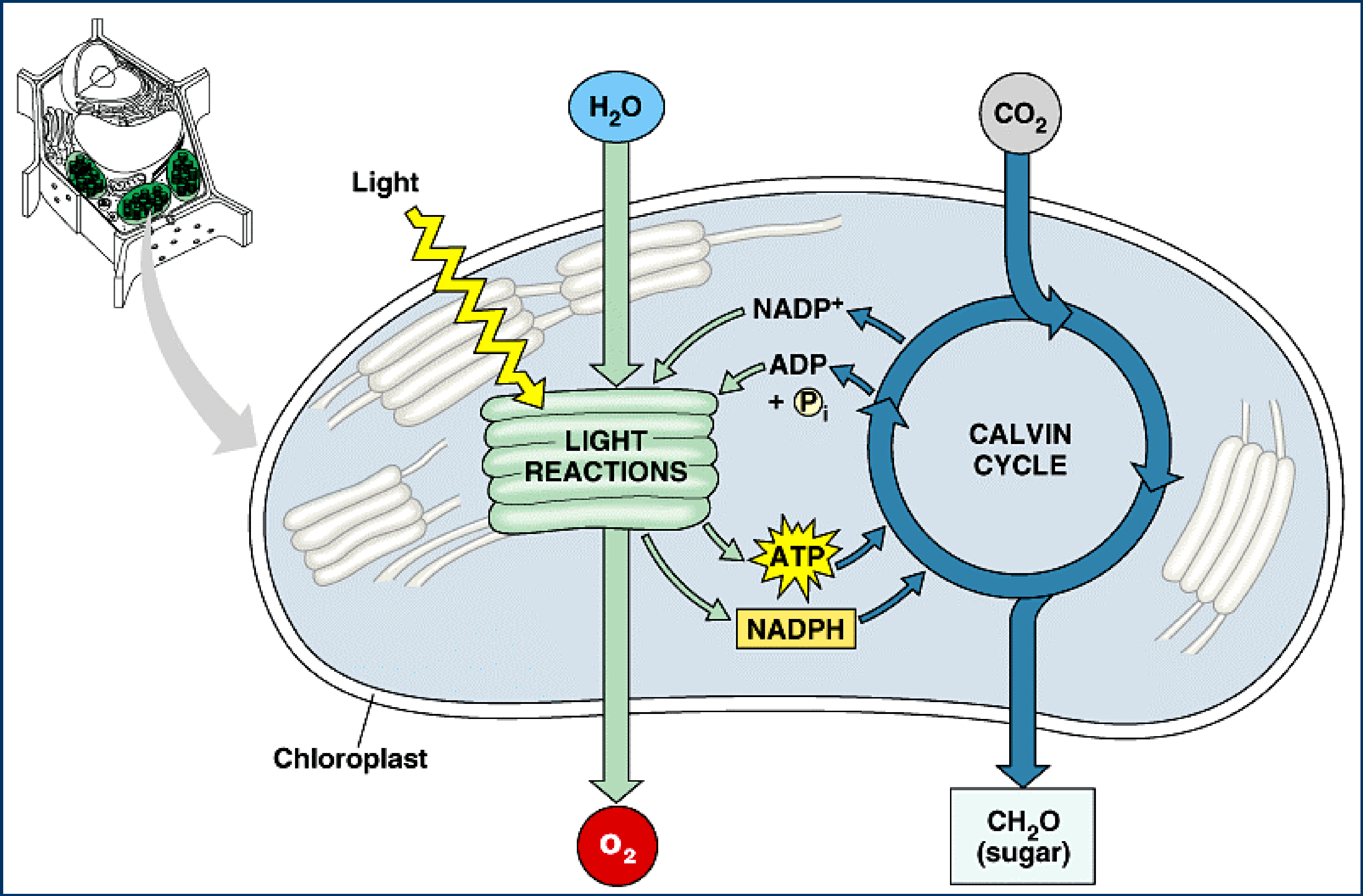
Photosynthesis VS Cellular Respiration

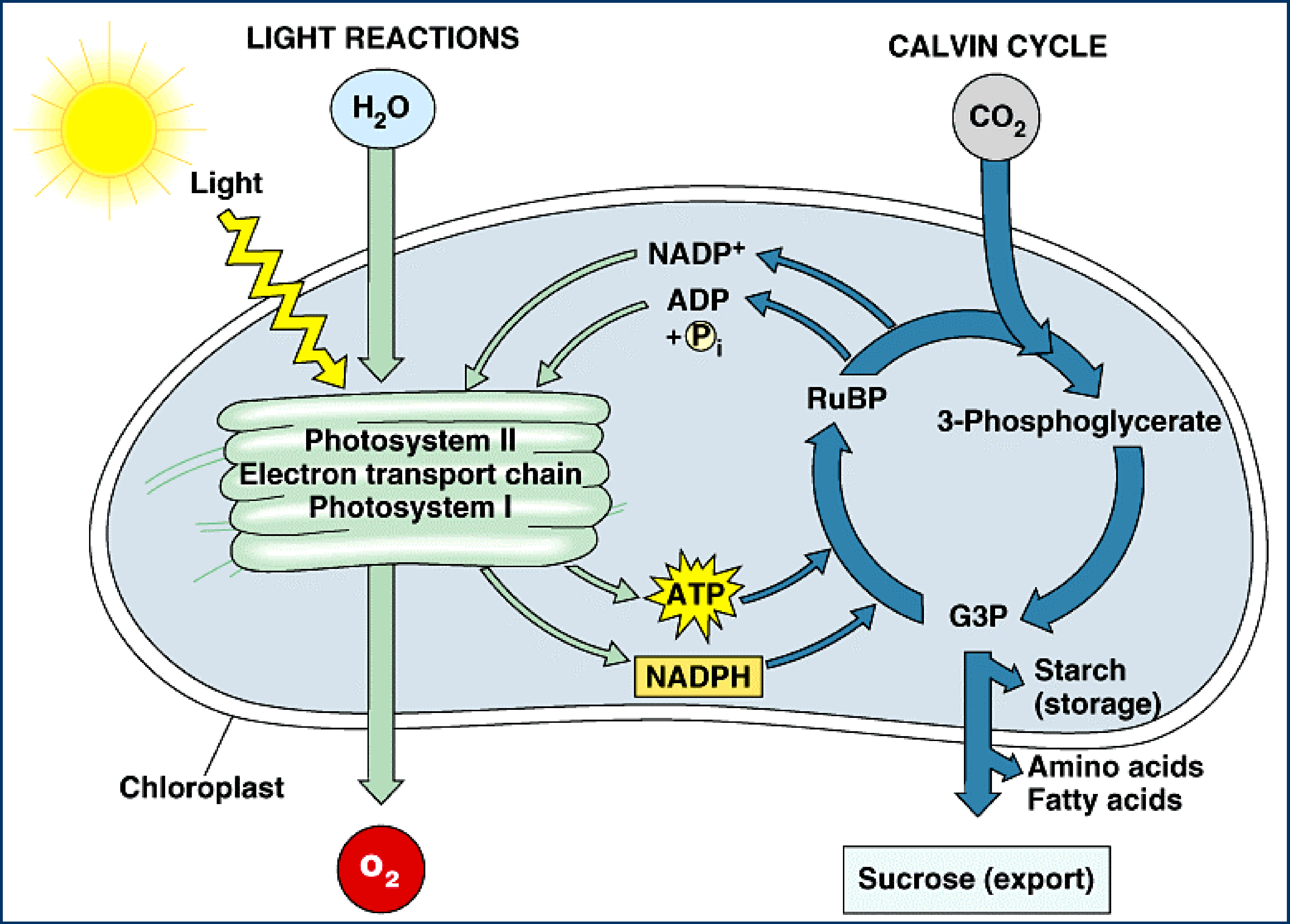
In ecosystem energy flow and chemical recycling between 2 processes: photosynthesis in the chloroplast and cellular respiration in mitochondria.





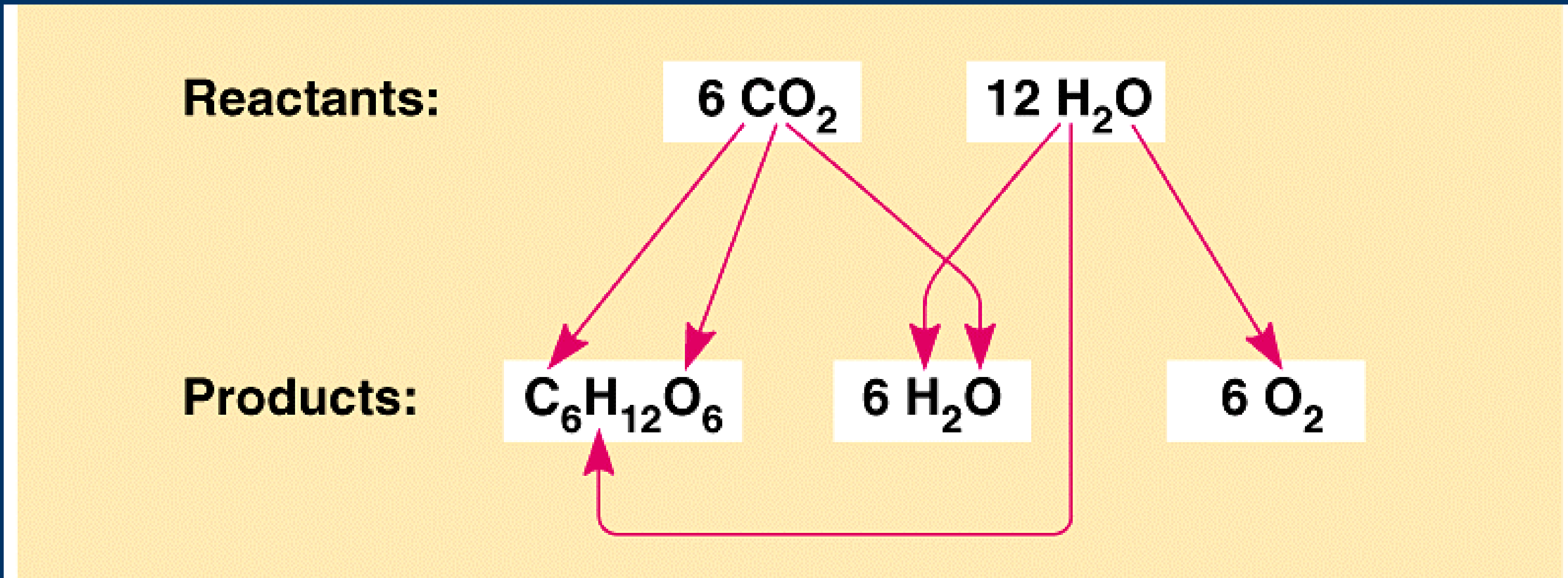
ATP, cell's energy currency, drives cellular works.


H_2O
CO_2
Light
NADP+
ADP
+ P_i
LIGHT
REACTIONS
CALVIN
CYCLE
ATP
NADPH
Chloroplast
O_2
CH_2O
(sugar)



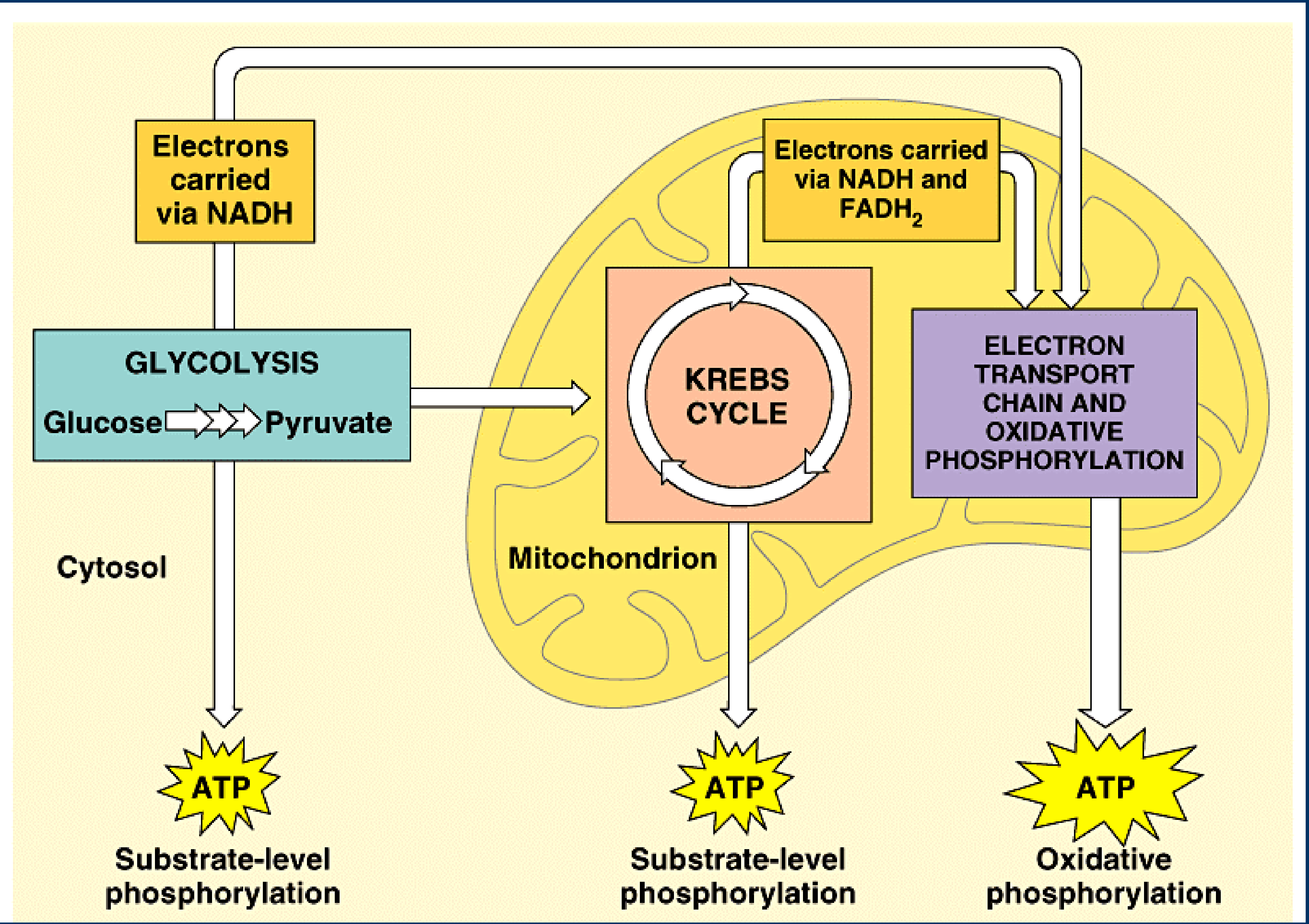
LIGHT REACTIONS
CALVIN CYCLE
H_2O
CO_2
Light
$NADP^+$
ADP
+ P_i
RuBP
3-Phosphoglycerate
Photosystem II
Electron transport chain
Photosystem I
ATP
NADPH
G3P
Starch
(storage)
Amino acids
Fatty acids
Chloroplast
O_2
Sucrose (export)

Tracking Atoms through Photosynthesis



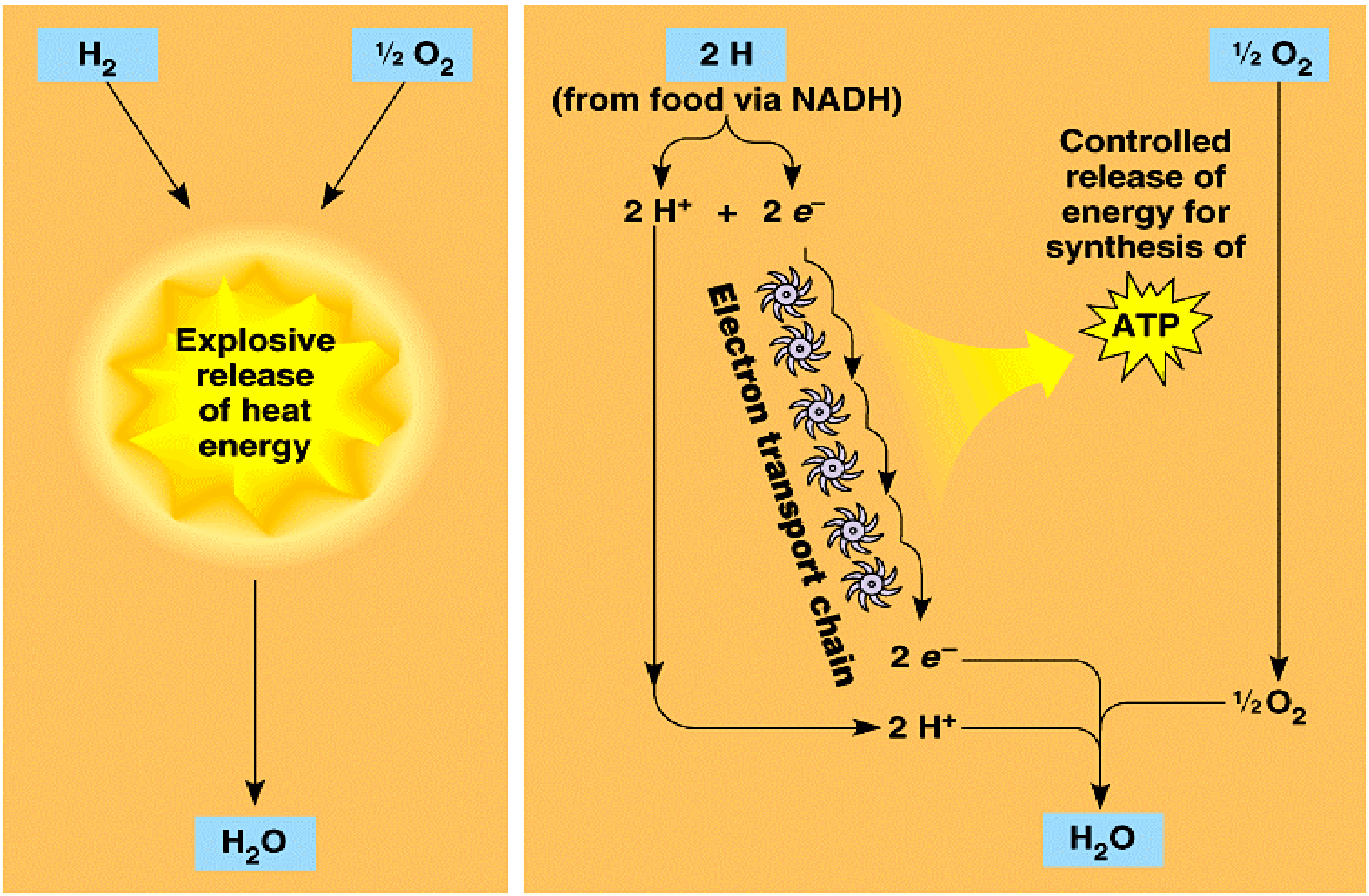
Hydrogen extracted from water is incorporated into sugar and the oxygen released to the atmosphere (where it will be used in respiration).

Overview of Cellular Respiration



Electron Transport Chain

Stepwise reduction reaction to avoid explosive release of heat.



(a) Uncontrolled reaction (b) Cellular respiration

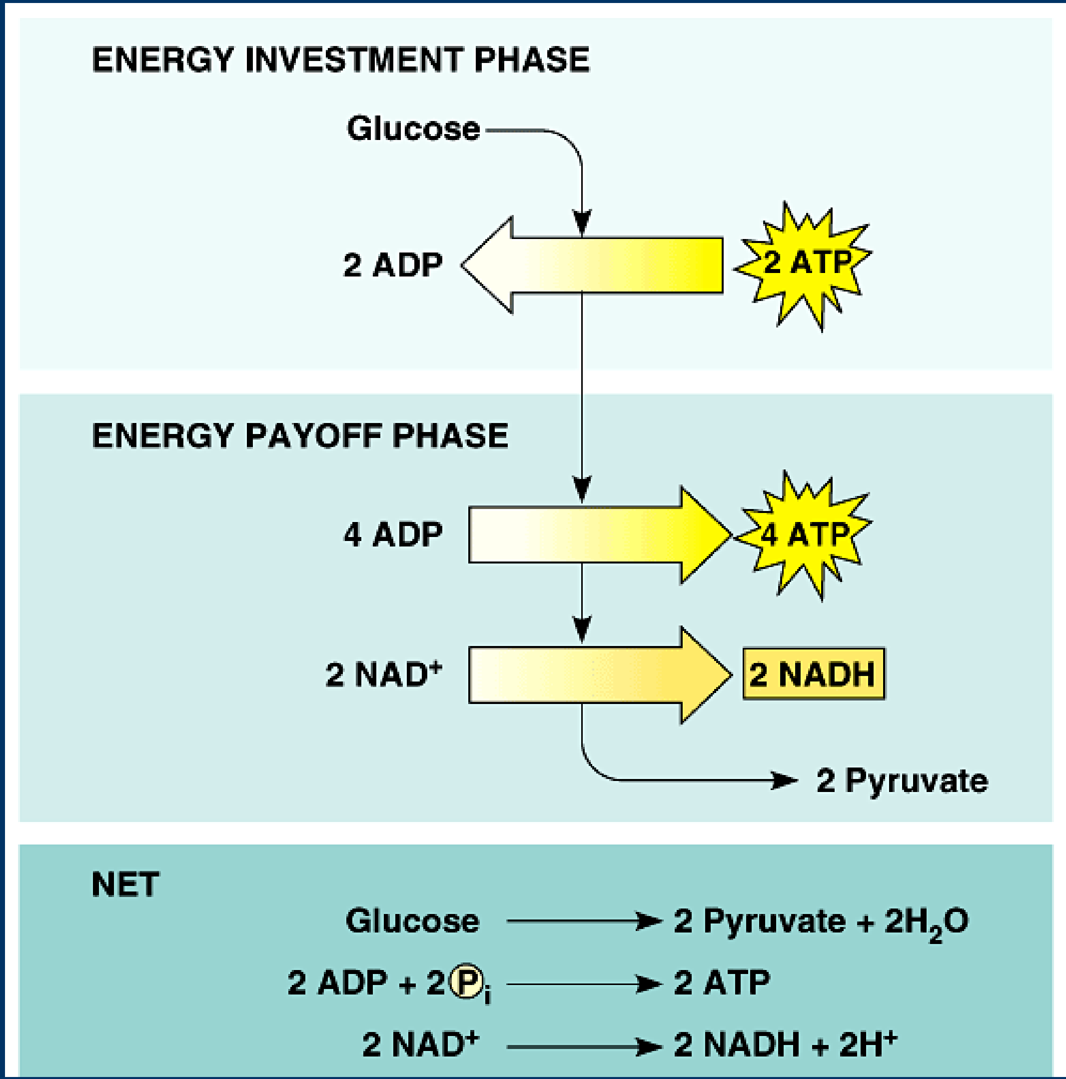
Glycolysis

-in cytosol

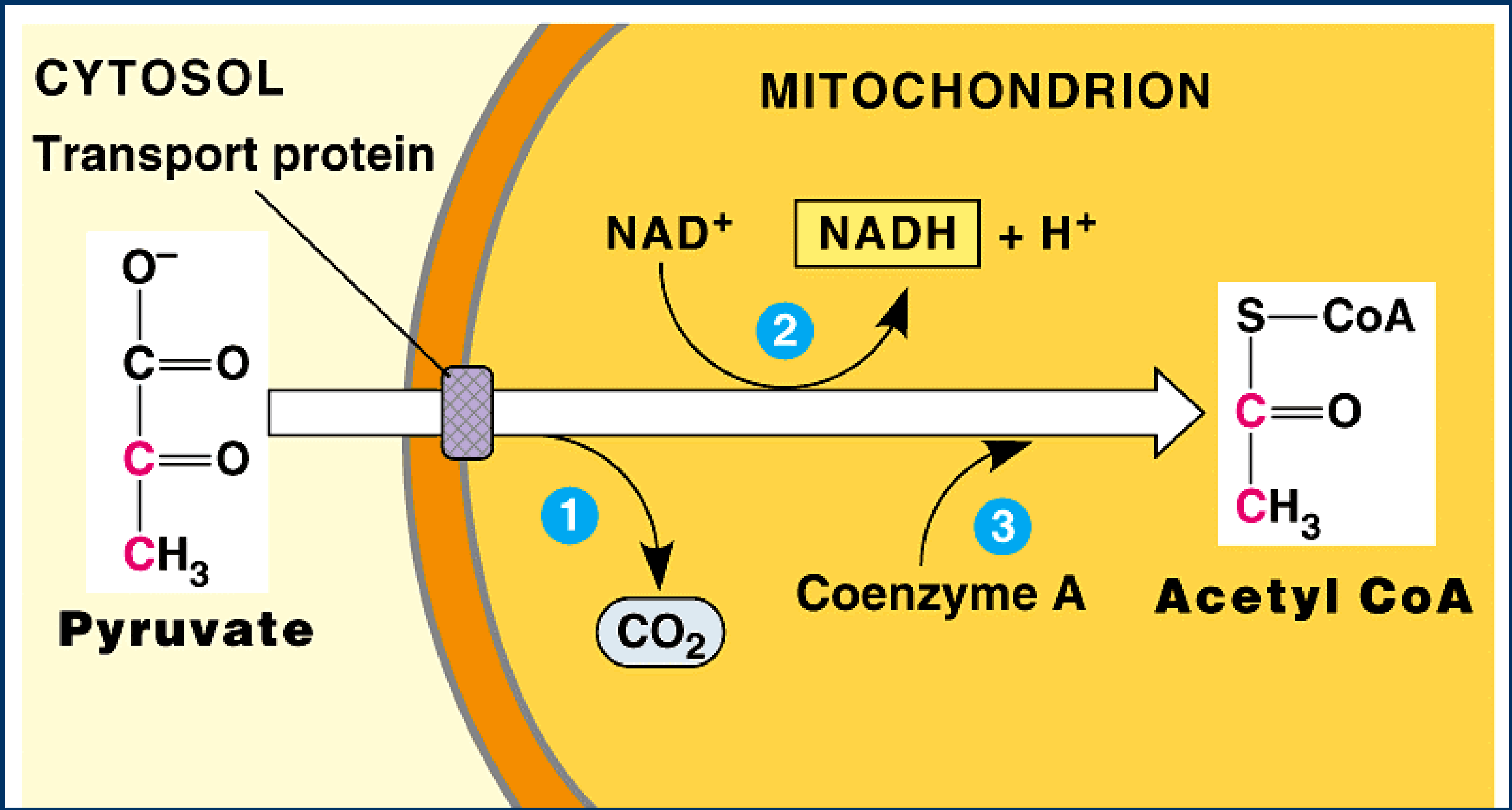
-glucose → 2pyruvate

-net result = 2ATP and 2NADH

-ATP is produced by substrate level phosphorylation



Conversion of Pyruvate to Acetyl CoA: the junction between glcolysis and Krebs cycle

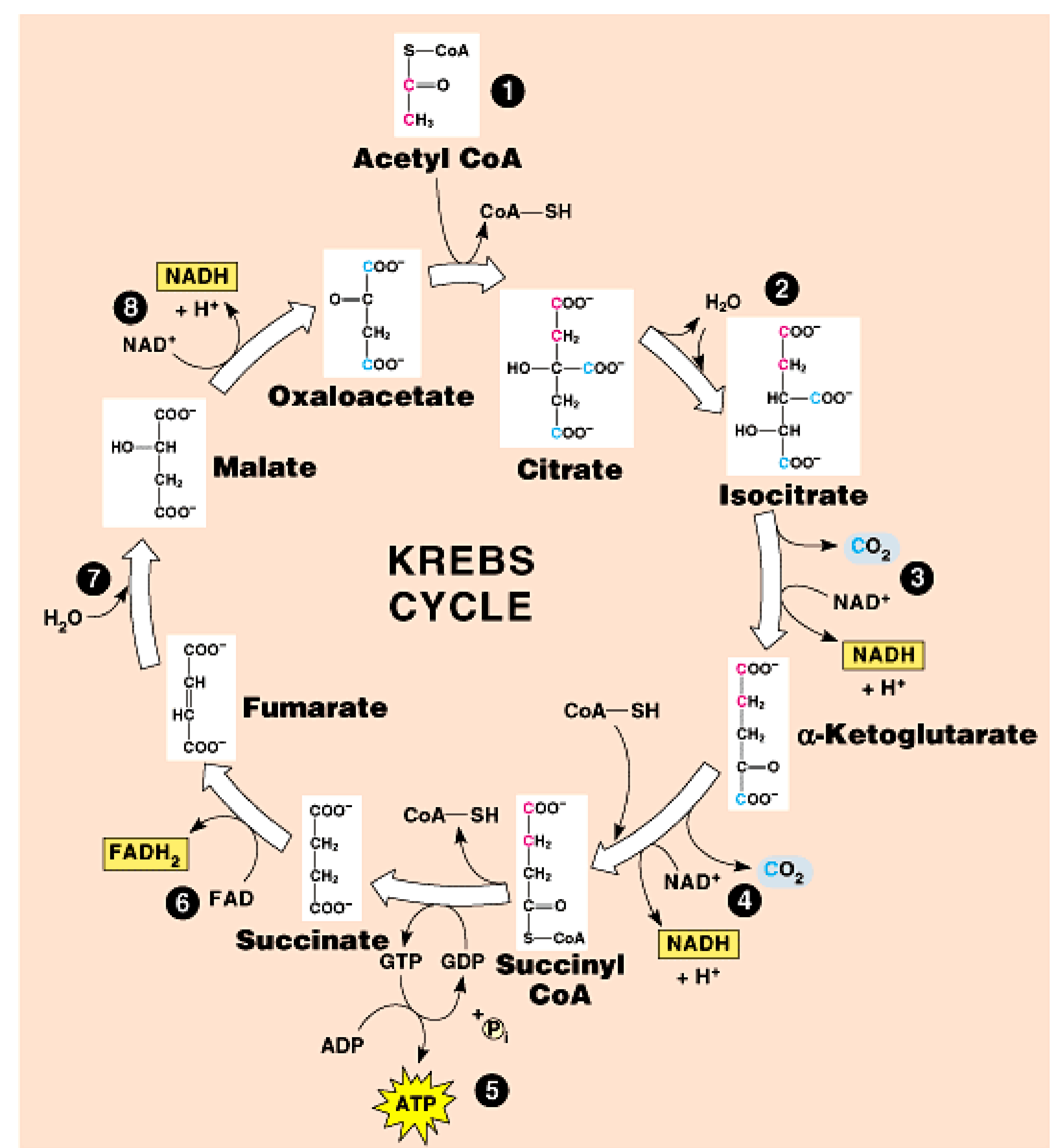


1 Pyruvate → 1 Acetyl CoA + CO_2

yield 1 NADH

Krebs Cycle

-matrix of mitochondria
-1 acetyl CoA yields
    3NADH + H^+
    1 $FADH_2$
    1ATP
    $2CO_2$
(large quantity of electron carriers are produced)

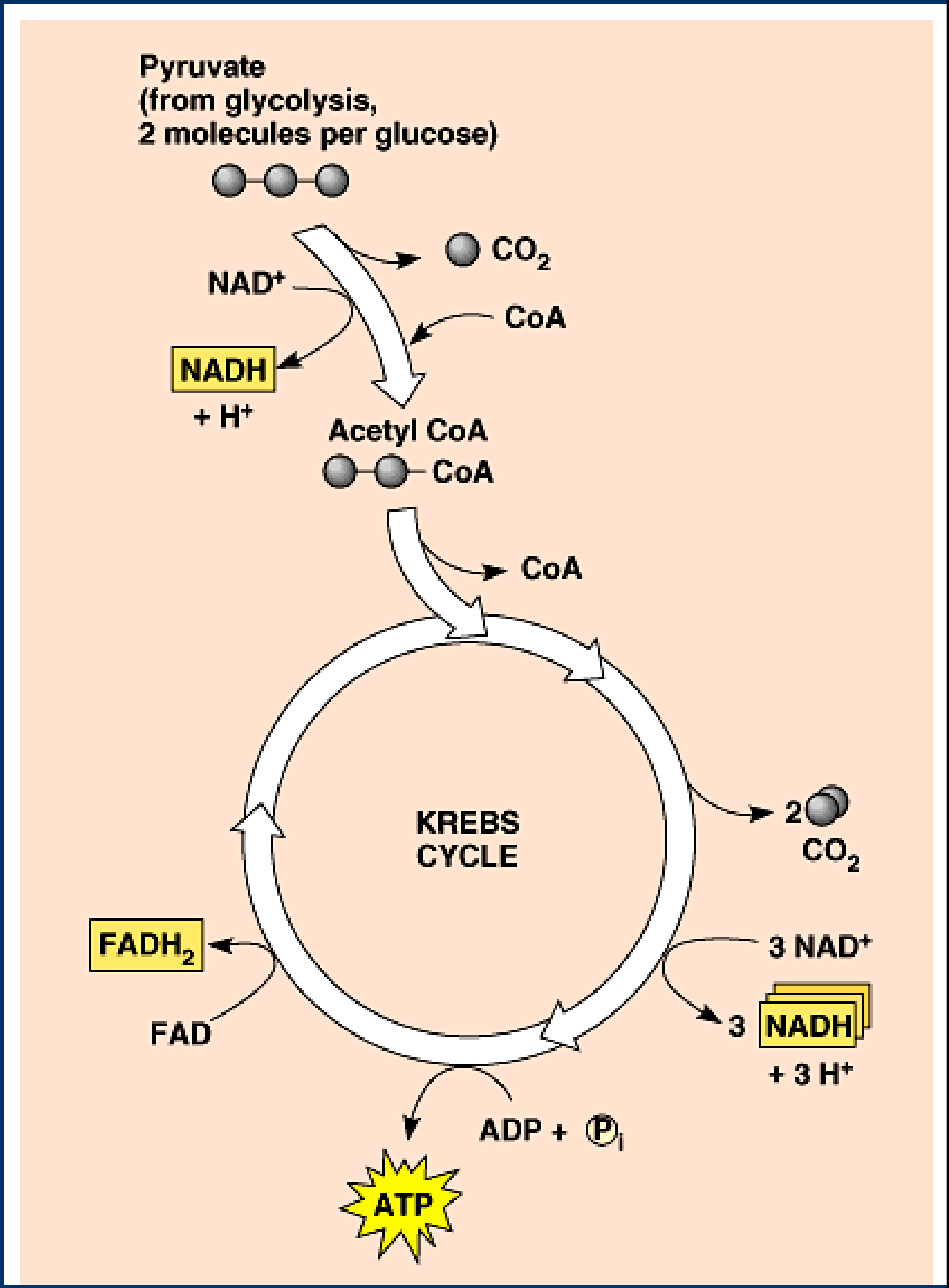


Summary of Krebs Cycle

1 Pyruvate yields:

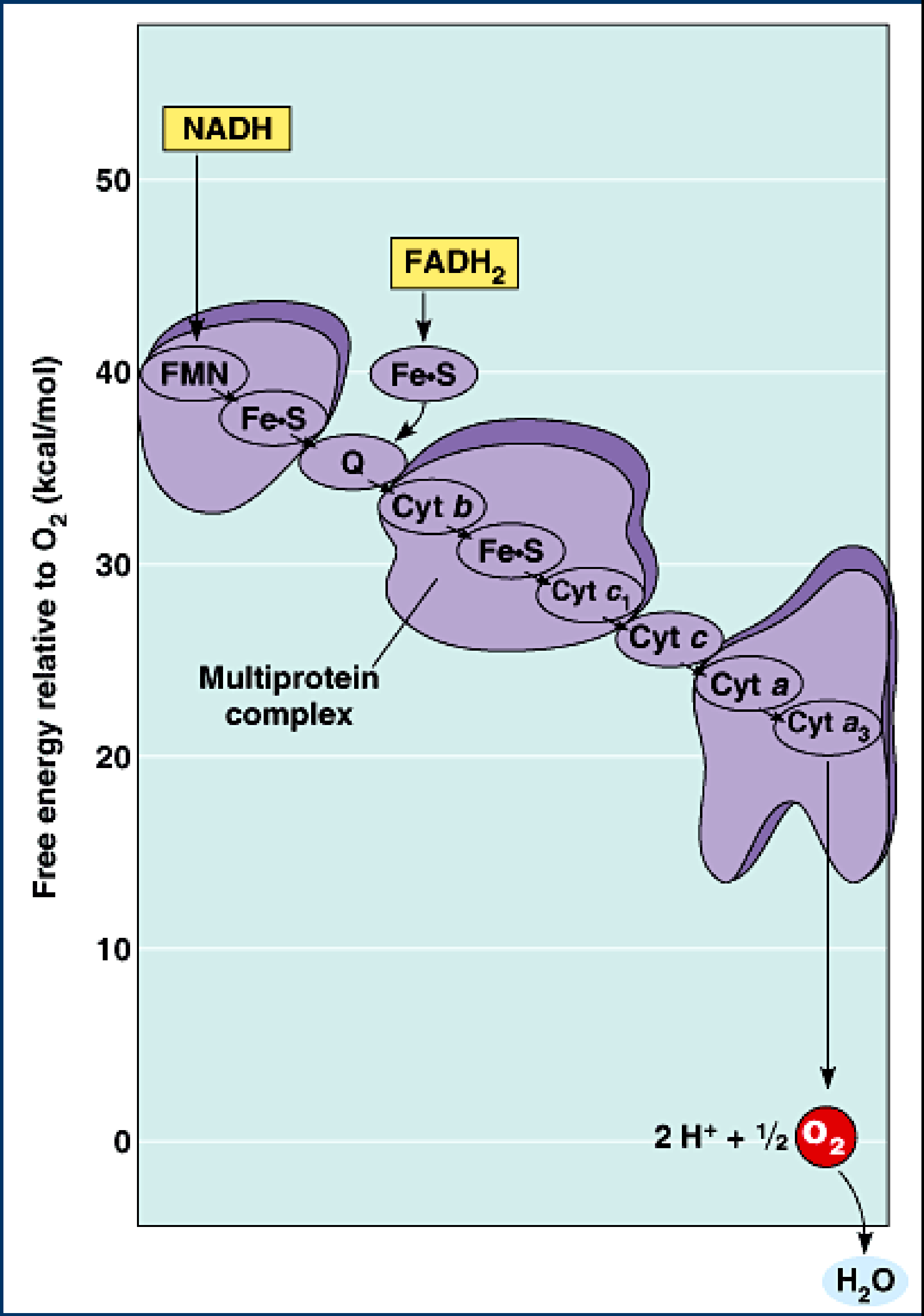
- -3 CO_2
- -1 ATP from substrate level phosphorylation
- -4 NADH + H^+
- -1 $FADH_2$

1 Glucose yields 2 pyrvate from Glycolysis



Electron Transport Chain

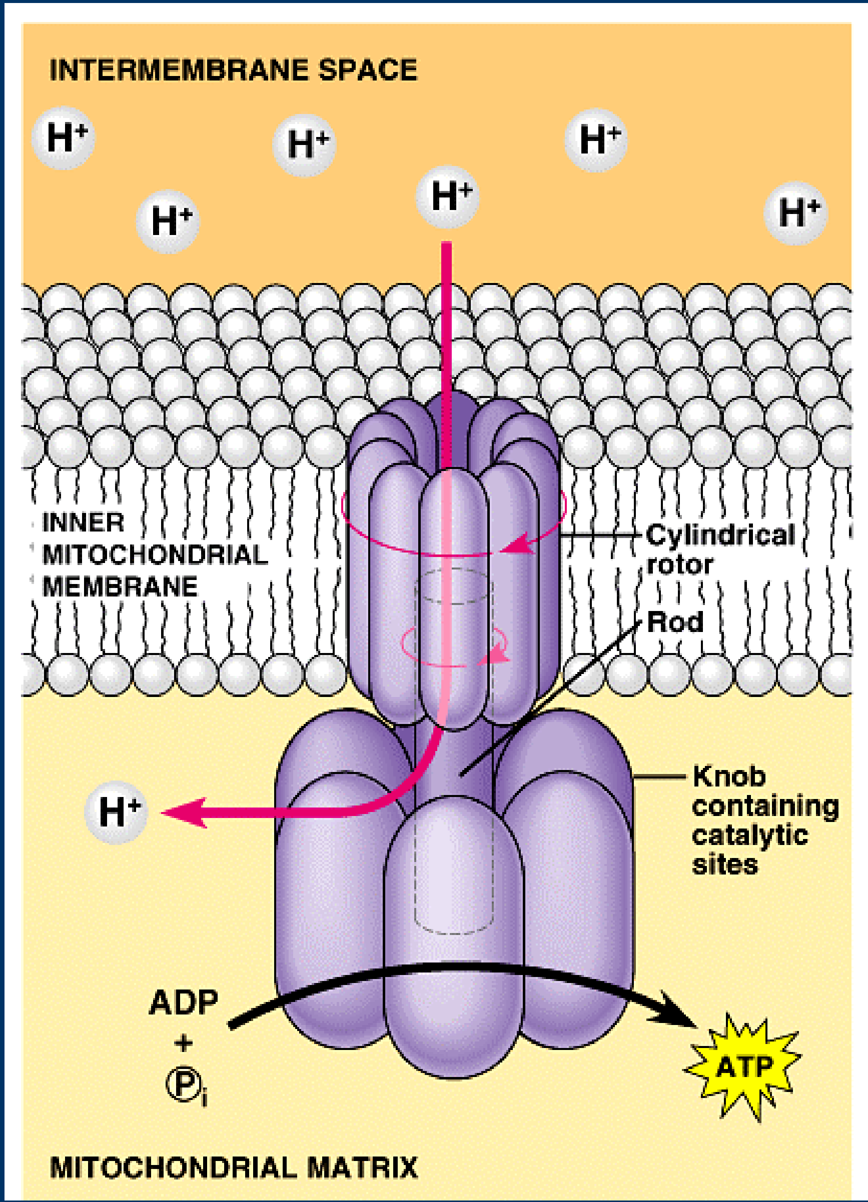
-inner membrane of mitochondria
-electron is transferred to electron acceptor with higher affinity (more electronegative)
-O_2, the most electronegative electron acceptor, is the final electron acceptor
-free energy was released during electron transfer



Chemiosmosis: The Energy-Coupling Mechanism

-innermembrane of mitochondria is impermeable to proton (H^+)

-H^+ was pumped across the membrane by the free energy released by the electron transfer (from matrix to the intermembrane space)
= generation of proton motive force



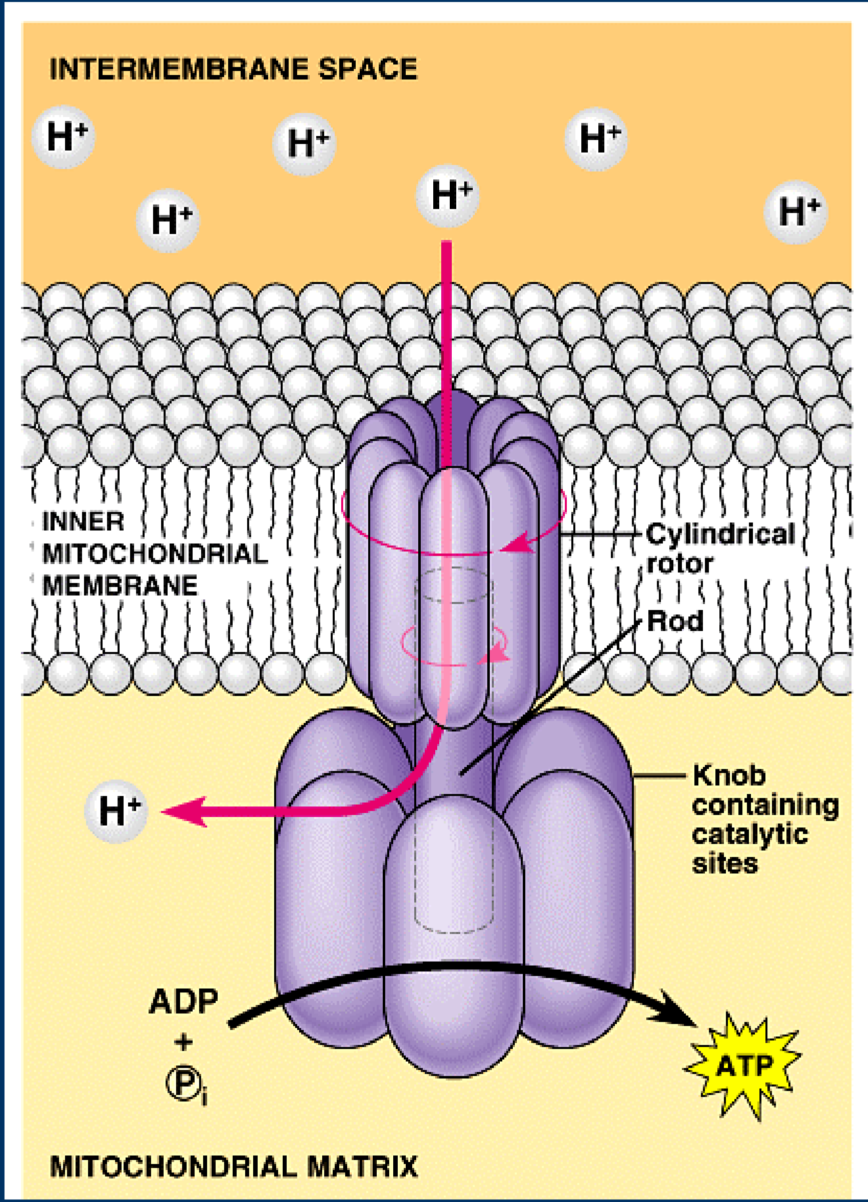
ATP synthase

Chemiosmosis: The Energy-Coupling Mechanism

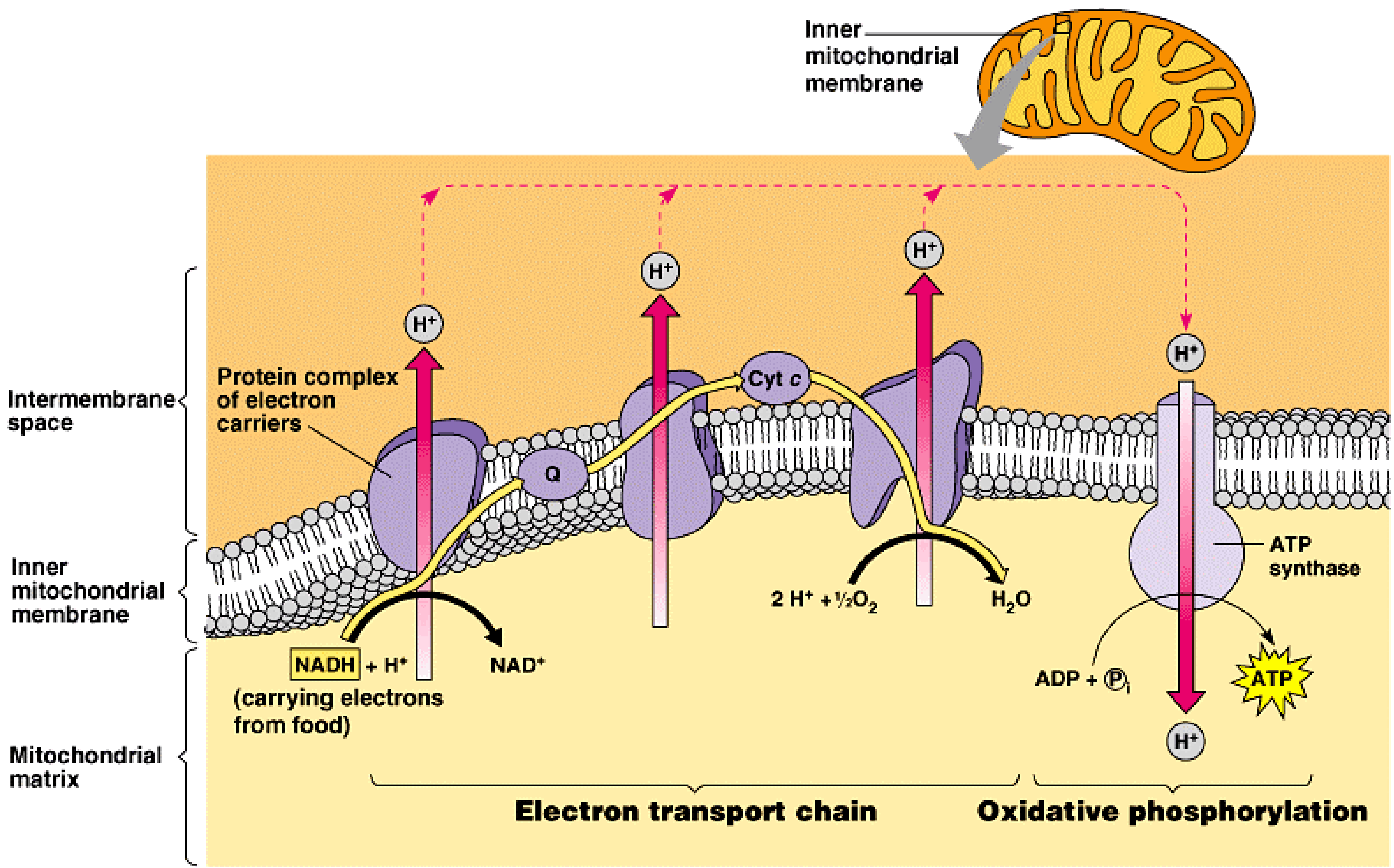
-H^+ flow back to the matrix by a channel in ATP synthase

-free energy released from the H^+ flow is used to synthesize ATP

=Oxidative Phosphorylation



ATP synthase

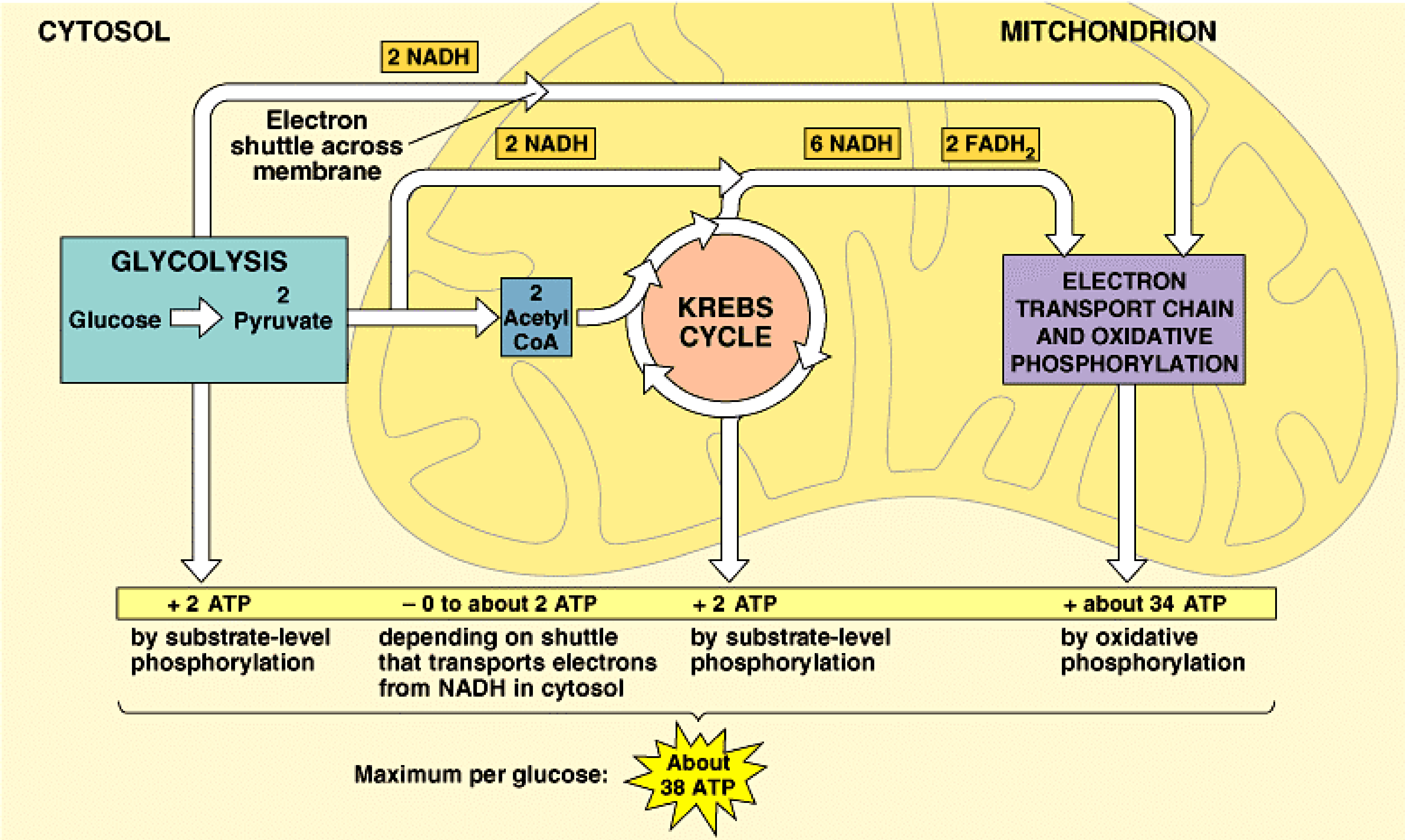


Inner mitochondrial membrane
Intermembrane space
Inner mitochondrial membrane
Mitochondrial matrix
Protein complex of electron carriers
H+
Q
Cyt c
NADH + H+
(carrying electrons from food)
NAD+
2 H+ + ½O2
H2O
ATP synthase
ADP + Pi
ATP
Electron transport chain
Oxidative phosphorylation

1 NADH yields ~ 3ATP
8 NADH ~ 24 ATP

1 $FADH_2$ yields ~ 2 ATP
2 $FADH_2$ ~ 4ATP

2 NADH from Glycolysis have to be transported into mitochondria by the electron shuttle system to either FADH or NAD = 2-3 ATP/NADH (cytosol)
net = 24 + 4 + 6 or 4 = 34 - 32 ATP from oxidative phosphorylation


CYTOSOL
MITCHONDRION
2 NADH
Electron shuttle across membrane
2 NADH
6 NADH
2 $FADH_2$
GLYCOLYSIS
Glucose
2 Pyruvate
2 Acetyl CoA
KREBS CYCLE
ELECTRON TRANSPORT CHAIN AND OXIDATIVE PHOSPHORYLATION
+ 2 ATP
by substrate-level phosphorylation
– 0 to about 2 ATP
depending on shuttle that transports electrons from NADH in cytosol
+ 2 ATP
by substrate-level phosphorylation
+ about 34 ATP
by oxidative phosphorylation
Maximum per glucose:
About 38 ATP

Efficiency of Cellular Respiration

ΔG for oxidation of glucose to CO_2 and H_2O = - 686 kcal/mol

38ATP are generated from this process = 38 X 7.3 kcal = 277.4 kcal

efficiency = $\frac{277.4 \times 100}{686}$ = 40%

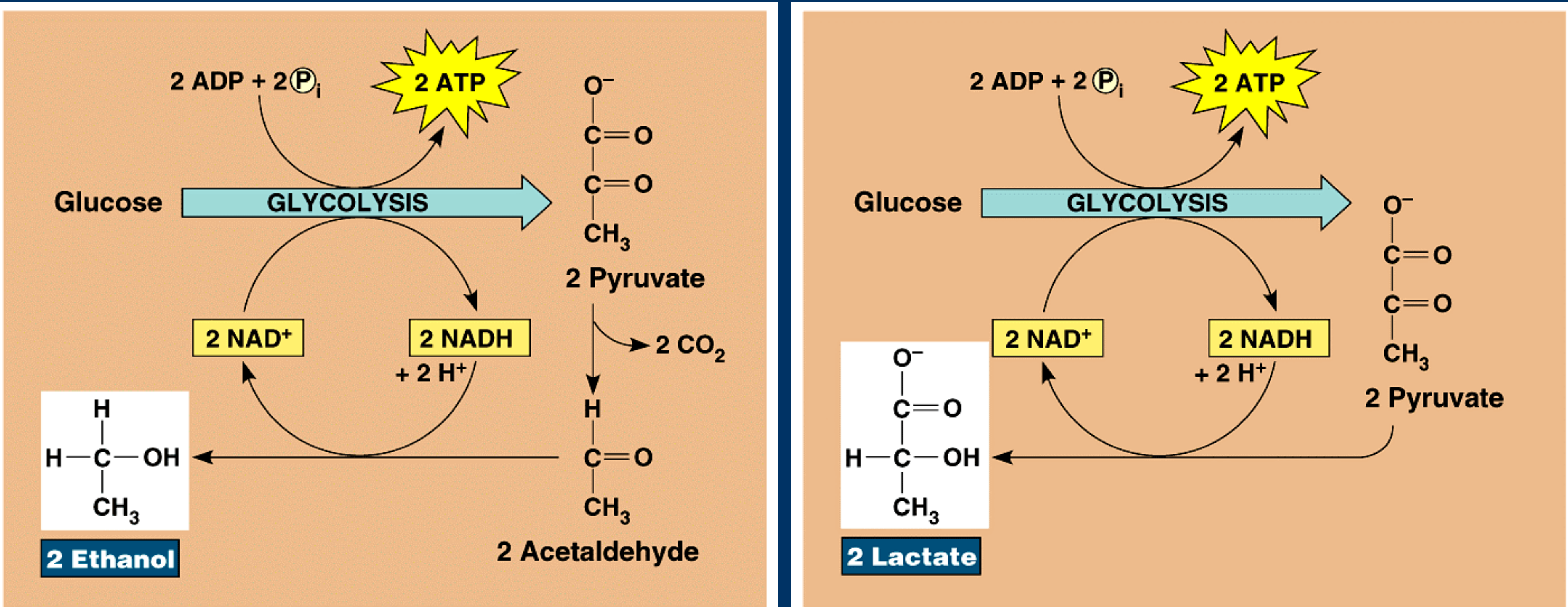
60% of the stored energy was lost as heat

-maintain body temperature

-dissipated as sweat

<u>Fermentation</u>: anaerobic process

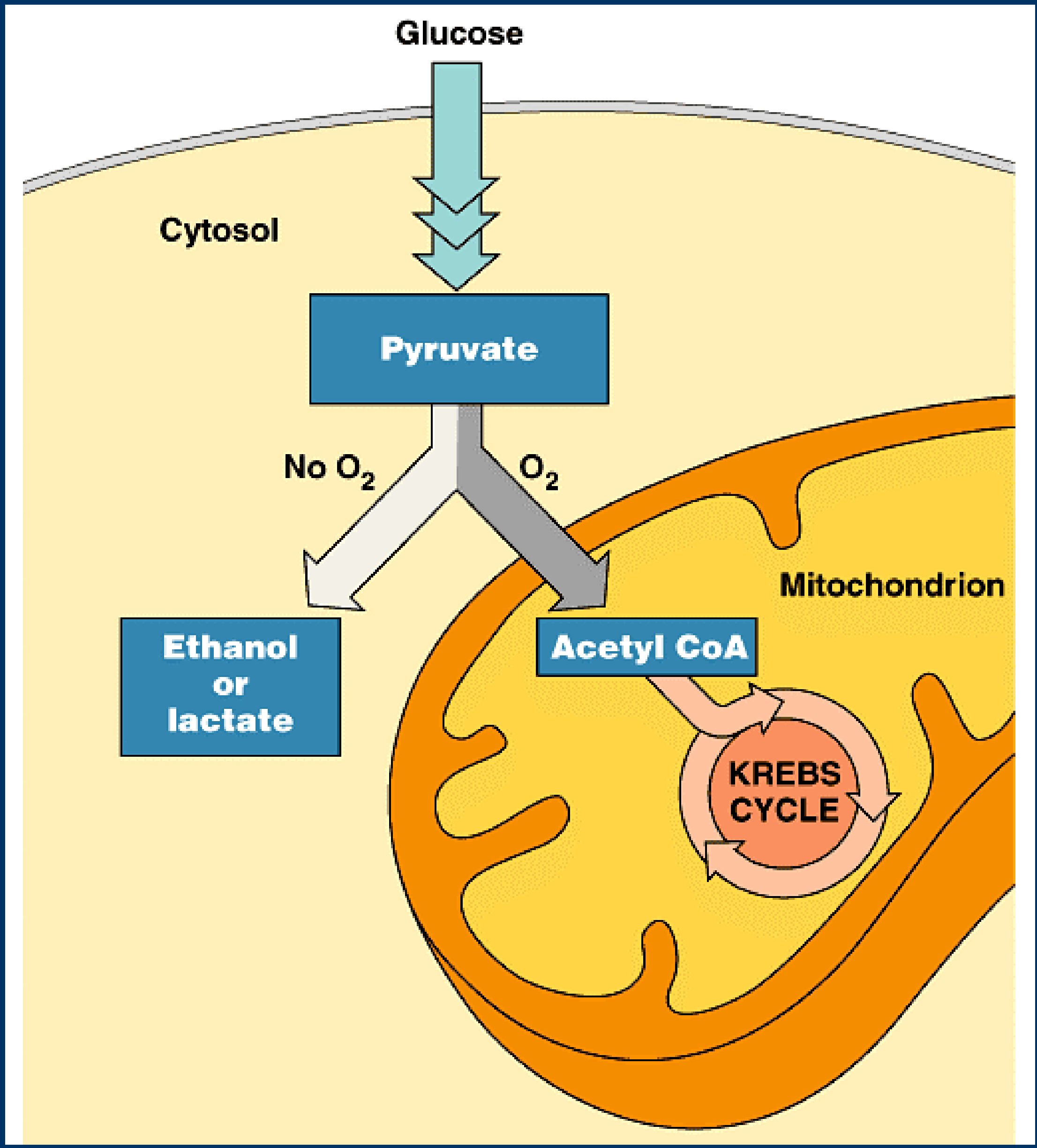
-organic compound is an electron acceptor
-produce ethanol or lactate



(a) Alcohol fermentation

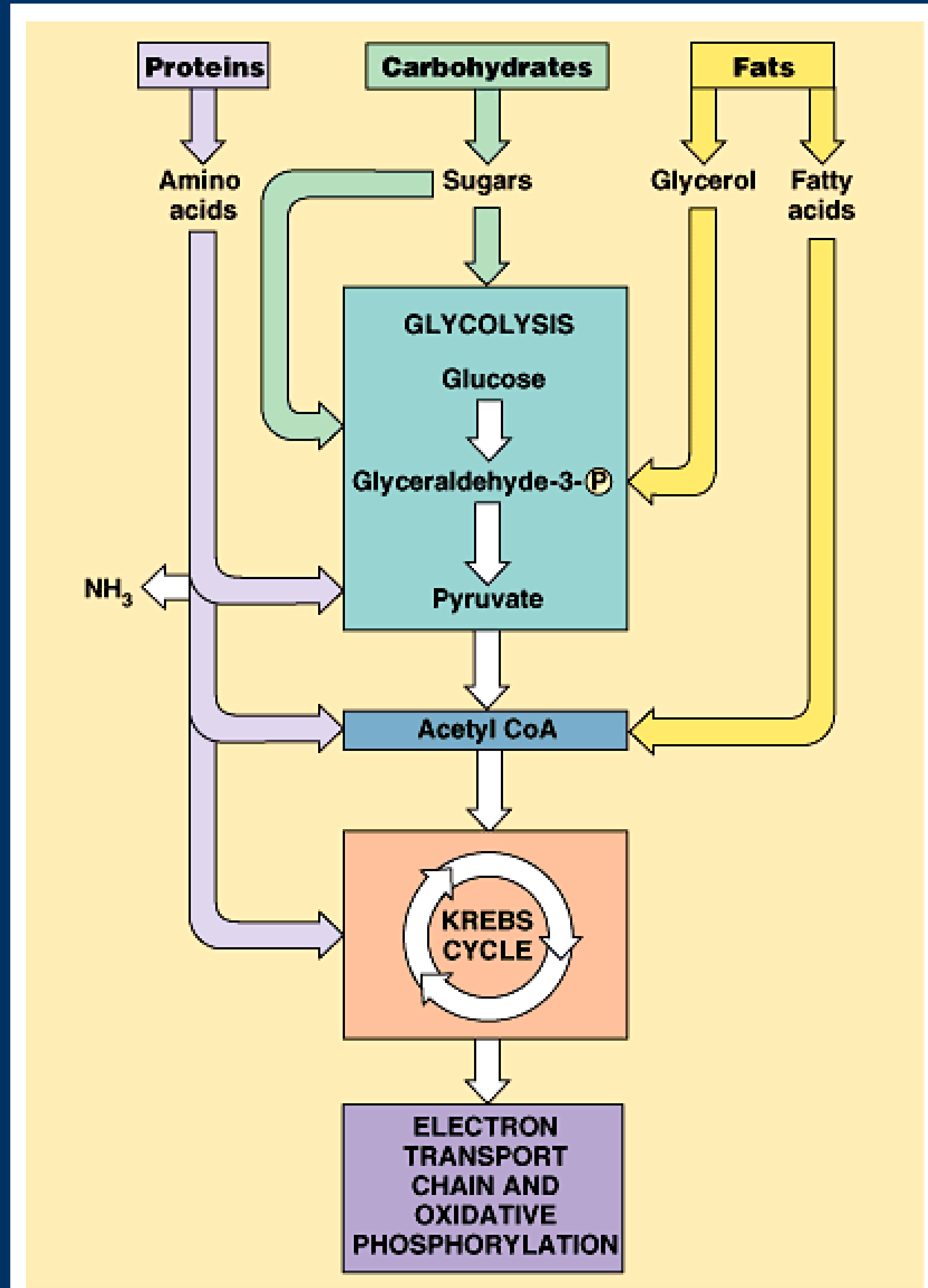
(b) Lactic acid fermentation

Pyruvate as a Key Juncture in Catabolism



Catabolism of Various Macromolecules

Every macromolecules are broken down into intermediates of Glycolysis or Krebs Cycle.



Energy transformations in biological systems obey 2 fundamental laws of thermodynamics:

The first Law of Thermodynamics: the law of conservation of energy

-the energy of the universe is constant

-*energy can be transferred and transformed but it can not be created or destroyed*

The Second Law of Thermodynamics

Every energy transfer or transformation makes the universe more disordered.

Entropy is a measure of disorder or randomness.

Thus, every events in the universe have direction = toward the increase in the entropy of the universe.

e.g. -conversion of glucose to CO_2 and H_2O

-sugar cube dissolved in a cup of water

The Organisms Live at the Expense of Free Energy

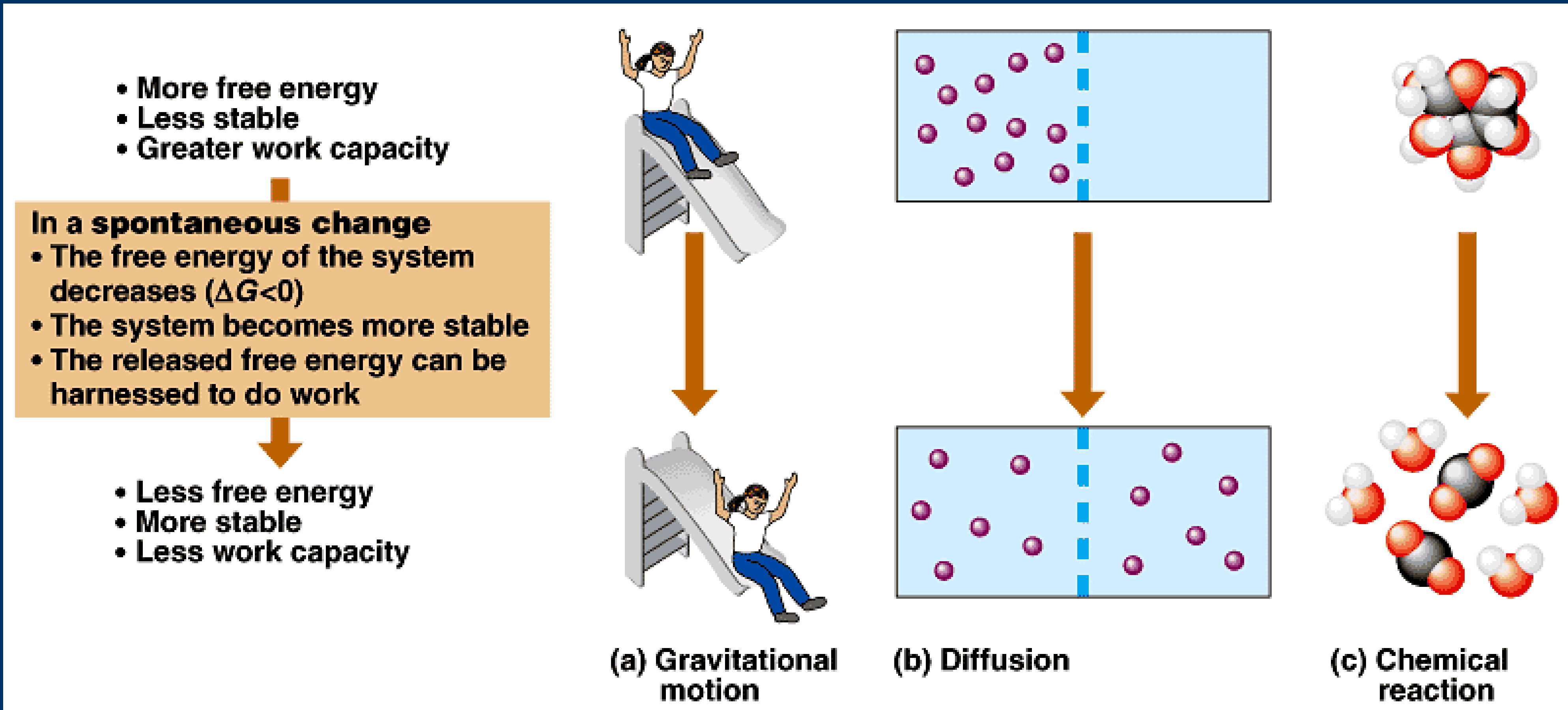
Spontaneous change/reaction:

- -occur without input of energy
- -increase the stability of the system

Nonpontaneous change/reaction:

- -can occur only if energy is added to the system
- -decrease the stability of the system

Free energy = the portion of a system’s energy that can perform work or is available for work when temperature is uniform throughout the system.

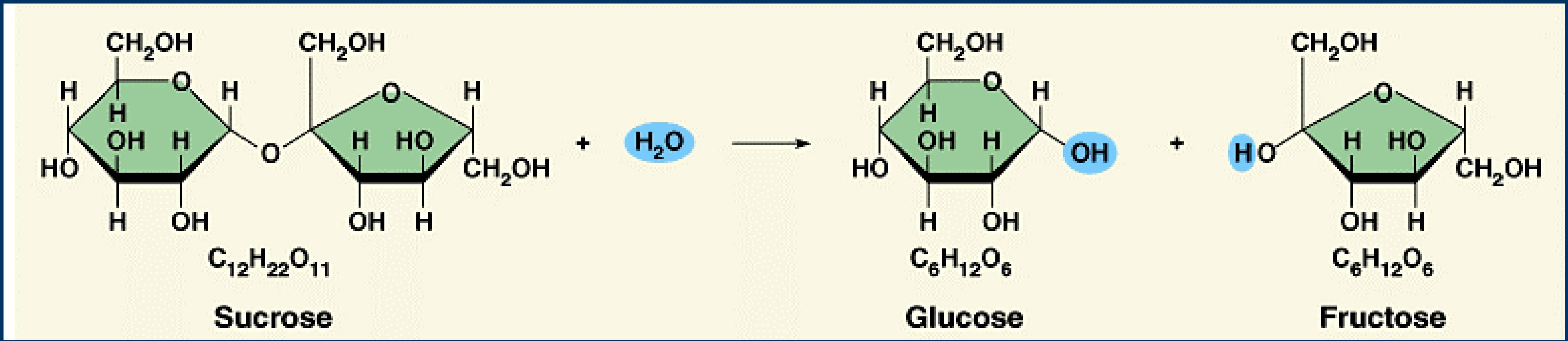


A process can occur spontaneously only if it increase the disorder (entropy) of the universe.

For biological systems the changes in both systems and surroundings have to be measures: unpractical.

Enzymes: the biological catalyst (usually = protein)

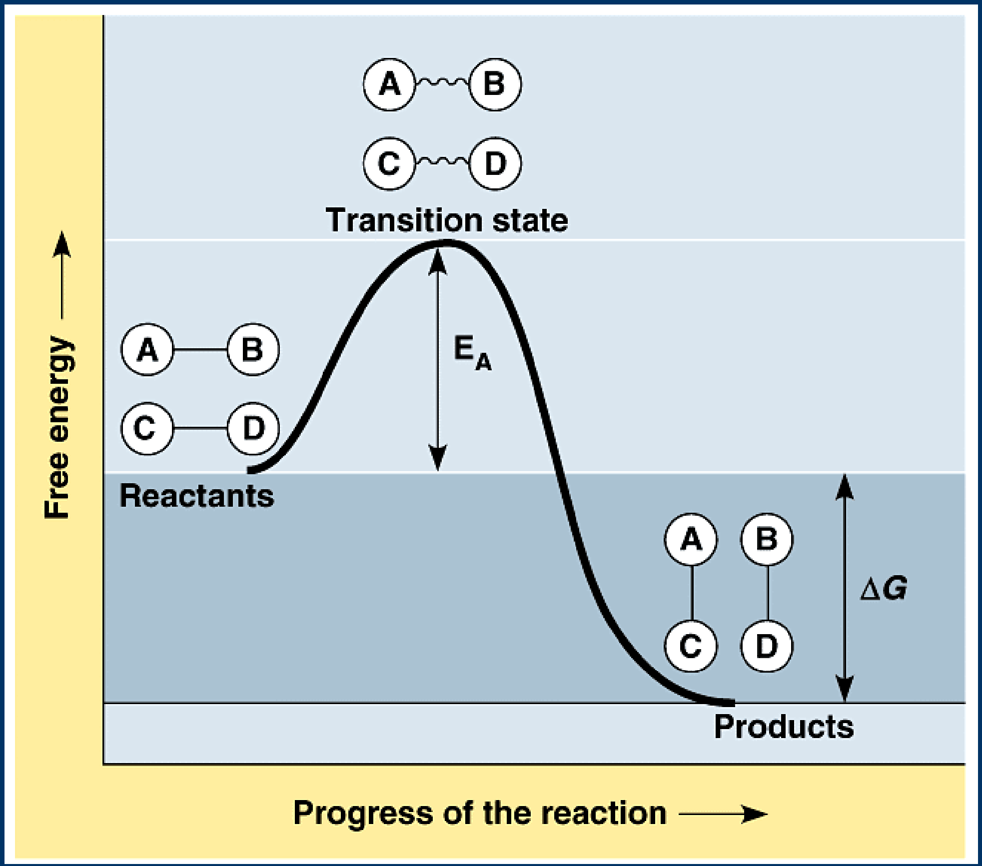
-increase the rate of reaction
-are not consumed by the reactions
-do not change the free energy change or direction of the reaction



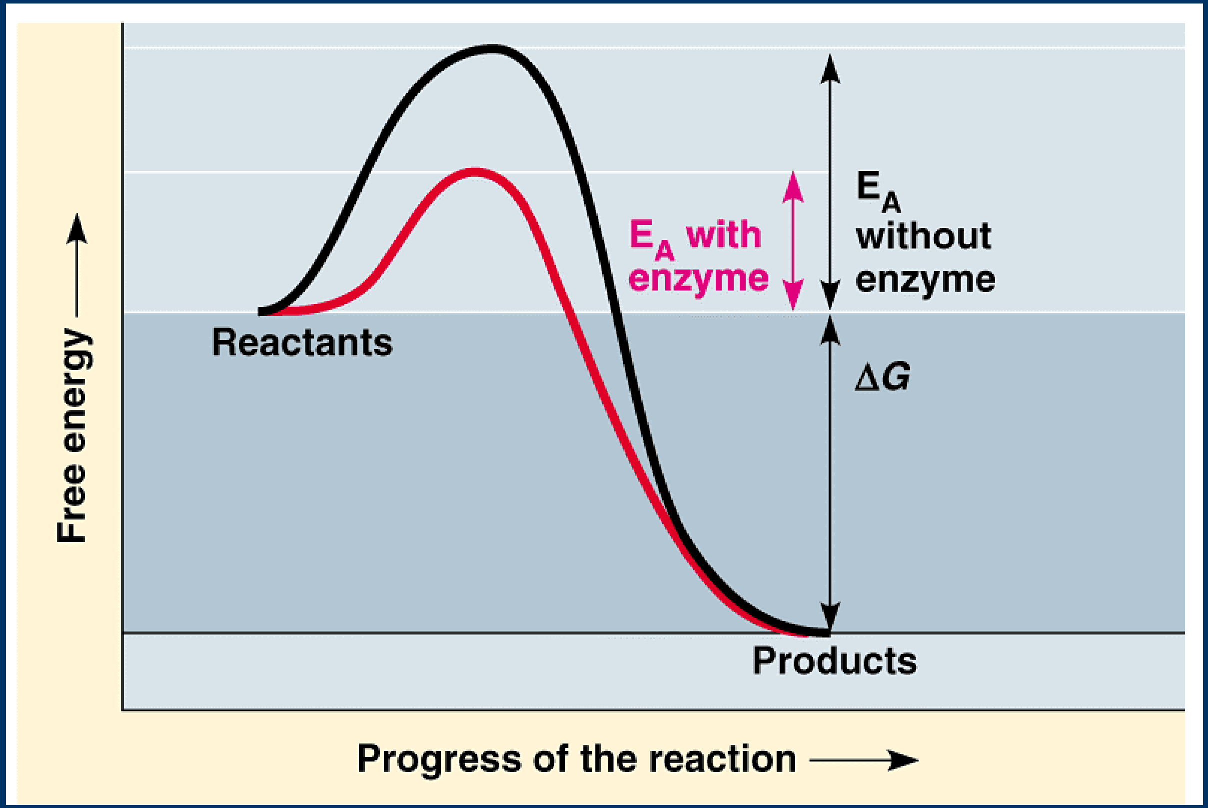
ΔG = -7kcal/mol

This reaction can be catalyzed by sucrase.

The reactants molecule must absorb energy from surroundings to break their bonds, and energy is released when the new bonds of the product molecules are formed.



The energy required to break bonds in reactant molecule = activation energy or free energy of activation E_A.



Enzymes catalyze or speed up the reaction by lower the activation energy.

Enzymes cannot make endergonic reaction exergonic or cannot change △G of the reaction.

Q:Why cells do not use heat to speed up the reactions?