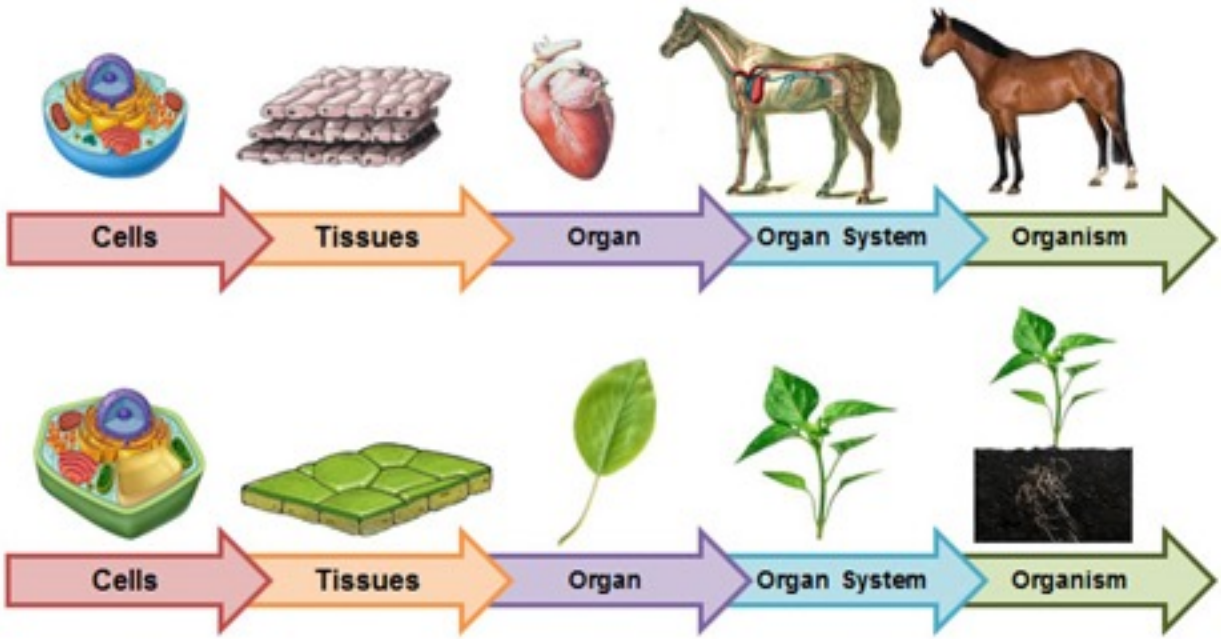
LSM1301

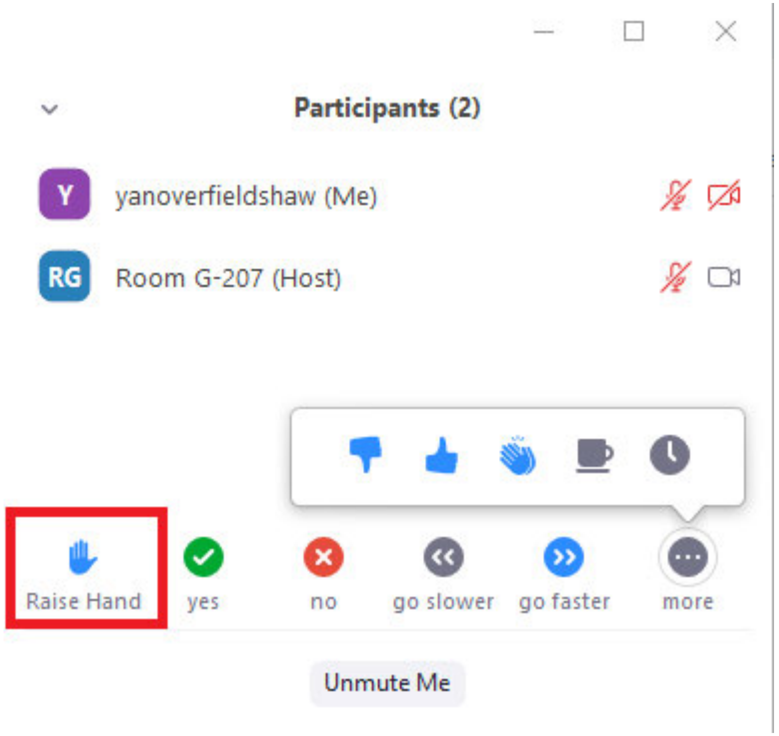


Energy of Life

Maxine Mowe
Office at S2-04
dbsmadm@nus.edu.sg
Tel: 65161614

Lecture participation/ asking questions

- Press the raise hand function
- Type your question in the chat
  - I will only see this when I pause to ask for questions
  - Keep your questions until I ask for questions
- Please remain muted during the lecture to minimize disruptions
- Longer questions should be put into Forum on Luminus



Lecture Topics and Assignments

This is a temporary plan, and is subject to change.

- Introduction (1 Lecture Session)

- Dr. NP Lectures/labs/Museum (5 Lects, 2 Labs, 1 Museum, 3 Tutorials)
  - Total Assignments (25%)

- Chemistry of Life (1 Lect session)
- Cell Structure and Function (1 Lect)
- Today Energy of Life (1 Lect)
- DNA and Gene Expression (2 Lect)
- Biotechnology (1 Lect)
- Summary & Tutorial (1 Session)
  - Total Assignments = 4 lab assignments (25%)

Learning Plan (Energy of Life)

Topic	Learning outcomes for the WK	Activities for online session	Activities for face-to-face session	Assignments/Assessments
Energy of Life	• *Define endergonic and exergonic reactions* • *Explain how enzymes are involved in the reactions* • *Explain how energy is transferred by energy carrier molecules* • *Explain how cell obtain energy from food using glucose as an example* • *Describe the 4 stages of glucose breakdown* • *Analyse the energy product in both aerobic and anaerobic conditions* • *Discuss the relationship between glucose breakdown, blood sugar and diabetes*	• *Read lecture notes to learn the terms of endergonic and exergonic reactions* • *Watch LumiNUS video to know how enzyme works* • *Watch video: Krebs / citric acid cycle | Cellular respiration | Biology | Khan Academy https://www.youtube.com/watch?v=juM2ROSLWfw (18 min)* • *Participate discussion on LumiNUS forum*	• *Demonstrate the mitochondria structure with physical models* • *Summary the key steps of glucose breakdown and energy released (drawing flow chart)* • *Play home-made video to further enhance the understanding of ETC* • *Use the ETC model to explain the energy conversion* • *Demonstrate of fermentation using beer brewing kit*	• *Enhance understanding with Track-learning MCQs* • *Complete assignments related to lab sessions* • *Watch webcast lecture if needed*

Intended learning outcomes

At the end of this class, the student should be able

- To relate the concepts of the first and second laws of thermodynamics, exergonic and endergonic reactions, metabolic pathways, energy carrier molecules, and oxidation-reduction reactions to the storage of free energy and its release in cells
- To describe the complete breakdown of glucose to carbon dioxide in aerobic cellular respiration via glycolysis, acetyl-CoA formation, citric acid cycle, and oxidative phosphorylation, and to relate the pathways to the flow of carbon atoms, and flow of energy carrier molecules
- To describe the partial breakdown of glucose via fermentation, and to relate the anaerobic pathway to the flow of carbon atoms, and flow of energy carrier molecules
- To describe the breakdown of the three main groups of food, namely carbohydrates, lipids, and proteins, in humans, and to relate the process to basic concepts acquired in the topic of ‘Chemistry of Life’

Outline

- Energy
  - Laws of thermodynamics
- Metabolic Reactions
  - Energy carrier molecules
  - Energy release
- Aerobic Cellular Respiration
  - Glycolysis
  - Acetyl-CoA formation
  - Citric acid cycle
  - Electron transfer phosphorylation
- Fermentation
- Food and Energy

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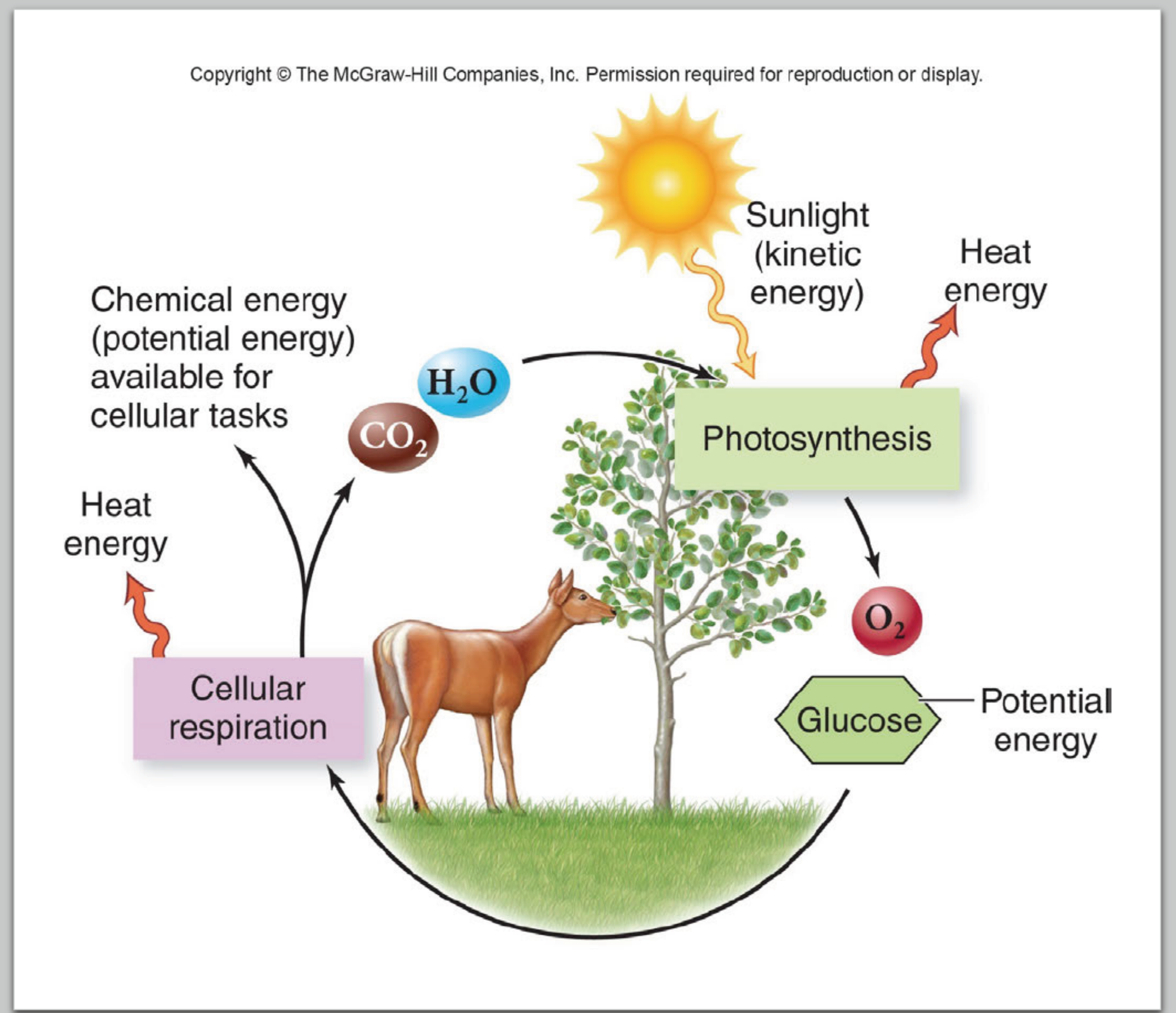
Energy

- Energy – the capacity to do work
- Two fundamental forms of energy
  - Kinetic energy – energy of motion being used to do work
  - Potential energy – stored energy to do work
- One form of energy can be converted to another form
  - Plants trap energy from sun via photosynthesis and convert it into chemical bond energy
  - All organisms use energy stored in bonds of organic compounds to do work
- Energy stored in chemical bonds – type of potential energy

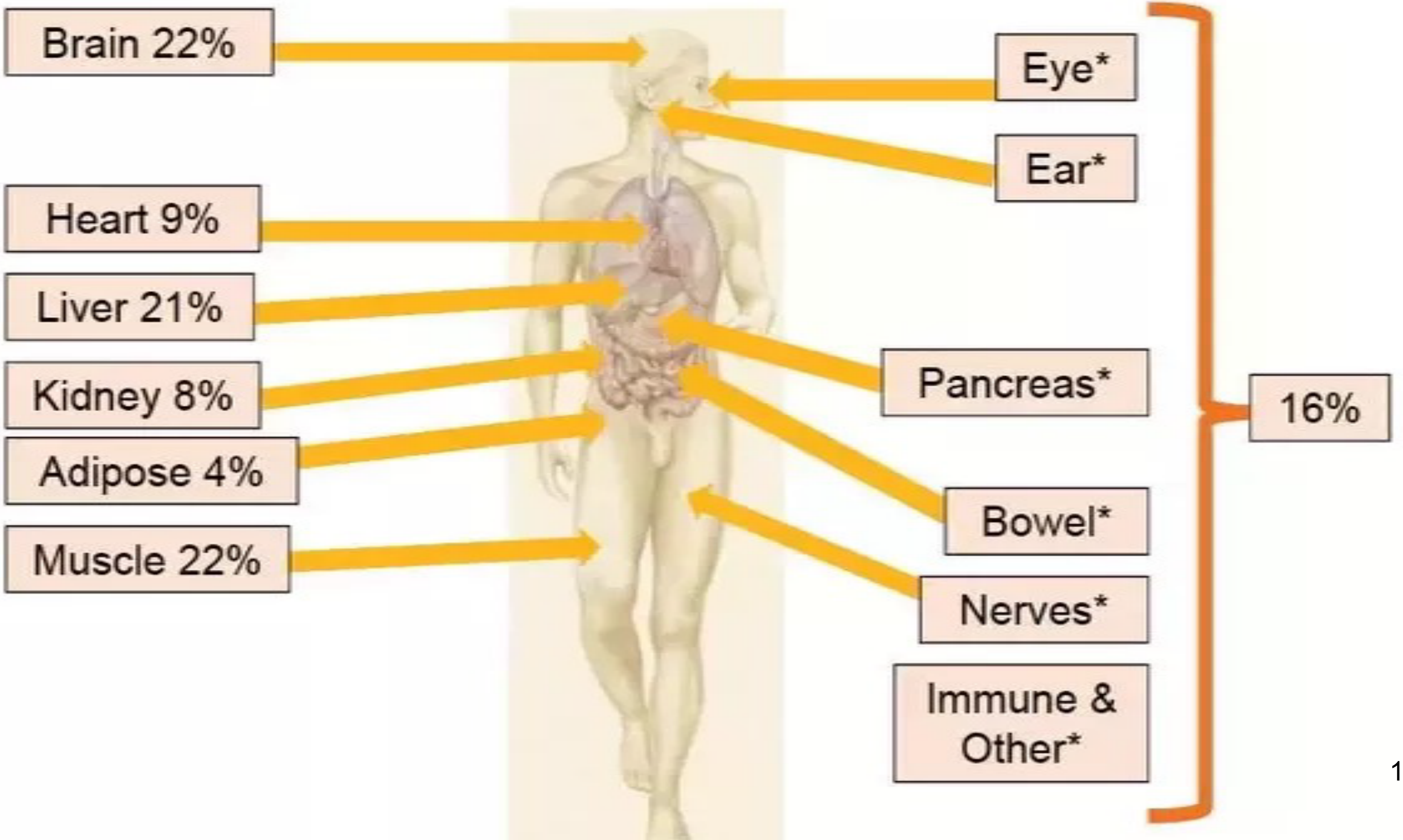
Energy

- Autotrophs
  - autos = self; trophe = nutrition
  - Self-feeders, producers
  - Plants capture light energy to make food – photosynthesis

- Heterotrophs
  - heterone = (an)other
  - Other-feeders, consumers
  - Organisms acquire energy from molecules of other organisms

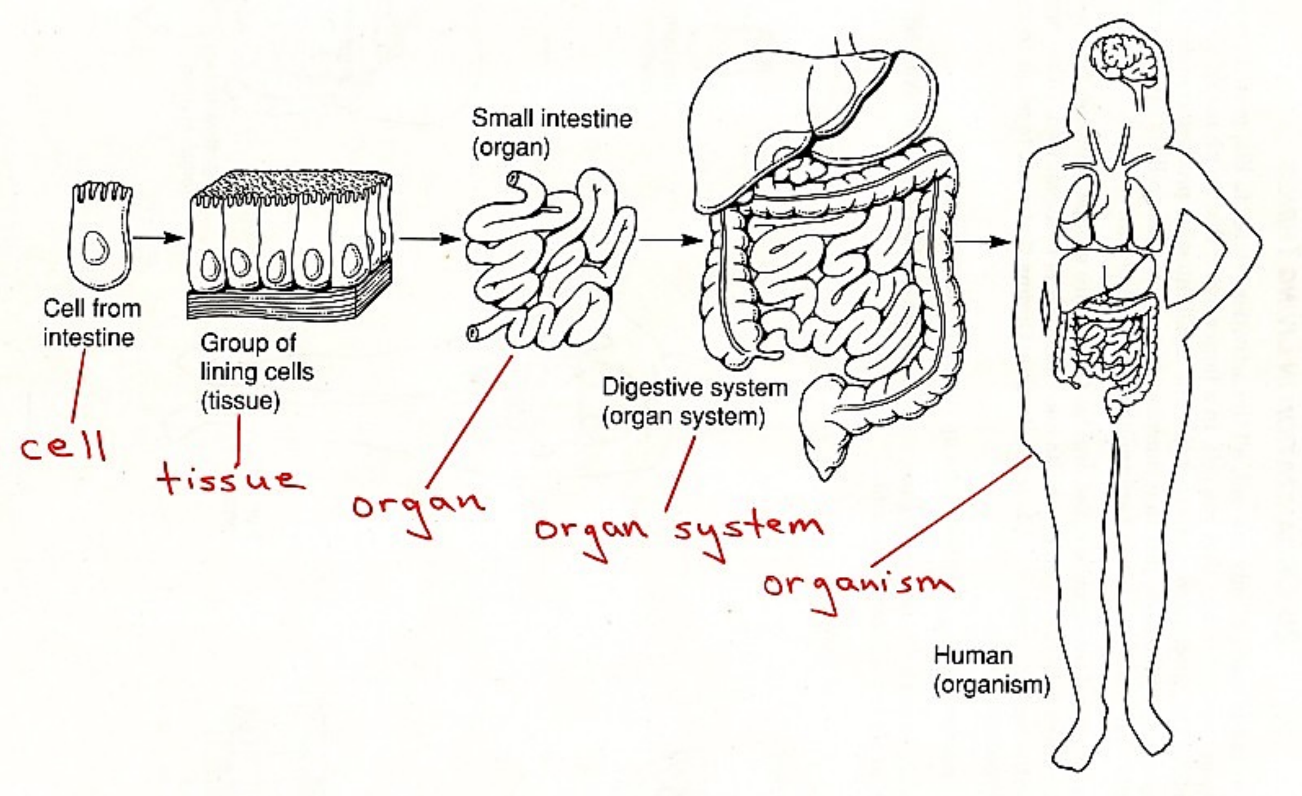


Case study: Where is energy used in the body?



Case study: How do we get energy?

The major absorbed end products of food digestion are monosaccharides, mainly glucose (from carbohydrates); monoacylglycerol and long-chain fatty acids (from lipids); and small peptides and amino acids (from protein).



Energy is trapped in the chemical bonds of nutrient molecules. How is it then made usable for cellular functions and biosynthetic processes?

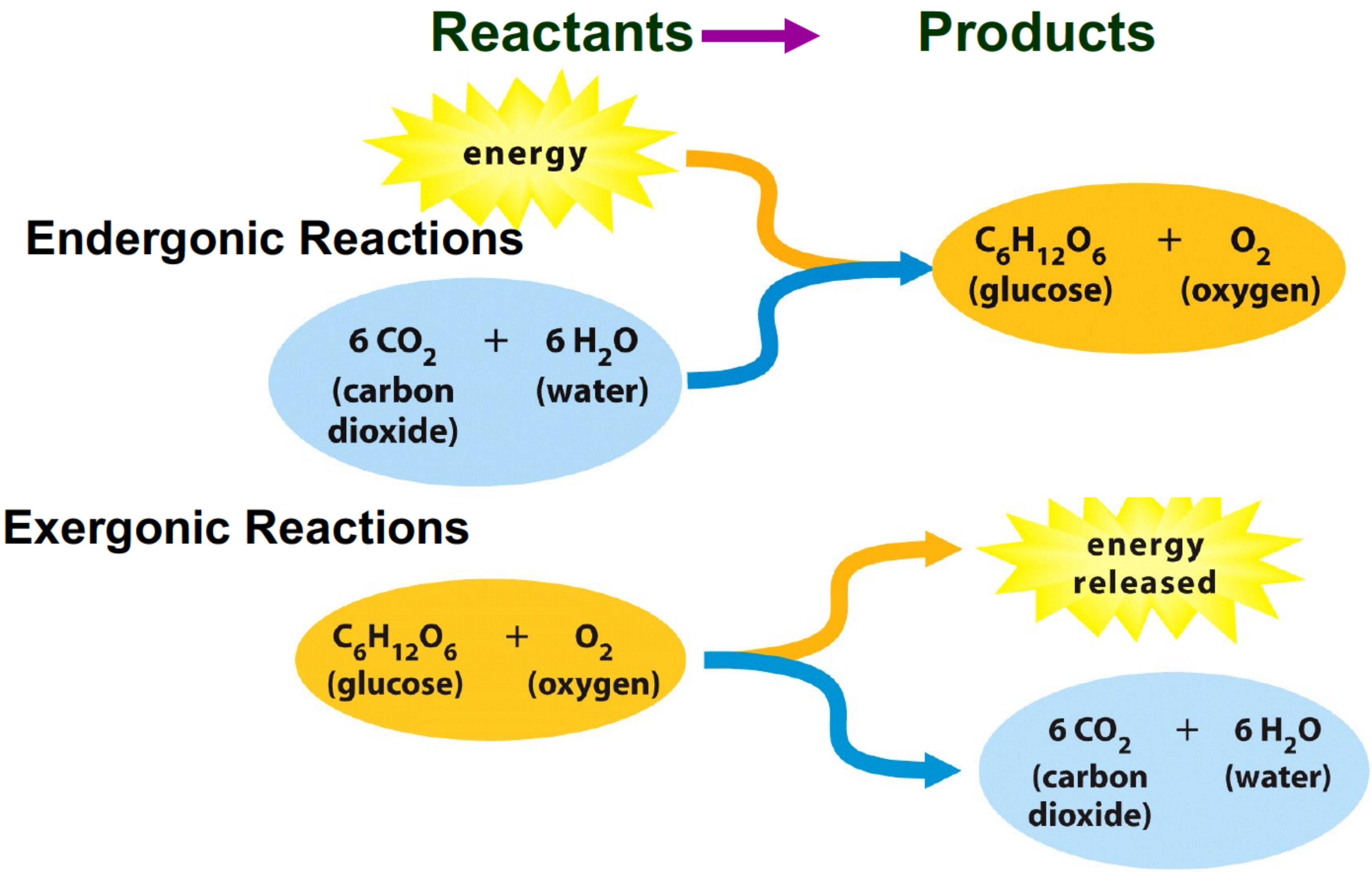
Metabolic reactions

- Metabolism
  - Sum of chemical reactions in cell
- Reactants
  - Chemical substances that enter a chemical reaction
- Products
  - Chemical substances that form as result of a chemical reaction
- Chemical reactions can be categorised based on energy gain or loss
  - Endergonic reactions
  - Exergonic reactions

Metabolic reactions

- Endergonic Reactions
  - Require an Input of Energy
  - Products contain more free energy than reactants
  - Example – photosynthesis
- Exergonic Reactions
  - Net release of energy
  - Products contain less free energy than reactants
  - Example – cellular respiration

Metabolic Reactions



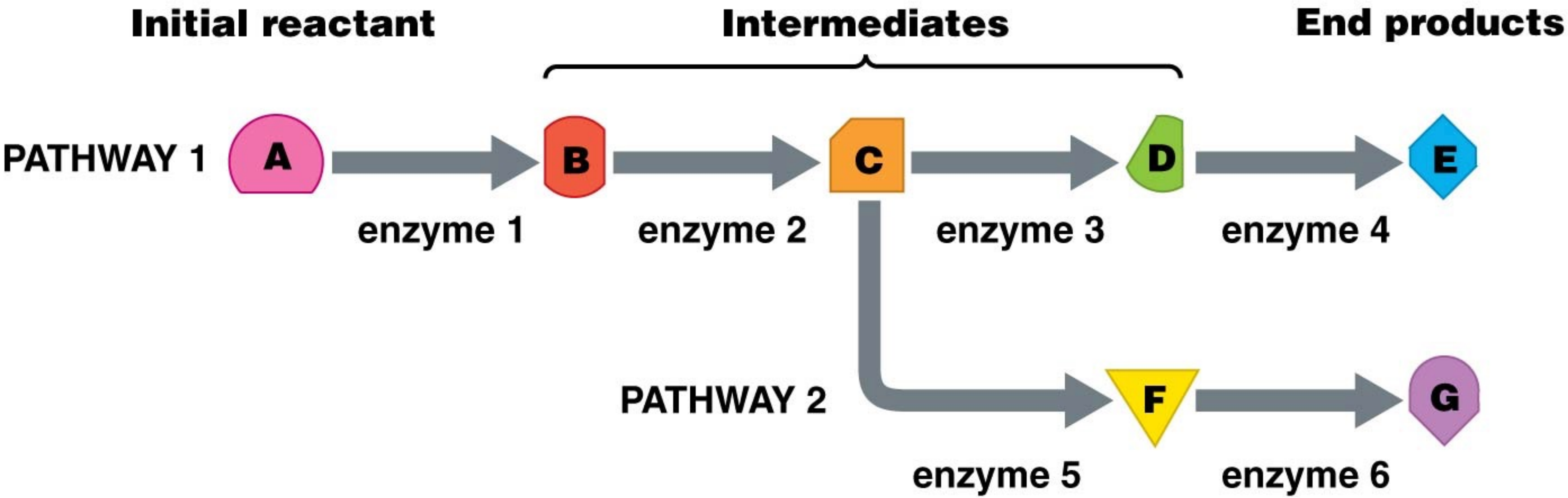
A Cells store free energy in the bonds of organic compounds.

B Cells retrieve free energy stored in the bonds of organic molecules.

Metabolic Reactions

- Metabolic reactions occur in sequences – metabolic pathways
  - Products of one earlier reaction become reactants of another later reaction
  - Catalysed by enzymes (biological catalysts)
  - Each reaction requires a unique and specific enzyme
- Catabolism
  - Breakdown of complex molecules such as food
  - Produces energy
- Anabolism
  - Synthesis of complex molecules
  - Uses energy

Metabolic reactions

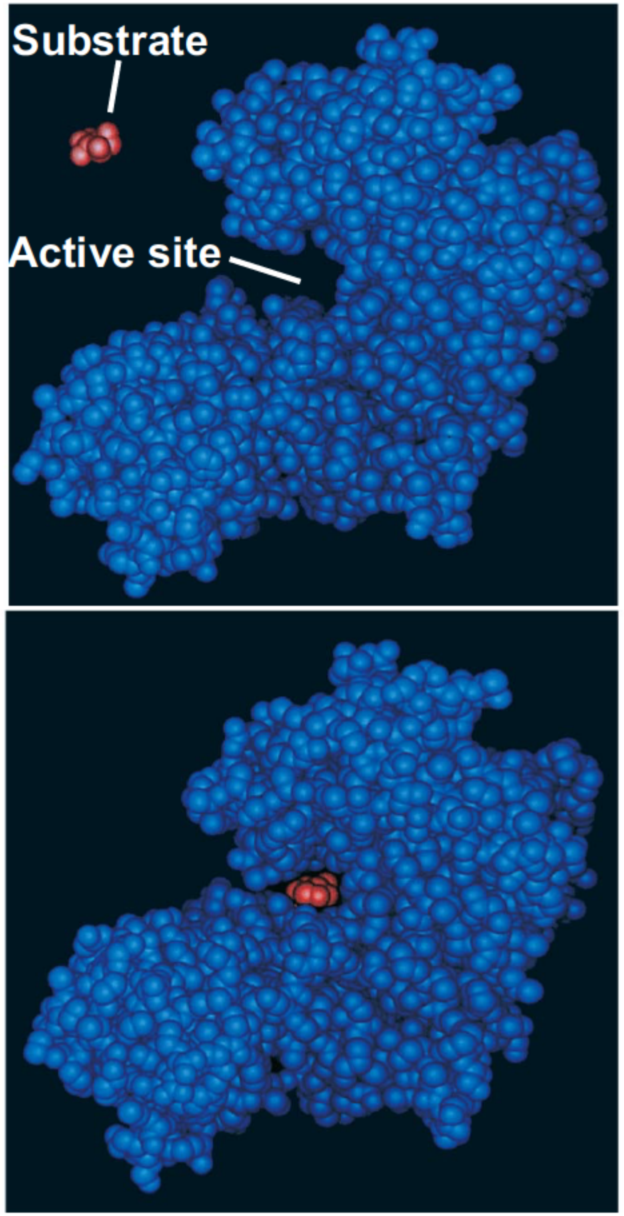


Enzymes Are Biological Catalysts

- Enzymes are catalytic compounds that drive biochemical reactions in living systems. The **majority of enzymes** are proteins.
- Enzymes orient, distort, and reconfigure molecules in the process of lowering activation energy
- Activation energy is the minimum energy required to start a chemical reaction.
- Some enzymes require **helper** (**coenzyme)** molecules to function (e.g. B vitamins, metal ions)
- Enzymes are very specific for the molecules they catalyze
- Enzyme activity is often enhanced or suppressed by their reactants, products and buffers.

Enzyme Structure

- Enzymes have a pocket called an **active site**
- Reactants (substrates) bind to the active site
  - Distinctive shape of active site is complementary and specific to the substrate
  - Active site amino acids bind to the substrate and distort bonds to facilitate a reaction



Enzymatic Action

Induced-fit model

- The active site is flexible, not rigid
- The shape of the enzyme, active site, and substrate adjust to maximum the fit, which improves catalysis.
- There is a greater range of substrate specificity

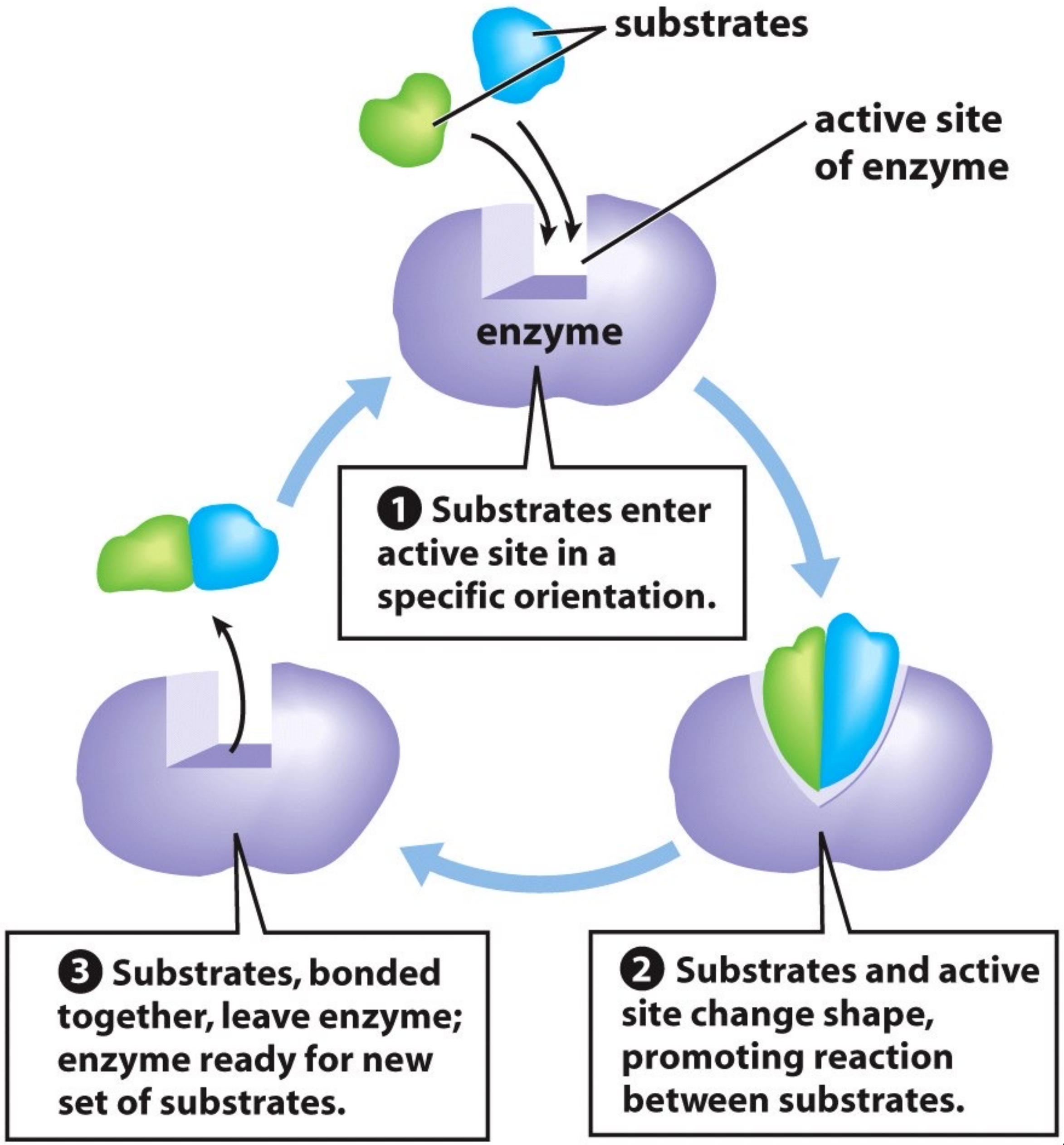


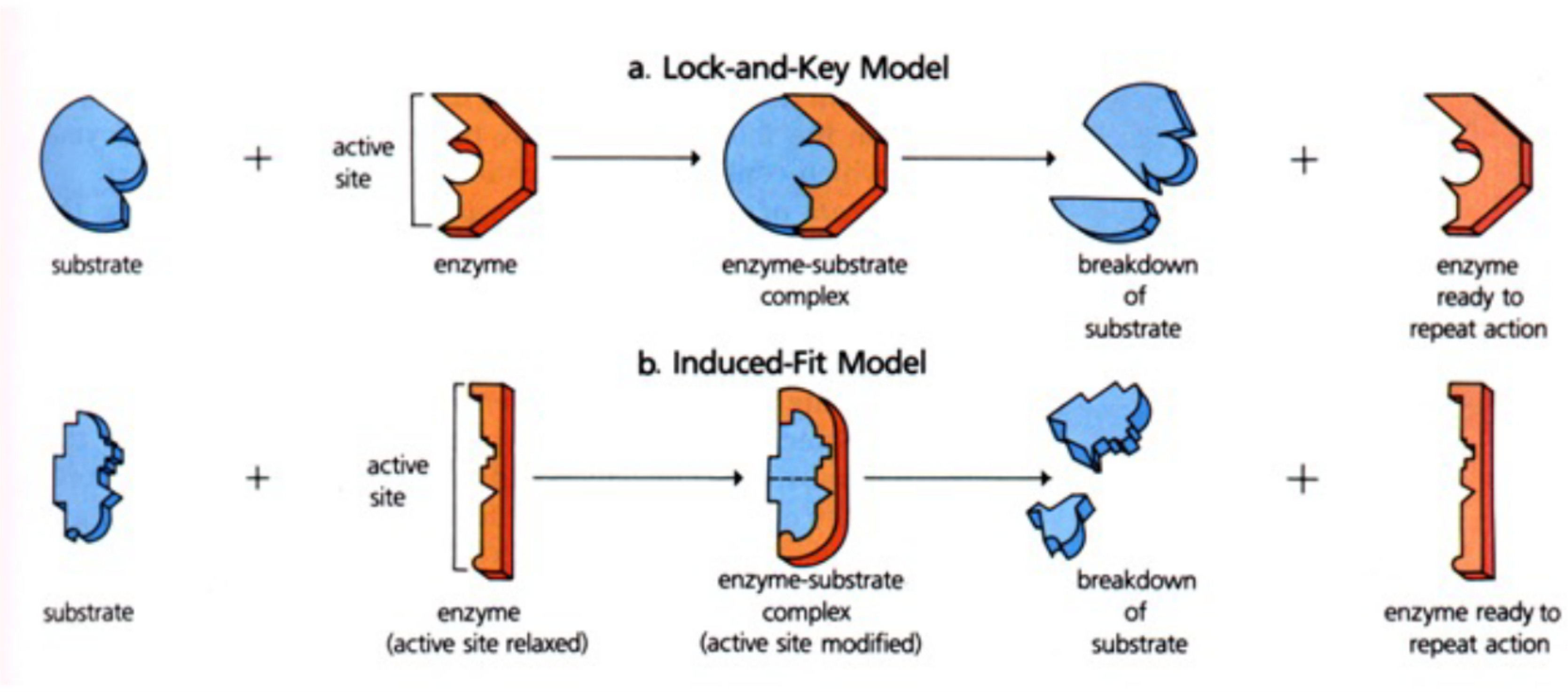
Figure 6-15 Biology: Life on Earth, 8/e

Induced-fit Model

FYI

In the induced-fit model of enzyme action:

- The active site is flexible, not rigid.
- The shapes of the enzyme, active site, and substrate adjust to maximum the fit, which improves catalysis.
- There is a greater range of substrate specificity.

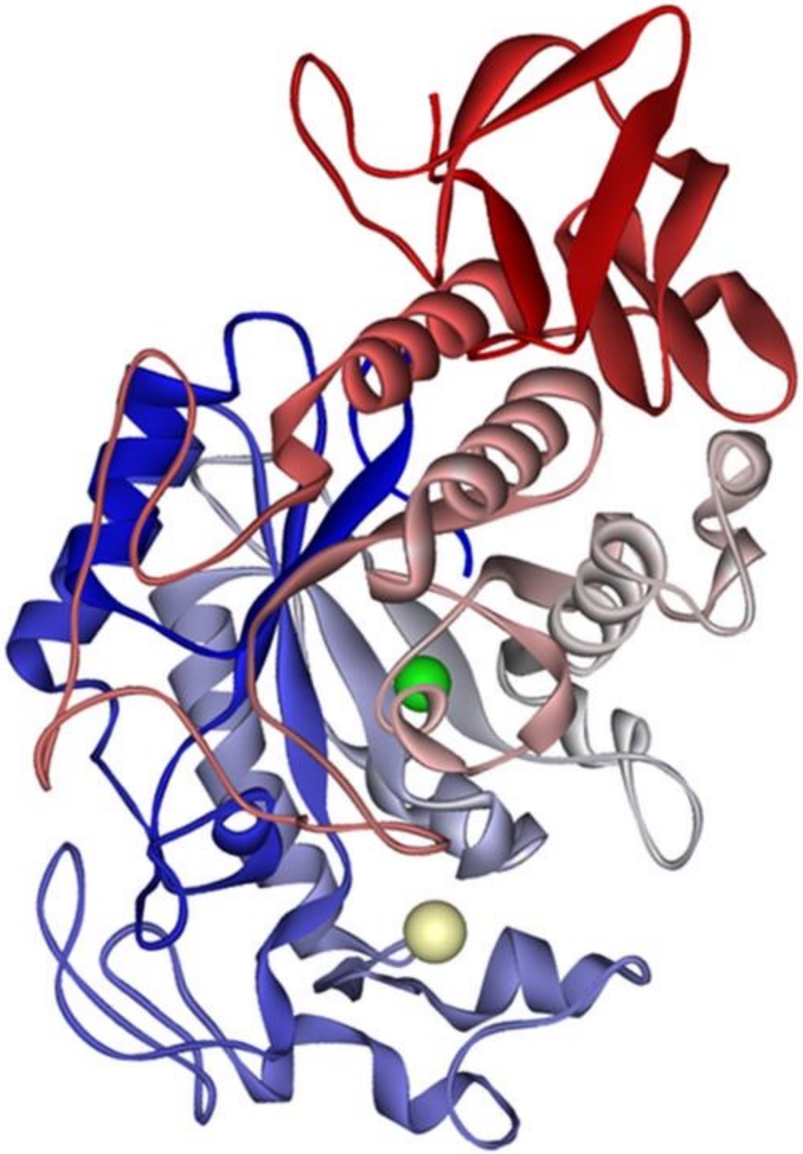


Case study: Example of enzymes

Salivary amylase hydrolyses polysaccharides, such as starch and glycogen, yielding glucose and maltose.

Calcium ion visible in pale khaki,

Chloride ion in green



How enzymes work (video)

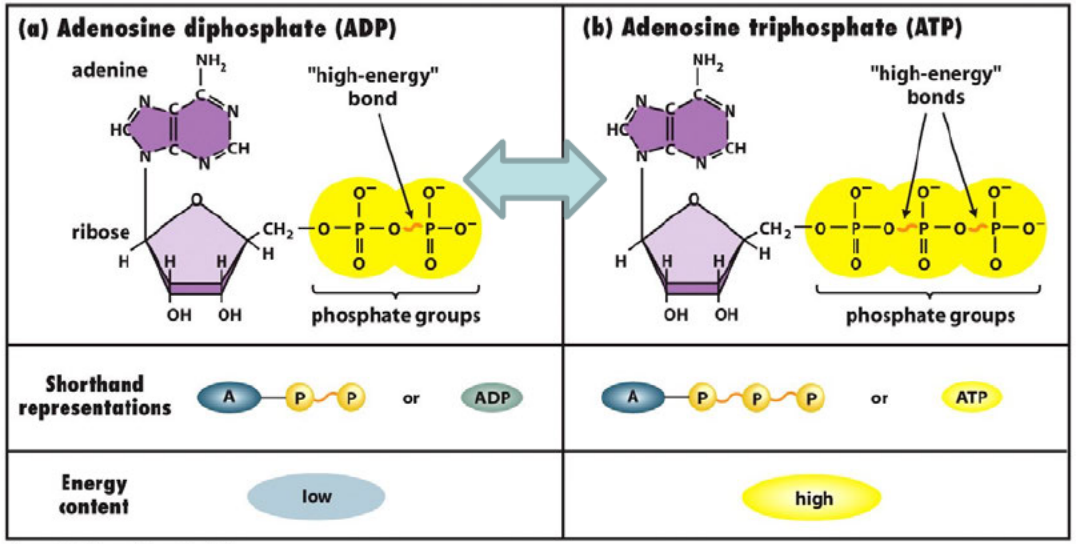
https://www.youtube.com/watch?v=UVeoXYJlBtI

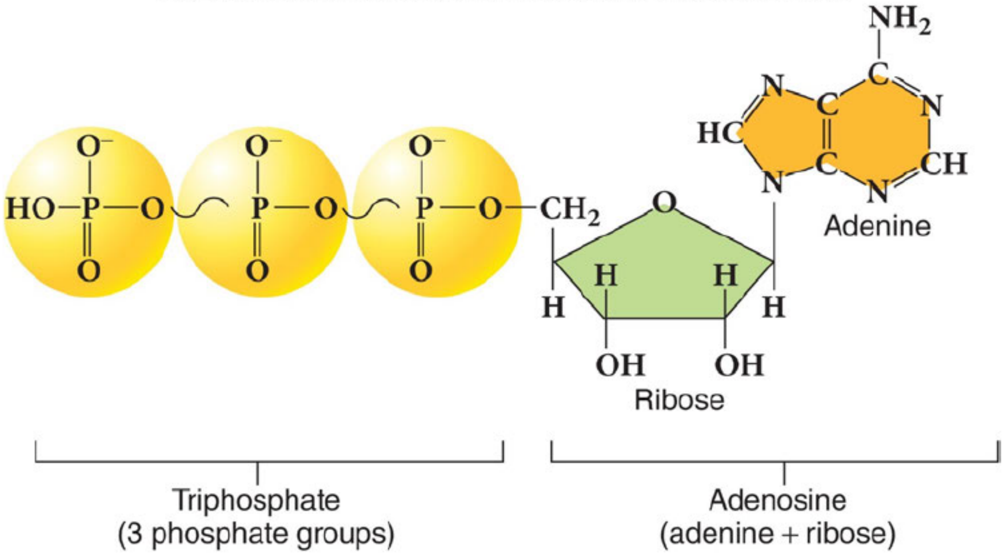
Energy Carrier Molecules

- High-energy, unstable molecules
  - Synthesised at sites of exergonic reactions
  - Capturing some released energy

Most common:

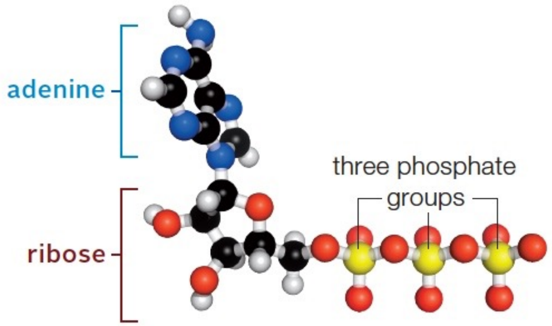
- Adenosine triphosphate (ATP)



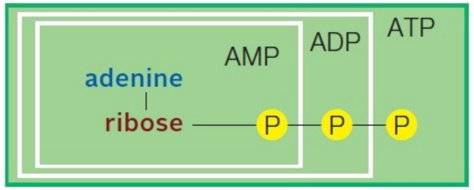


Energy Carrier Molecules

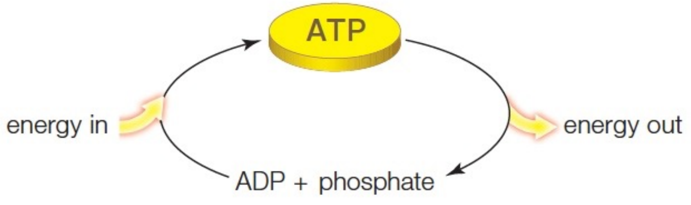
- ATP links endergonic to exergonic reactions through coupled reactions
  - Energy released by exergonic reaction used to combine relatively low-energy adenosine diphosphate (ADP) and phosphate (P) into ATP
  - Energy captured in high-energy bonds of ATP
- ATP used to drive endergonic reaction
  - Where energy is needed, ATP is broken down into ADP and P
  - Stored energy released



A Structure of ATP.



B After ATP loses one phosphate group, the nucleotide is ADP (adenosine diphosphate); after losing two phosphate groups, it is AMP (adenosine monophosphate).



C ATP forms by endergonic reactions that phosphorylate ADP. ADP forms again when a phosphate group from ATP is used to phosphorylate another molecule. Energy from such transfers drives endergonic reactions that are the stuff of cellular work.

Coupled reaction: glucose breakdown and protein synthesis

phosphoanhydride *bonds*

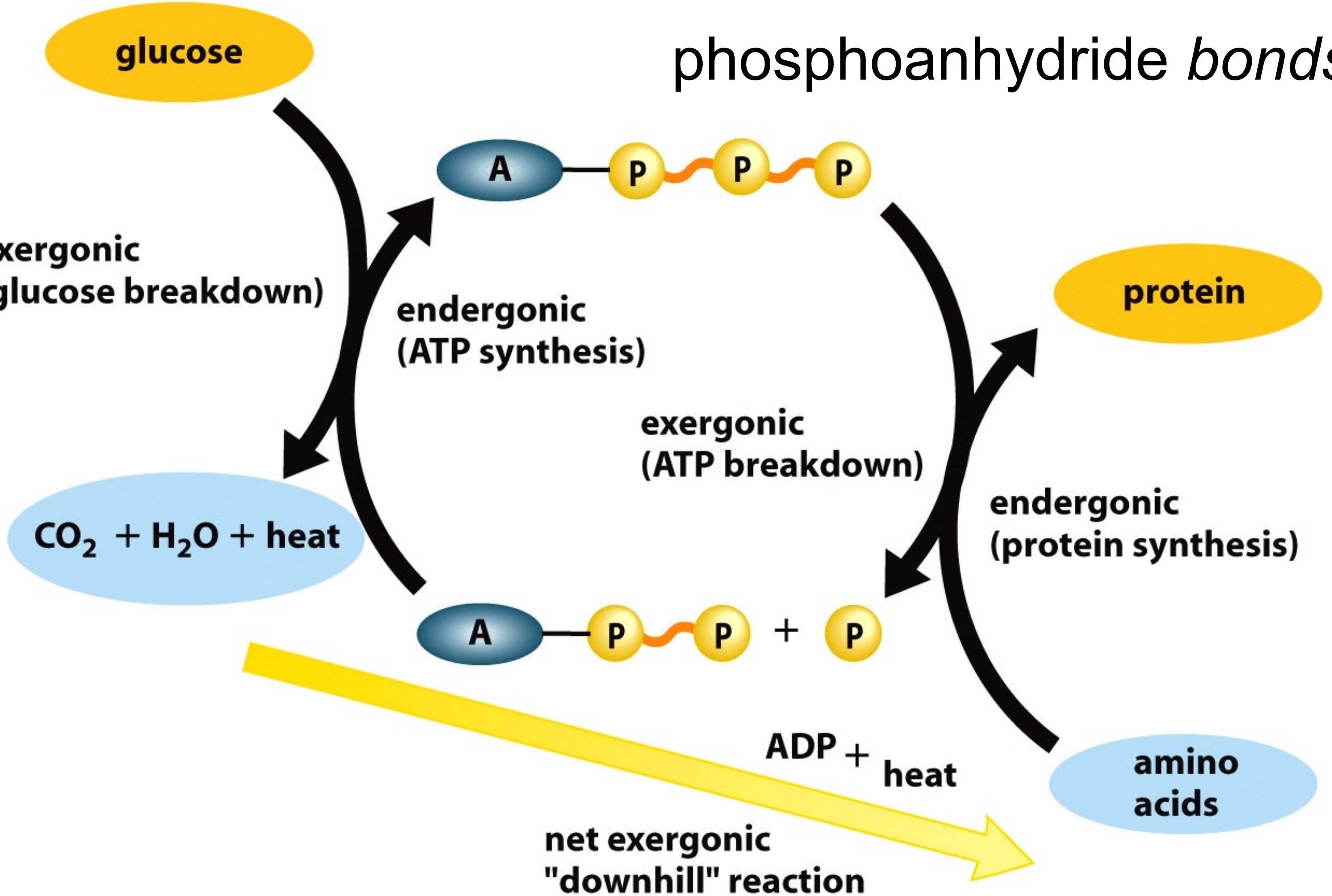
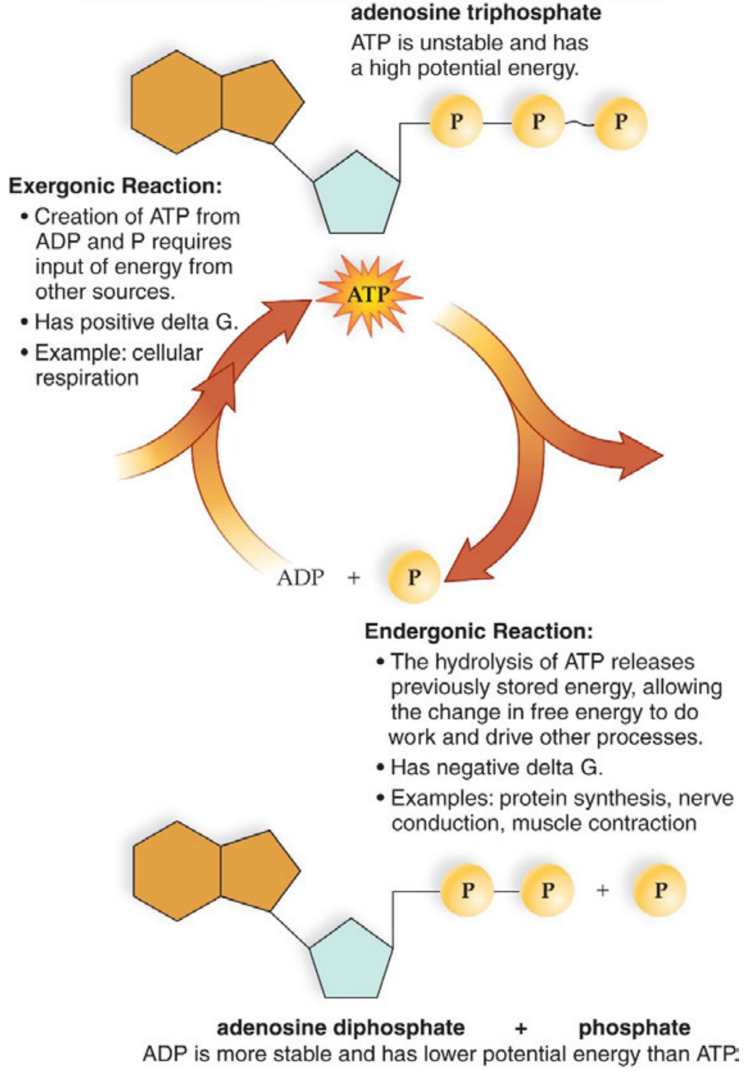


Figure 6-11 Biology: Life on Earth, 8/e

Energy Carrier Molecules

- ATP – short term energy storage
  - Not stockpiled in cells
  - Recycled at furious pace
- Long term energy storage molecules –triglycerides, starch and glycogen



Energy Carrier Molecules

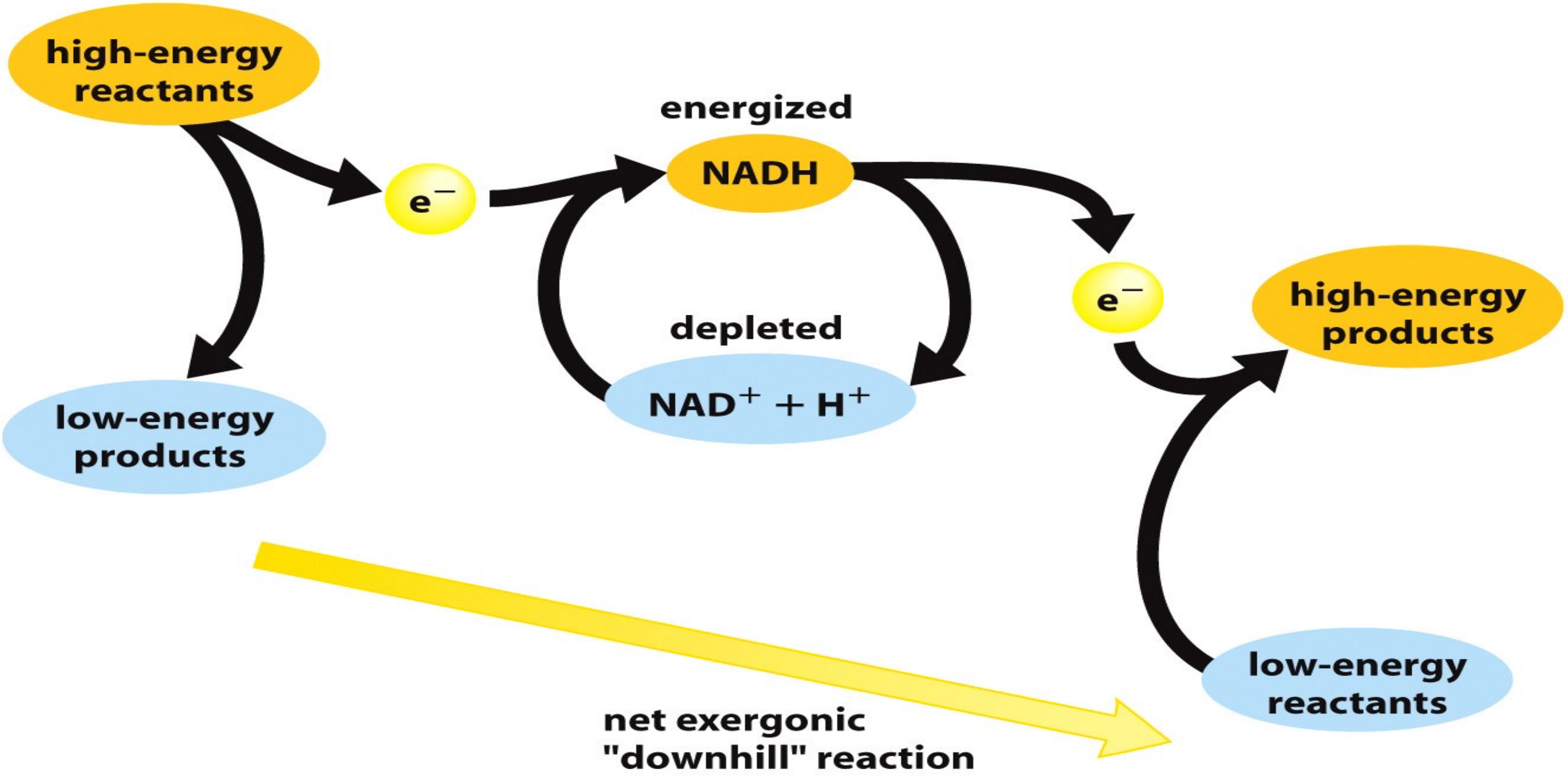
- Energy can be transferred to electrons in metabolic pathways
  - E.g. cellular respiration, photosynthesis
- High-energy electrons then passed from one molecule to another –oxidation-reduction (redox) reactions
  - Oxidation – loss of electrons
  - Reduction – gain of electrons
- Both oxidation and reduction reactions occur at same time – one molecule accepts electrons given up by another
  - Molecule that gives up electrons is oxidised
  - Molecule that accepts electrons is reduced

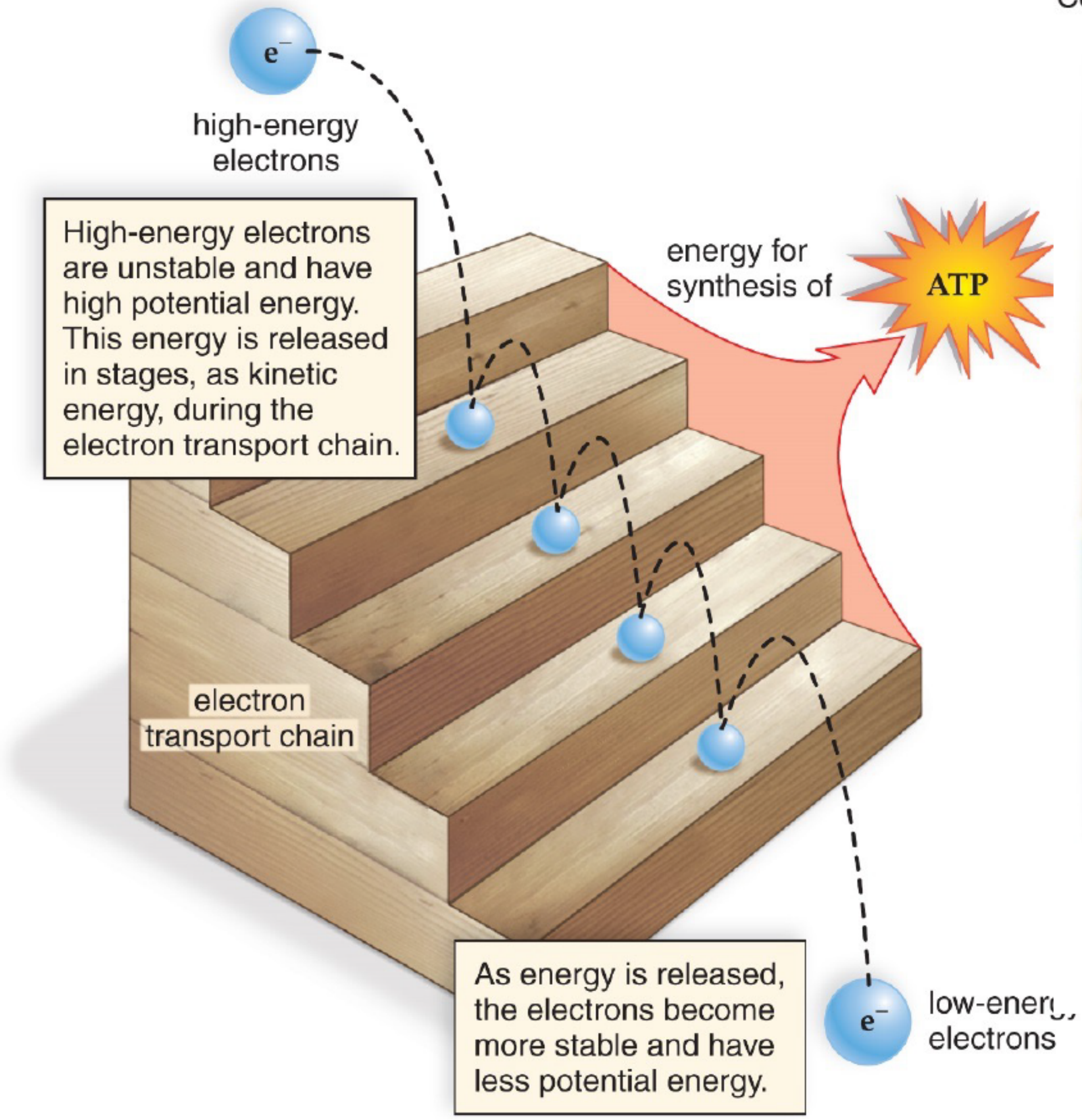
Energy Carrier Molecules

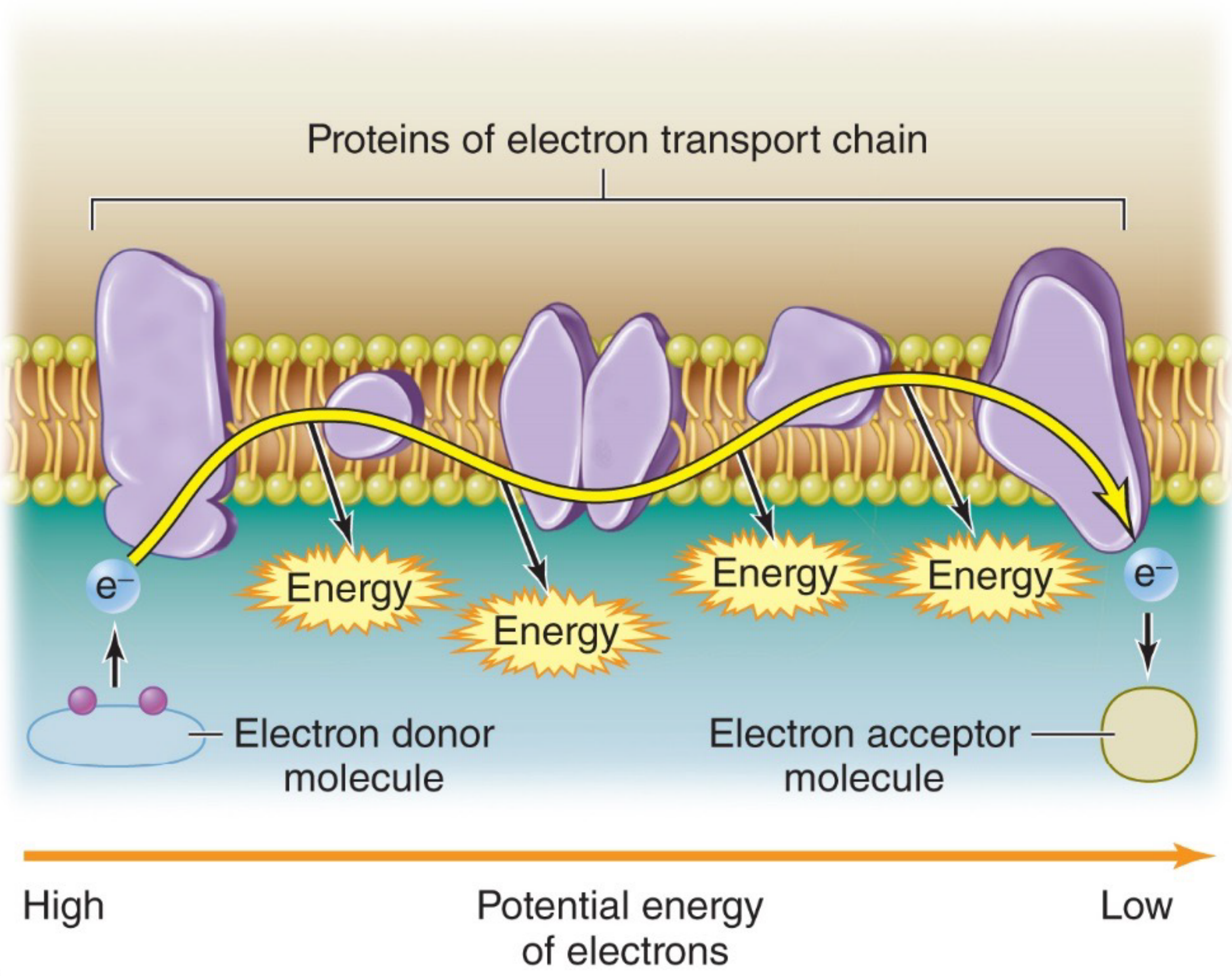
- Electron carriers transport high-energy electrons
  - E.g. nicotinamide adenine dinucleotide (NAD^+), flavin adenine dinucleotide (FAD)
- Electron carriers then donate high-energy electrons to other molecules – membrane-embedded proteins in mitochondria and chloroplasts
  - Electron transport chain
- Leads to synthesis of high-energy ATP
  - Left with low-energy electrons

Electron Carriers

1. Nicotinamide Adenine Dinucleotide (***NAD⁺***)
2. Flavin Adenine Dinucleotide (***FAD***)

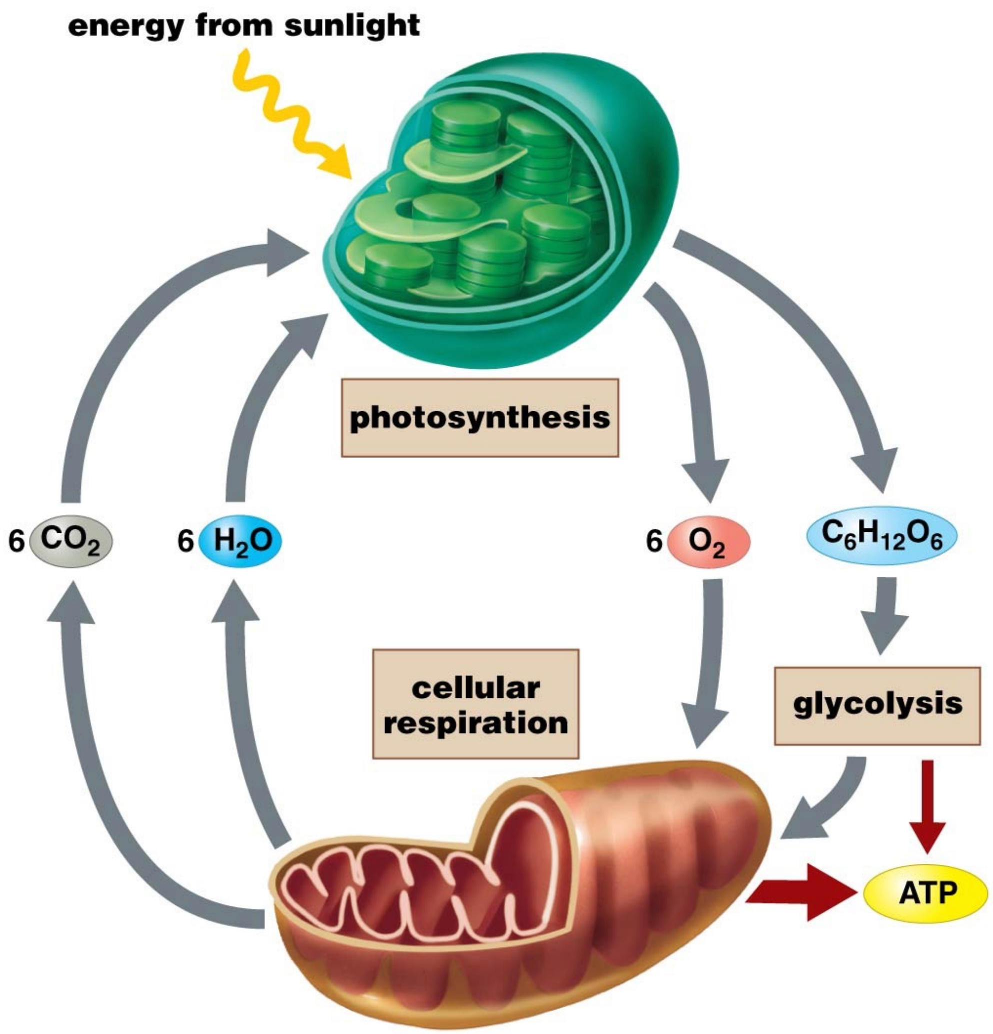



e⁻
high-energy electrons
High-energy electrons are unstable and have high potential energy. This energy is released in stages, as kinetic energy, during the electron transport chain.
energy for synthesis of
ATP
electron transport chain
As energy is released, the electrons become more stable and have less potential energy.
e⁻
low-energy electrons


Proteins of electron transport chain
e⁻
Energy
Energy
Energy
Energy
e⁻
Electron donor molecule
Electron acceptor molecule
High
Potential energy of electrons
Low

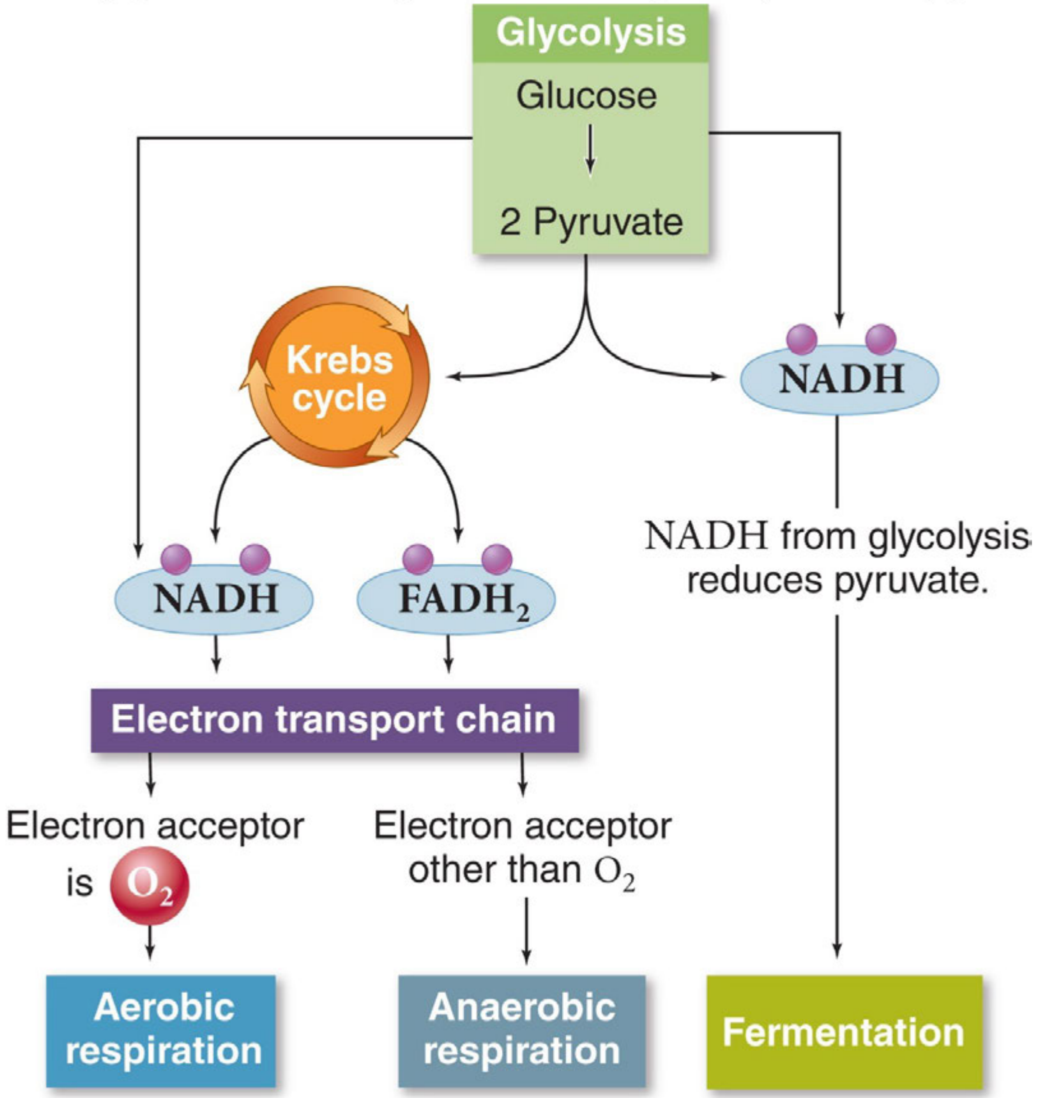
Energy Release

- During photosynthesis – energy of sunlight captured, stored in the form of glucose
- Glucose produced during photosynthesis
  - Consumed and broken down by nearly all organisms
  - Energy captured in the form of ATP
- Main metabolic pathways to generate ATP from glucose breakdown
  - Aerobic pathways
  - Anaerobic pathways



Energy Release

- Aerobic pathways
  - Require oxygen
  - Used by most eukaryotes
  - E.g. aerobic cellular respiration
- Anaerobic pathways
  - Do not require oxygen
  - Used by prokaryotes and protists in anaerobic habitats
  - E.g. anaerobic respiration,fermentation



Outline

- Energy
  - Laws of thermodynamics
- Metabolic Reactions
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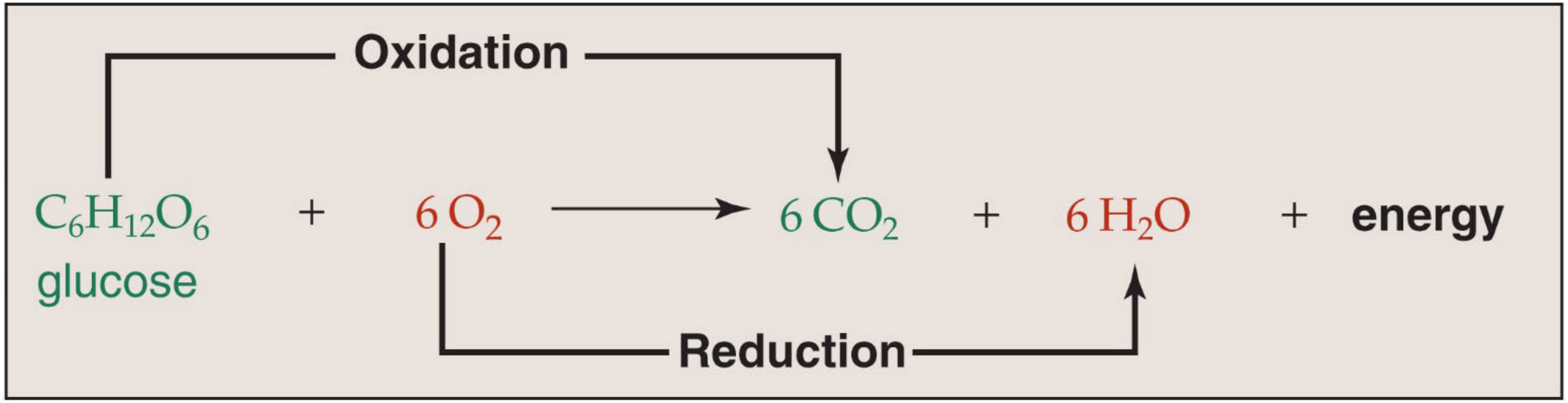
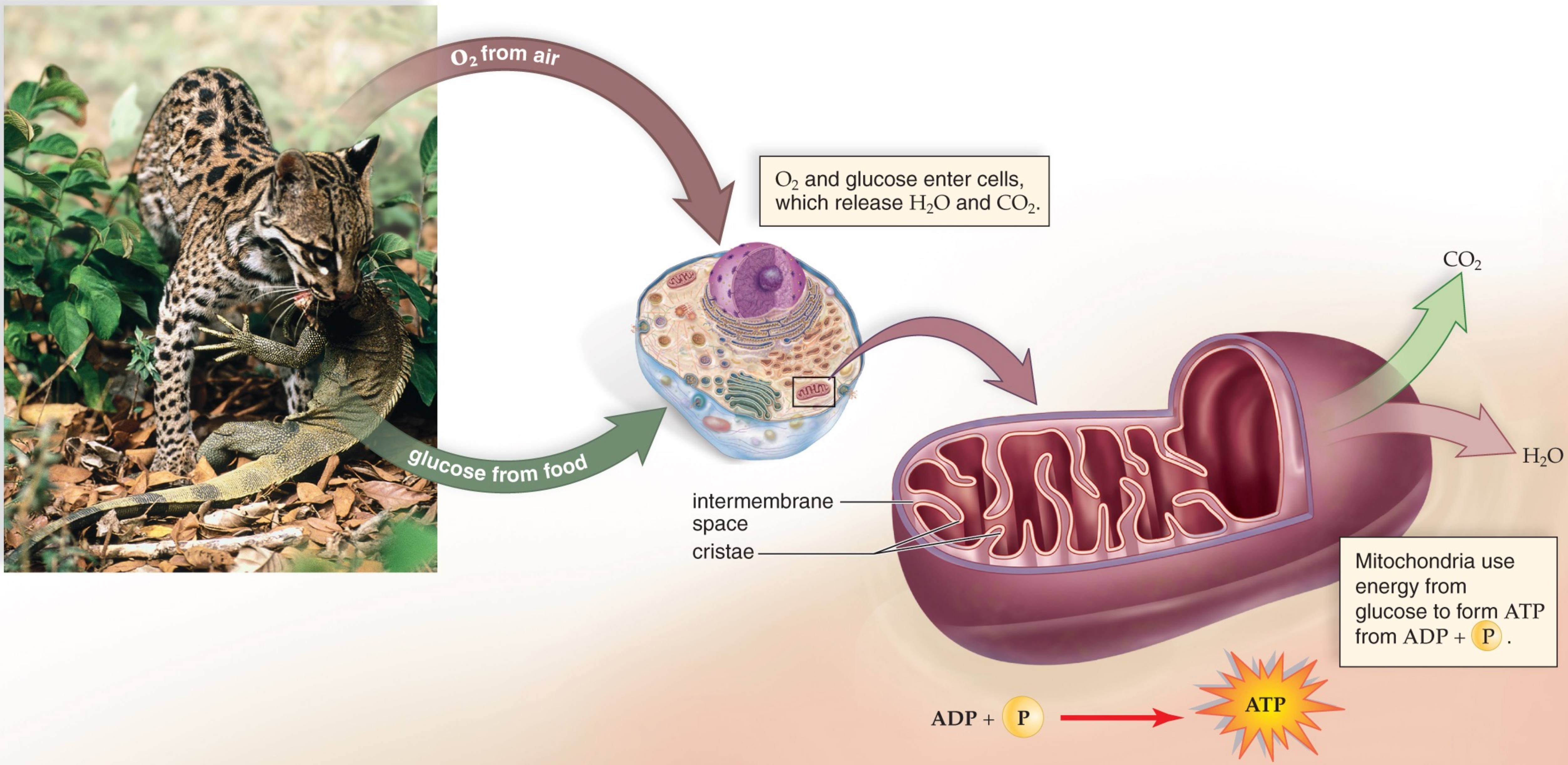
- Aerobic Cellular Respiration
  - Glycolysis
  - Acetyl-CoA formation
  - Citric acid cycle
  - Electron transfer phosphorylation
- Fermentation
- Food and Energy

Aerobic Cellular Respiration

- Usually involves breakdown of glucose to CO2 and H2O
- Energy extracted step-wise from glucose – allows for efficient production of ATP
  - Electrons removed from intermediates, received by oxygen, which combines with hydrogen ions (H+) to become water
  - Electrons carried by NADH (reduced form of NAD+) and FADH2 (reduced form of FAD)





O_2 from air
glucose from food
O_2 and glucose enter cells, which release H_2O and CO_2.
CO_2
H_2O
intermembrane space
cristae
Mitochondria use energy from glucose to form ATP from ADP + P .
ADP + P
ATP

Aerobic cellular respiration: 4 stages

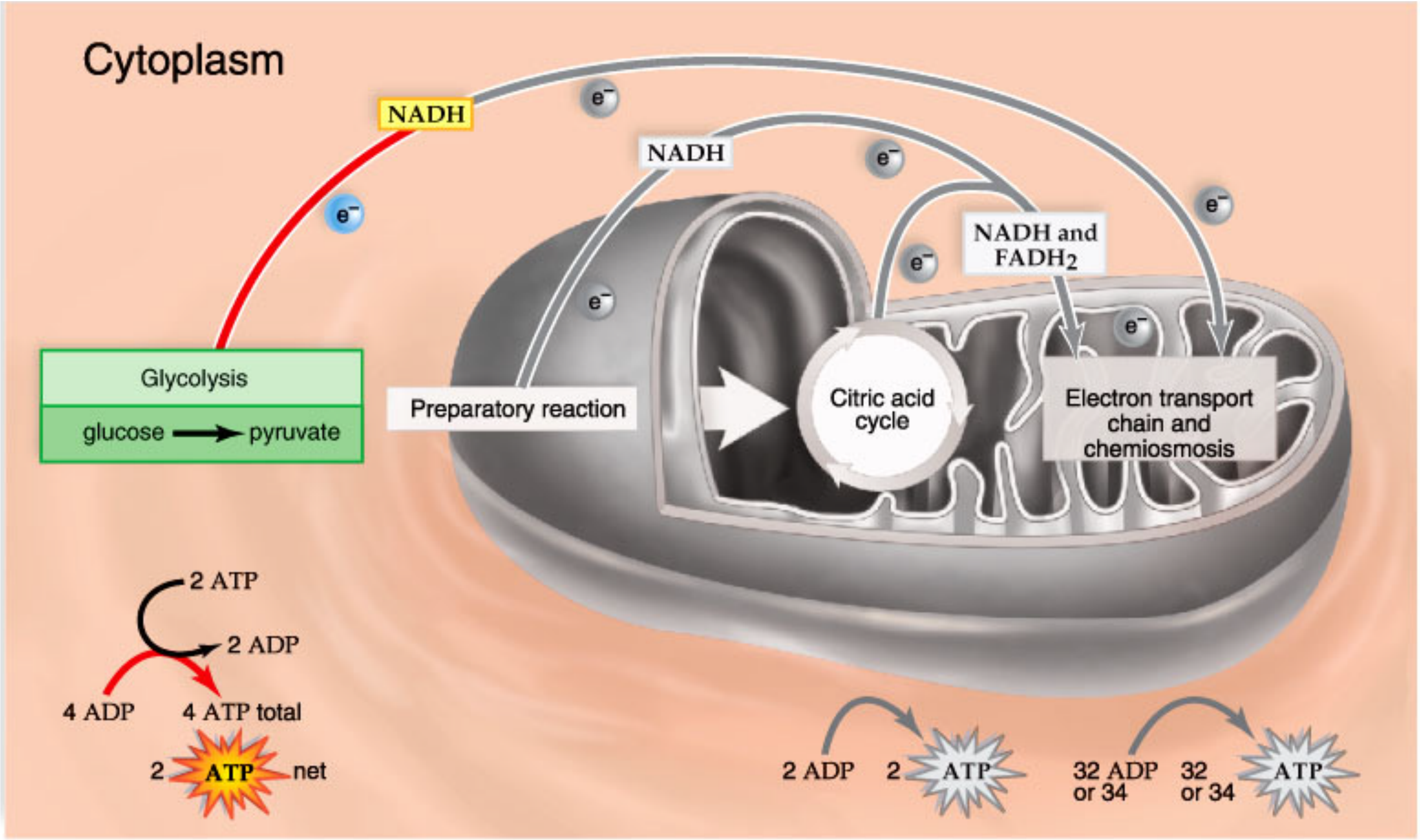
I. Glycolysis (occur in cytoplasm)

II. Converting Pyruvate to Acetyl-CoA
   - Occurs in cytoplasm (in prokaryotes)
   - Occurs in matrix of mitochondria (in eukaryotes)

III. Citric acid cycle (Krebs cycle)
   - Occurs in cytoplasm (in prokaryotes)
   - Occurs in matrix of mitochondria (in eukaryotes)

IV. Electron transport and oxidative phosphorylation
   - Occurs in plasma membrane (in prokaryotes)
   - Occurs in inner membrane of mitochondria (in eukaryotes)

Aerobic cellular respiration

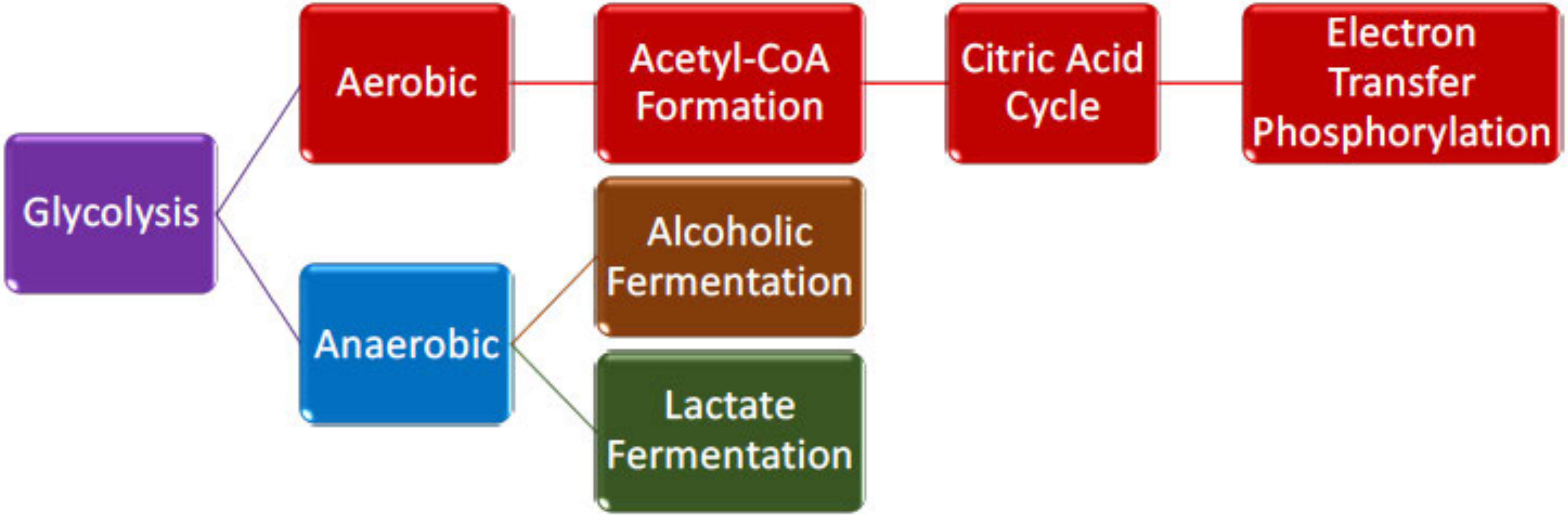


Breathing vs Respiration

Breathing: taking air in (inspiration) and out of your lungs (expiration); can be consciously controlled (voluntary action)

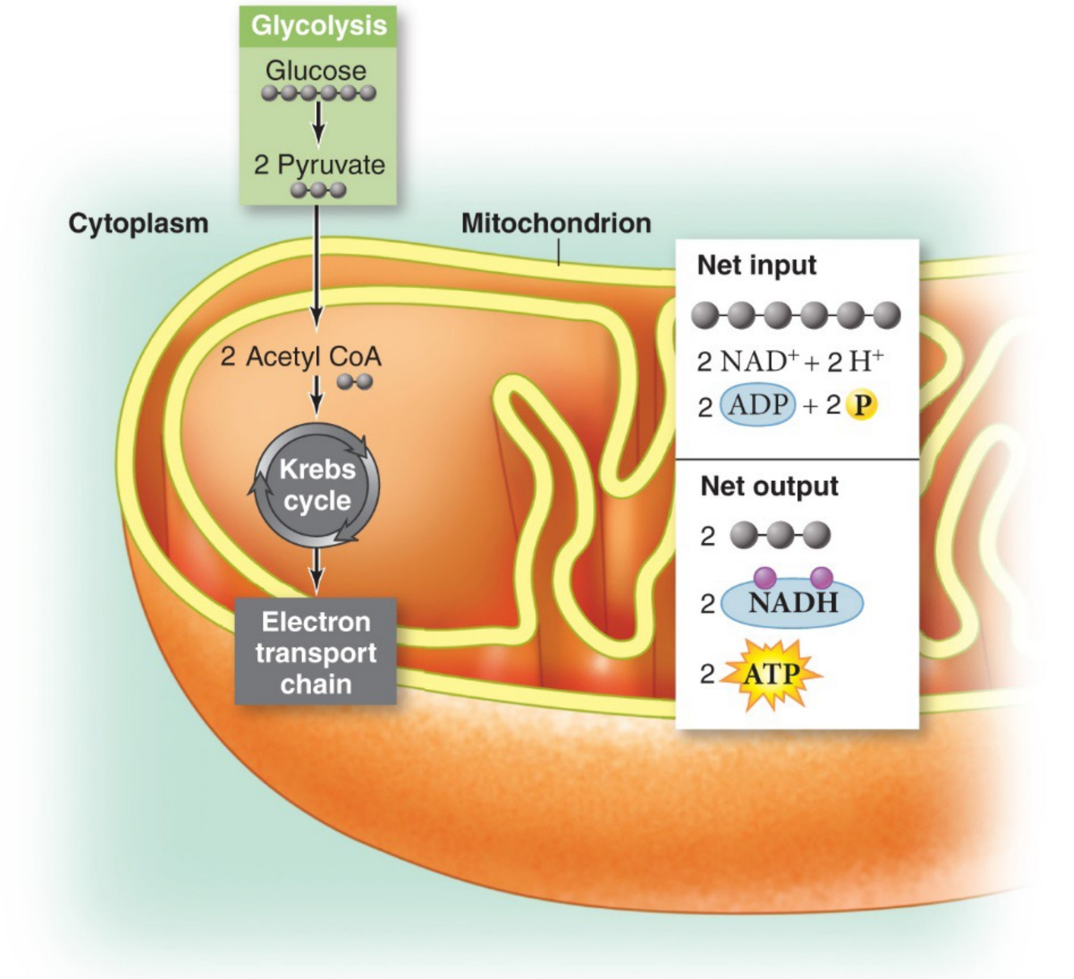
Respiration: the part of a metabolic process; cellular activity (occurs inside a cell); the end products are energy molecules, carbon dioxide and water; cannot be consciously controlled (involuntary action)

- Aerobic respiration (when oxygen is available)
- Anaerobic respiration (metabolism without oxygen)


Glycolysis
Aerobic
Acetyl-CoA Formation
Citric Acid Cycle
Electron Transfer Phosphorylation
Anaerobic
Alcoholic Fermentation
Lactate Fermentation

Glycolysis

- Breakdown of one glucose (6-carbon) molecule
  - Into two pyruvate (3-carbon) molecules
  - Net yield of two ATP molecules
- Consists of 10 reactions
- Does not require oxygen



I. Glycolysis Splits Glucose

- Occurs in two stages
  - Energy investment stage (activation stage)
  - Energy harvesting stage

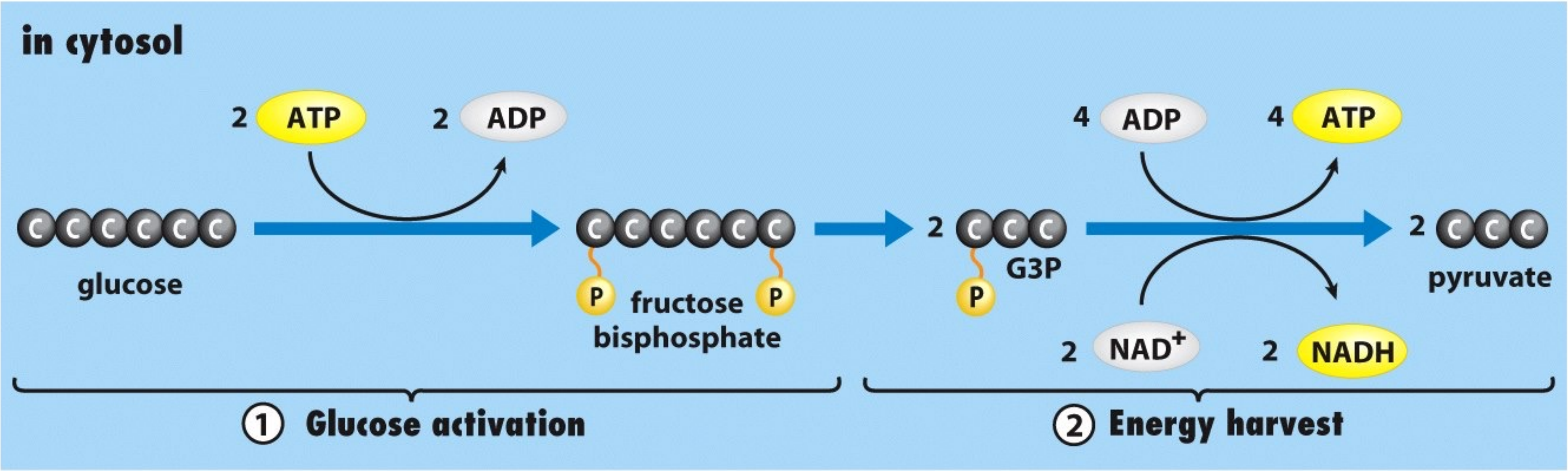
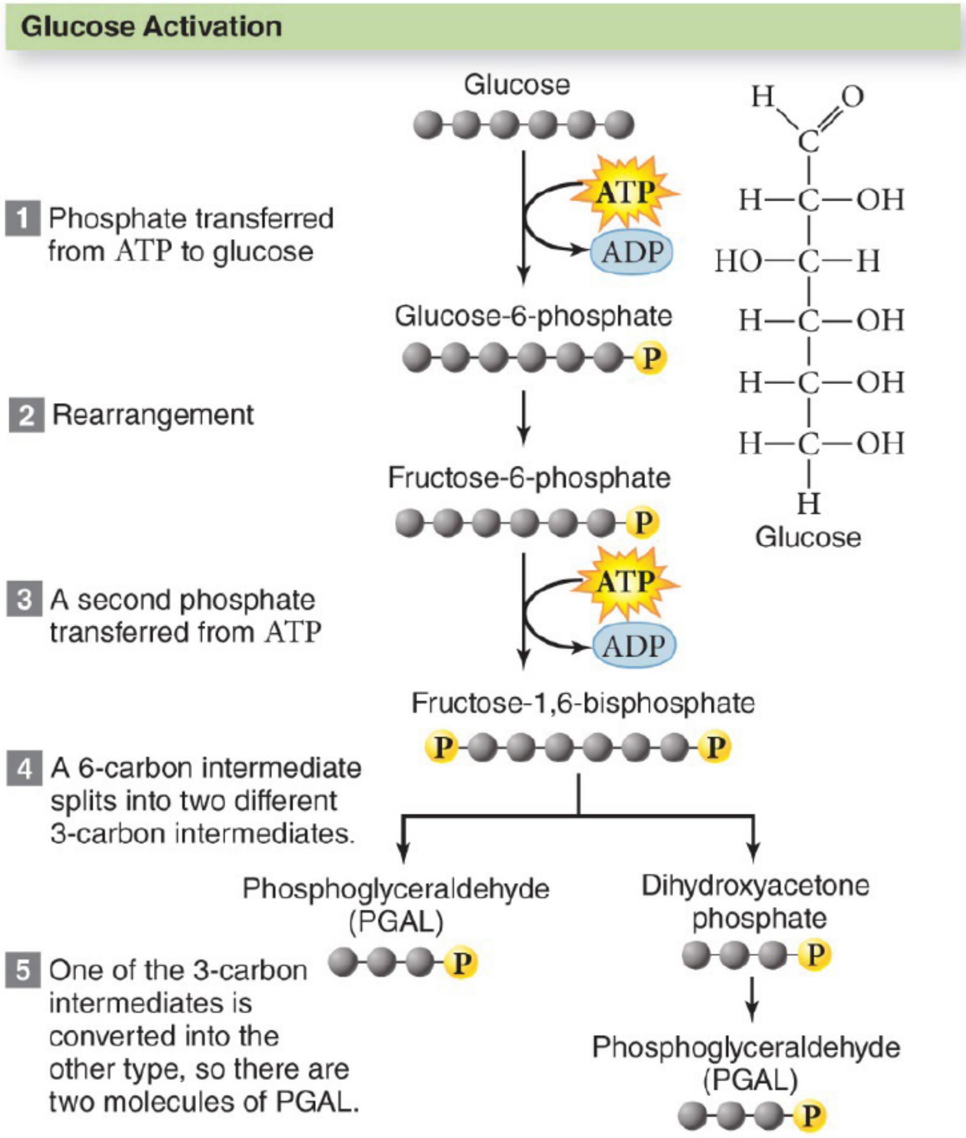


Figure 8-2 Biology: Life on Earth, 8/e

G3P: glyceraldehyde 3-phosphate

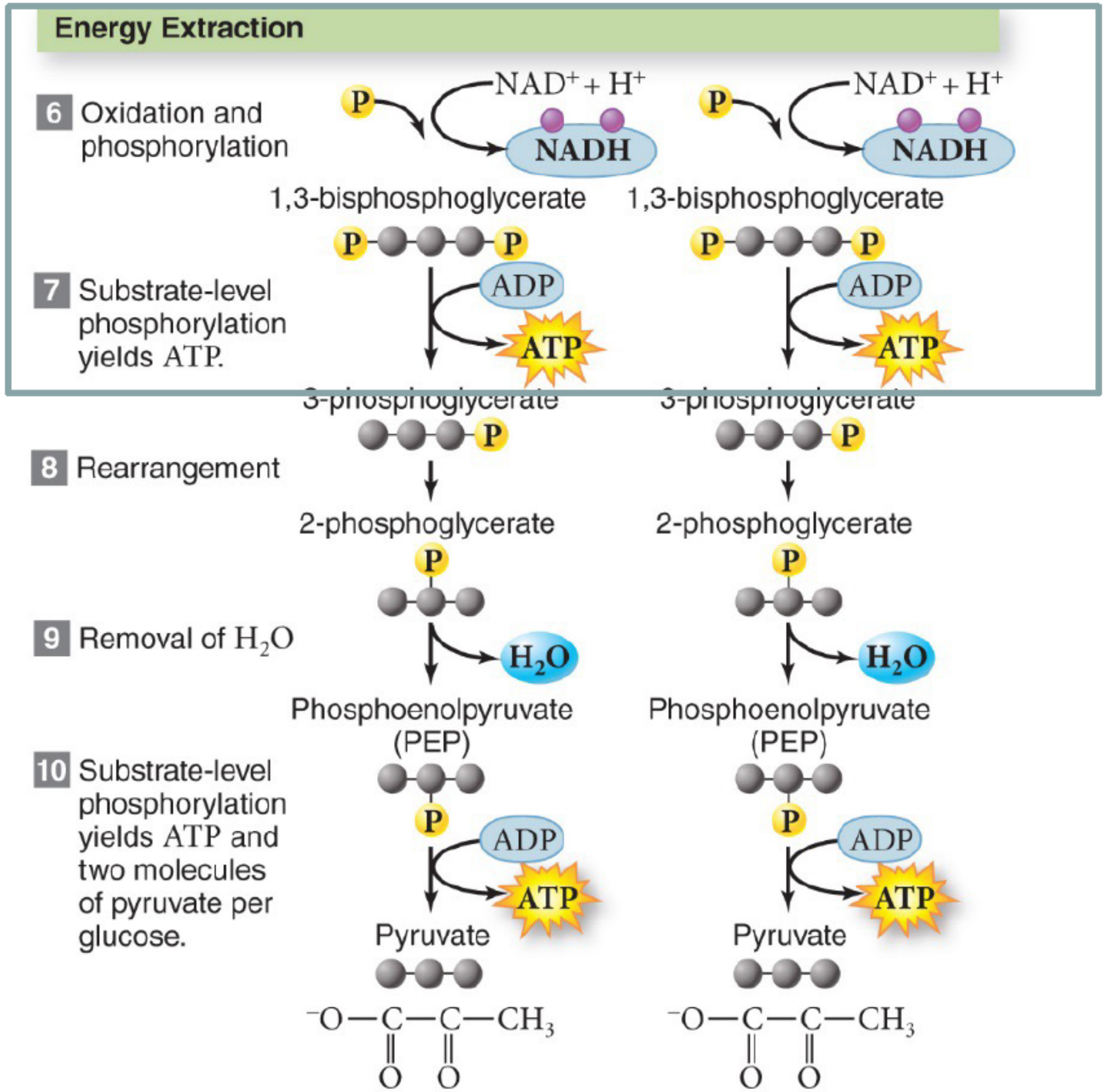
Glycolysis

- Energy investment stage
  - One glucose (6-carbon) molecule is split into two 3-carbon molecules
  - Phosphate groups added to the 3-carbon molecules
  - Phosphorylation results in more reactive molecule – glucose is relatively stable
  - Two ATP molecules used to activate one glucose molecule



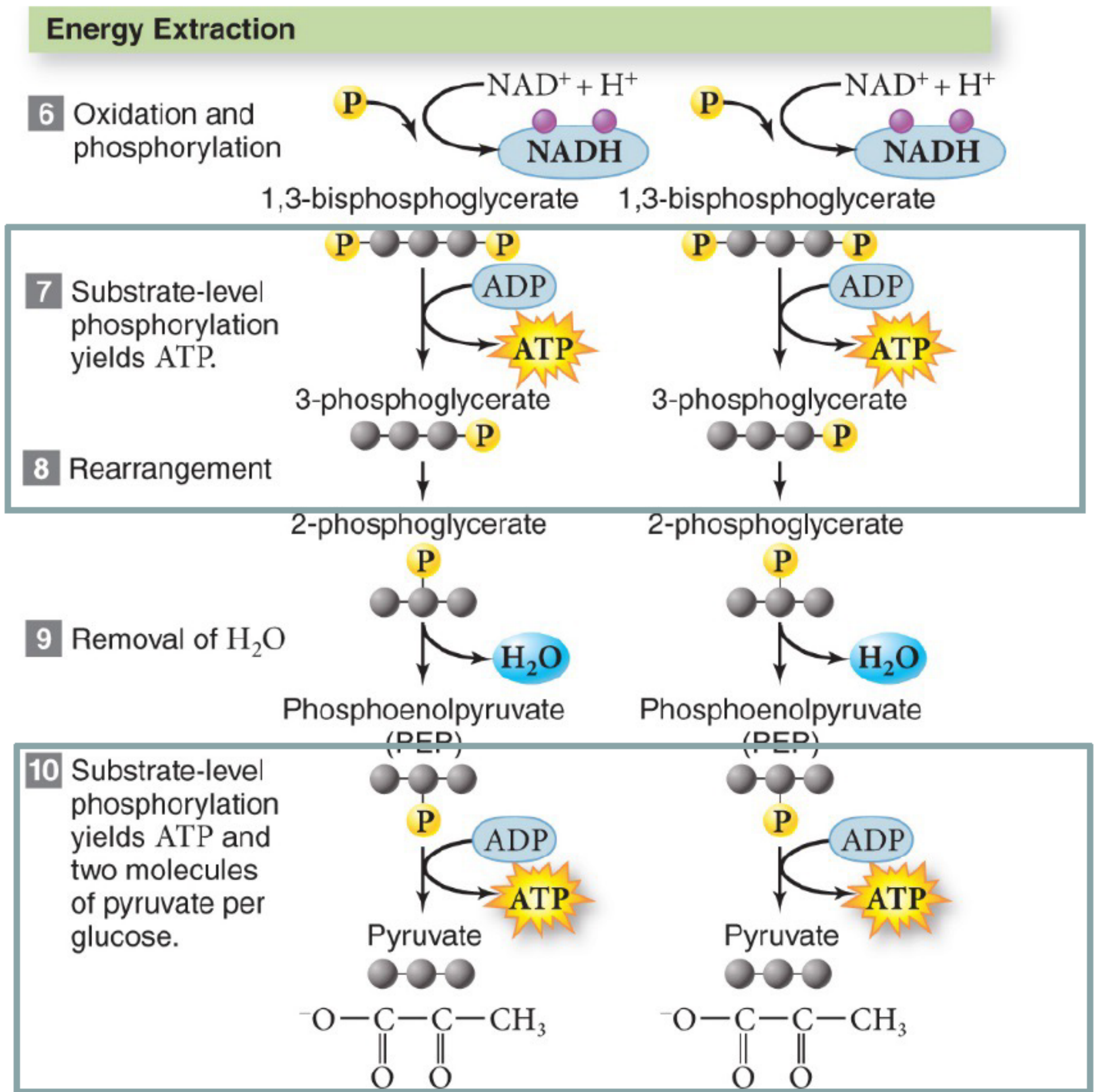
Glycolysis

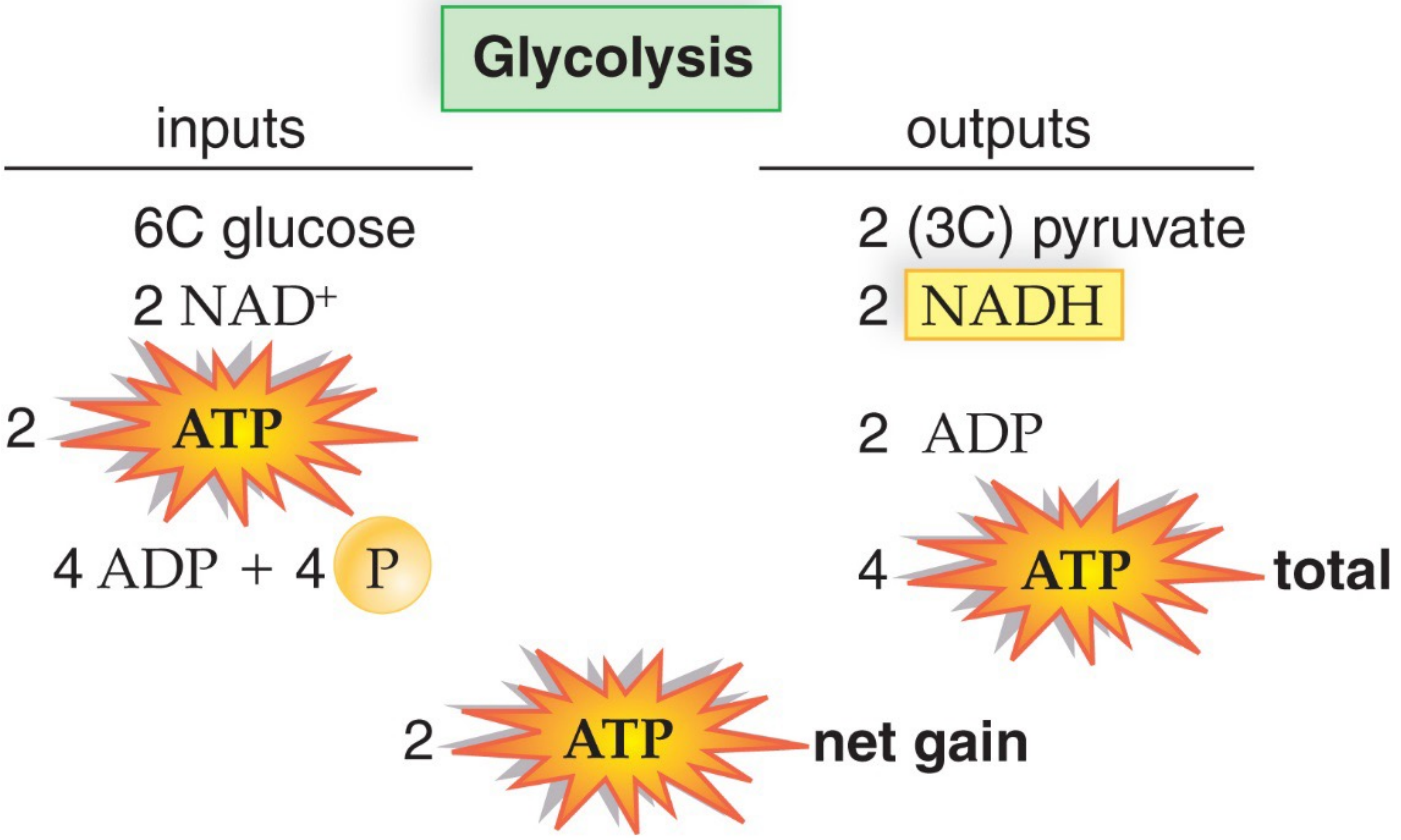
- Energy harvesting stage
  - Conversion of phosphorylated 3-carbon molecules to pyruvate molecules
  - Phosphorylated 3-carbon molecules oxidised by removal of electrons and H+
  - Electrons and H+ accepted by NAD+ resulting in high-energy electron-carrier molecule NADH
  - Two phosphorylated 3-carbon molecules produced per glucose molecule – two NADH molecules formed



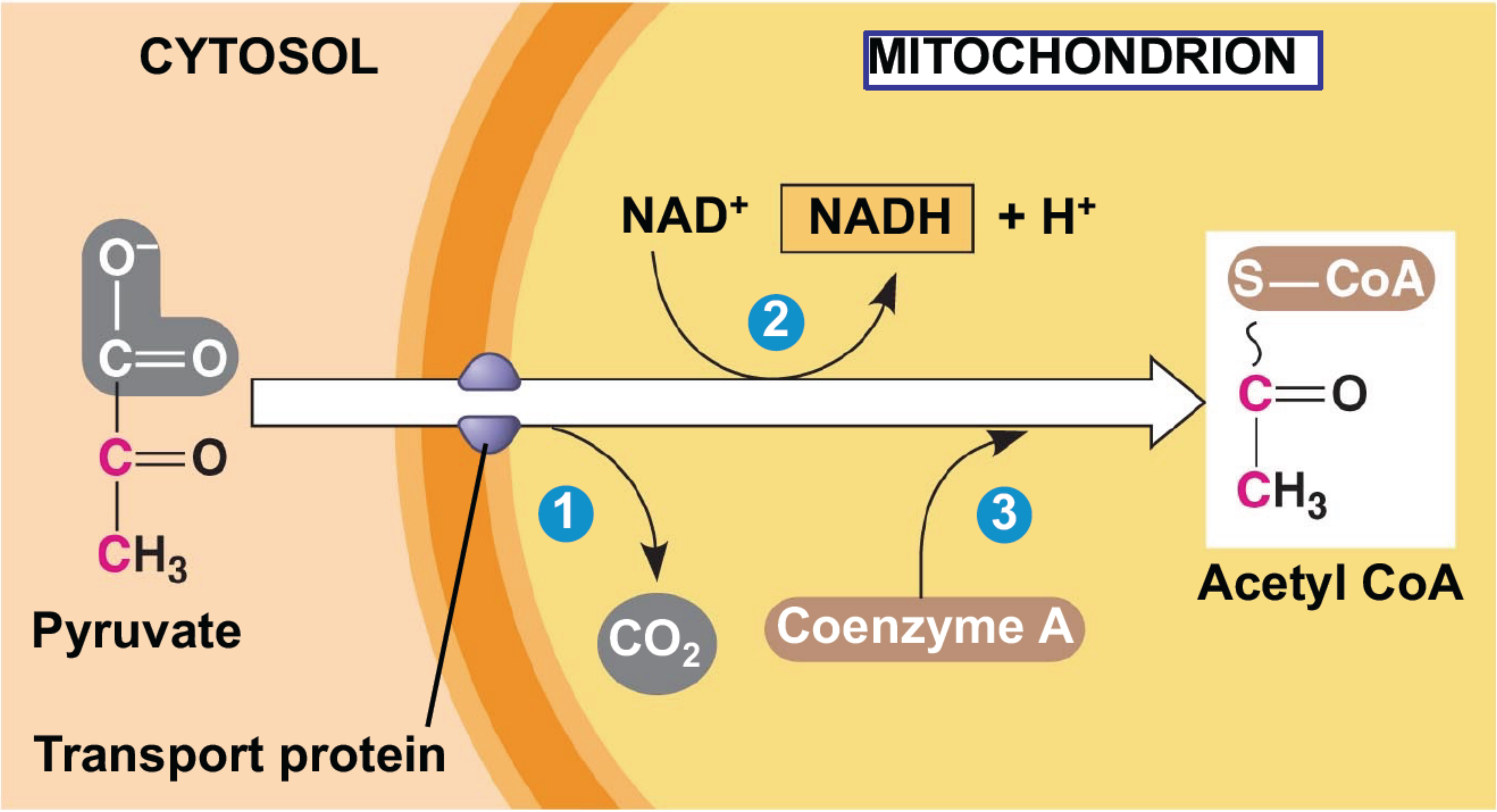
Glycolysis

- Energy harvesting stage
  - Two ATP molecules generated by substrate-level phosphorylation for each molecule of pyruvate produced
  - Two pyruvate molecules produced per glucose molecule - 4 ATP molecules generated
  - Two ATP molecules used to activate one glucose molecule – net gain of two ATP molecules



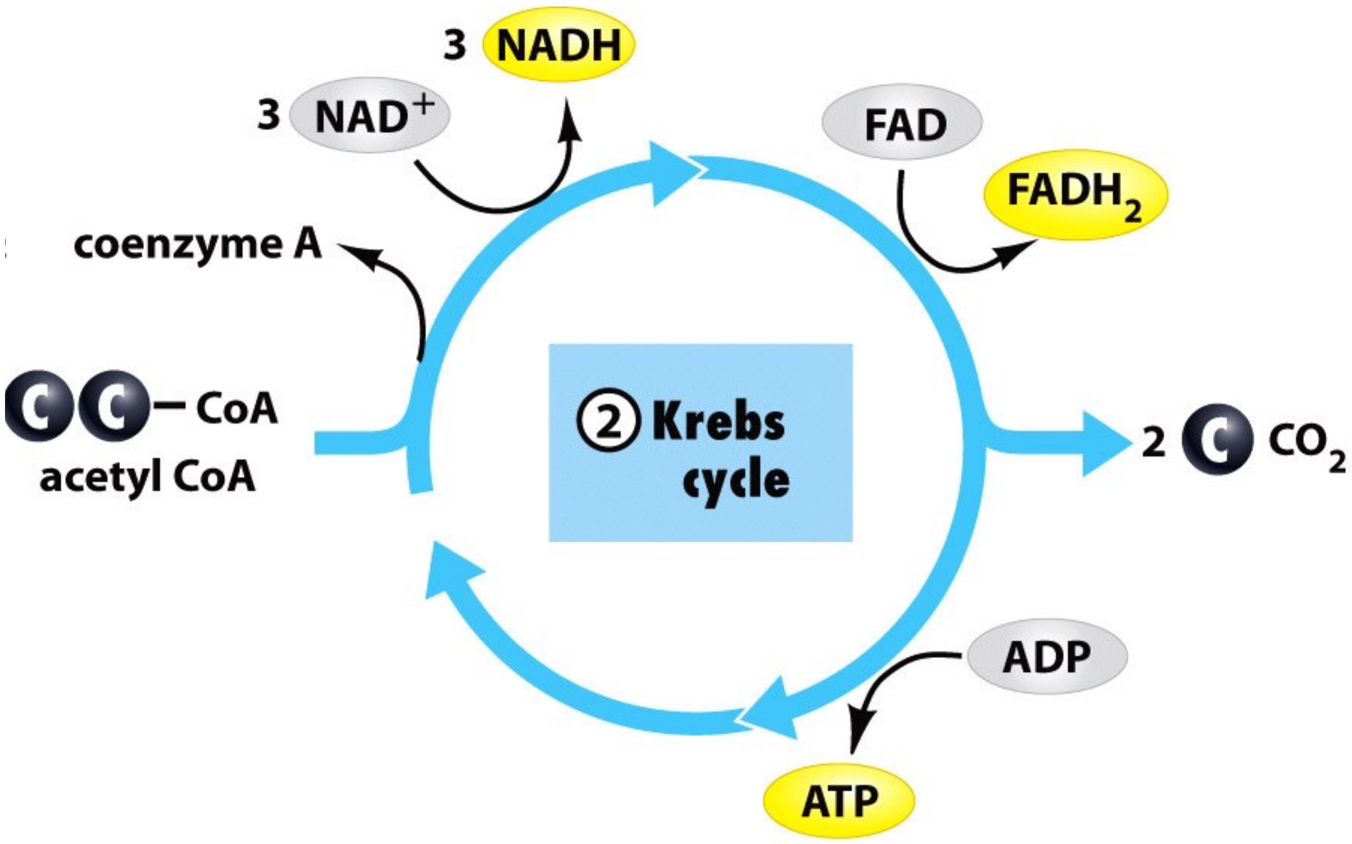

Glycolysis
inputs
6C glucose
2 NAD+
2 ATP
4 ADP + 4 P
outputs
2 (3C) pyruvate
2 NADH
2 ADP
4 ATP total
2 ATP net gain

Formation of Acetyl CoA i.e. Transition Reaction



2 NADH produced, No ATP generated

Citric Acid Cycle/Krebs cycle



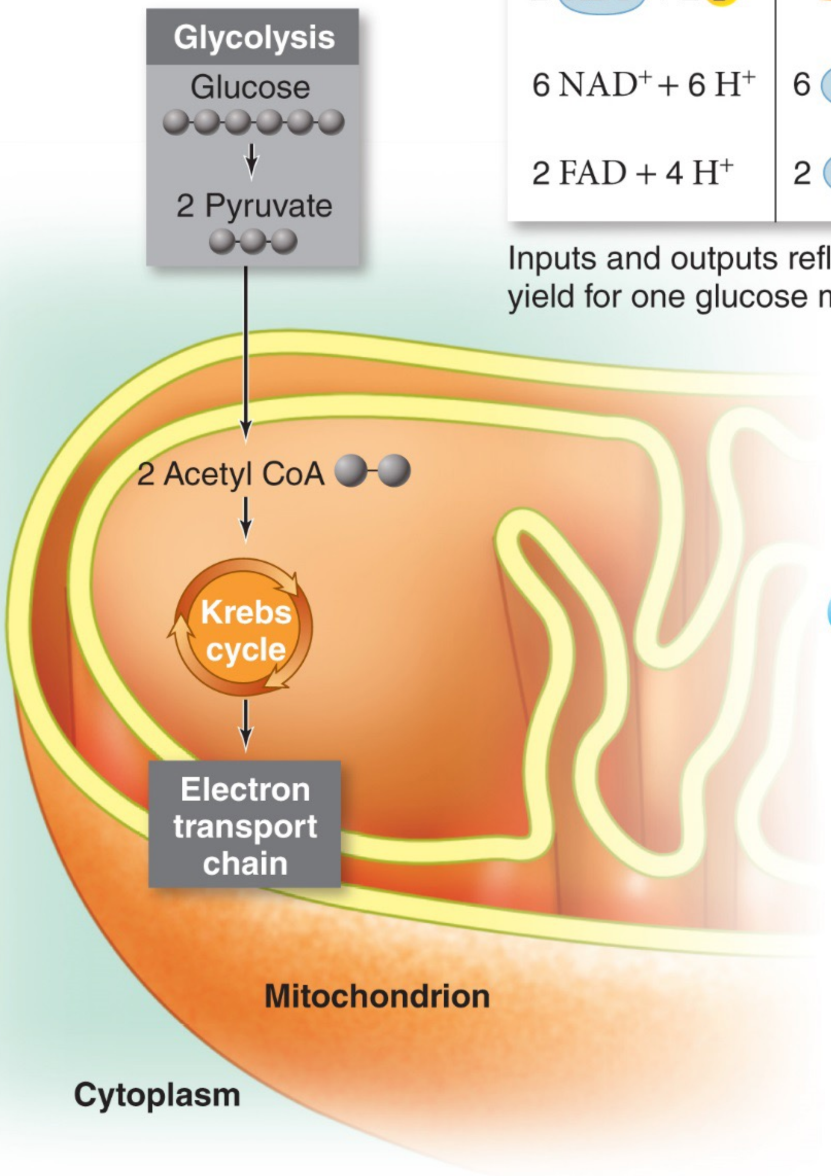
Hans Krebs

Each turn:

- 2 CO_2
- 1 ATP
- 3 NADH
- 1 $FADH_2$

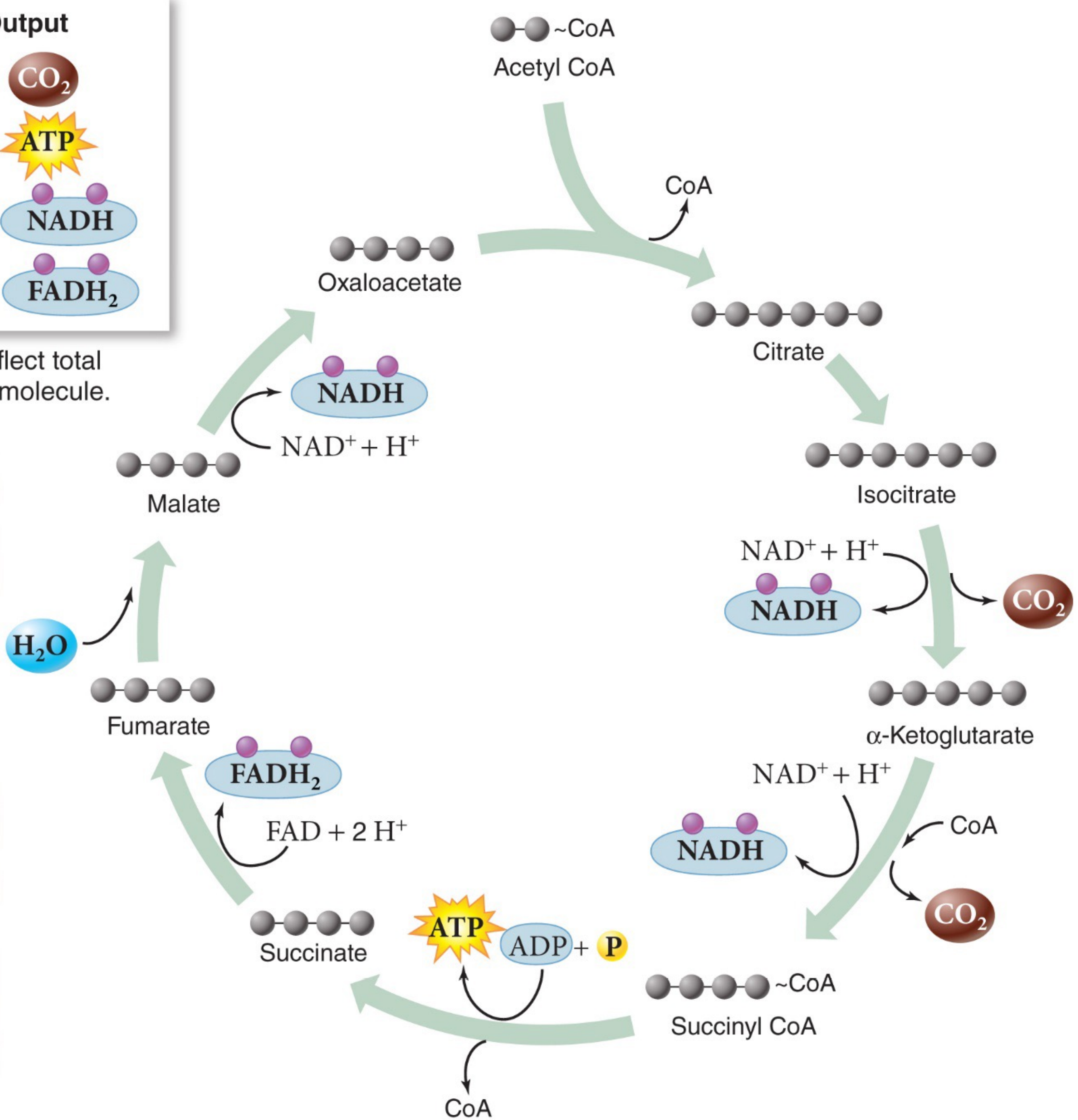
Also called Tricarboxylic acid cycle (TCA cycle)

FYI only



Input	Output
2 ~CoA	4 CO_2
2 ADP + 2 P	2 ATP
6 $NAD^+ + 6\ H^+$	6 NADH
2 FAD + 4 H^+	2 $FADH_2$

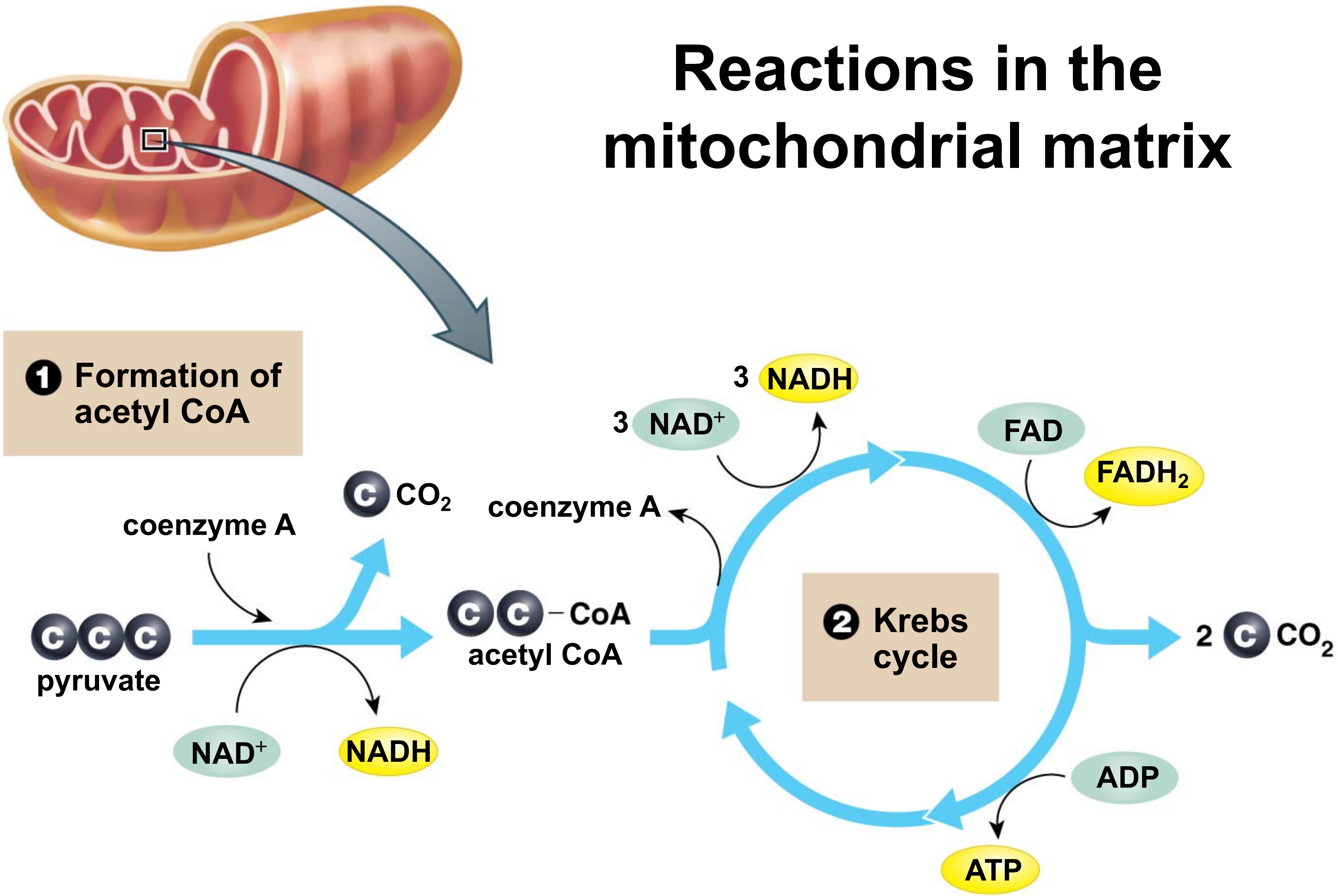
Inputs and outputs reflect total yield for one glucose molecule.



Summary of the Krebs cycle

- The Krebs cycle begins by combining **acetyl CoA** with a four-carbon molecule to form six-carbon citrate, and coenzyme A is released
- As the Krebs cycle proceeds, enzymes in the matrix break down the acetyl group, releasing two CO_2 molecules and regenerating the four-carbon molecule for use in future cycles
- **Each acetyl group produces one ATP, three NADH, and one $FADH_2$**
- Flavin adenine dinucleotide (FAD), a high-energy electron carrier similar to NAD, picks up two electrons and two H^+, forming $FADH_2$
- CO_2 is generated as a waste product. **CO_2** diffuses out of cells and into the blood, which carries it to the lungs, where it is exhaled

Reactions in the mitochondrial matrix



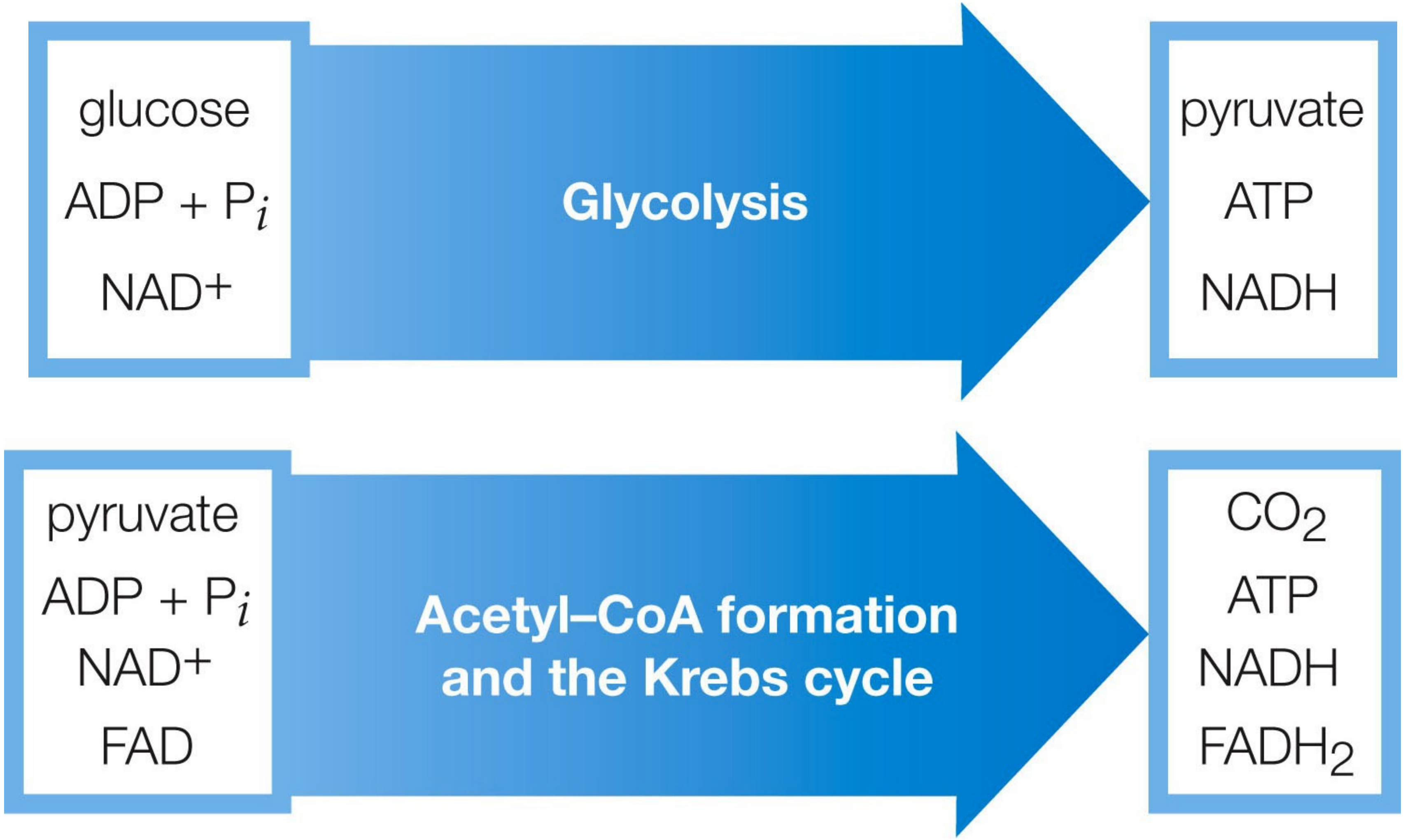
One glucose molecule needs two cycles to break into CO_2

Citric acid cycle

inputs	outputs
2 acetyl groups	4 CO_2
6 NAD^+	6 NADH
2 FAD	2 $FADH_2$
2 ADP + 2 P	2 ATP

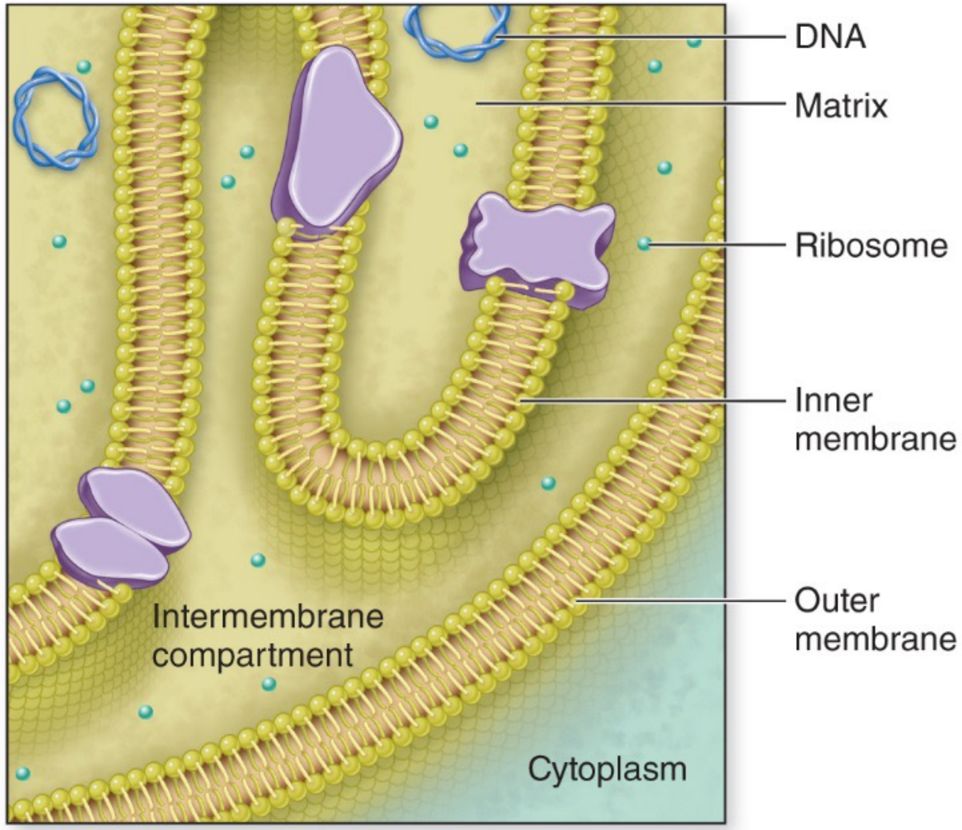
Electron Transfer Phosphorylation

- From glycolysis, acetyl-CoA formation and citric acid cycle
  - High-energy electrons captured by NAD+ and FAD
  - For every glucose molecule, ten NADH and two FADH2 produced



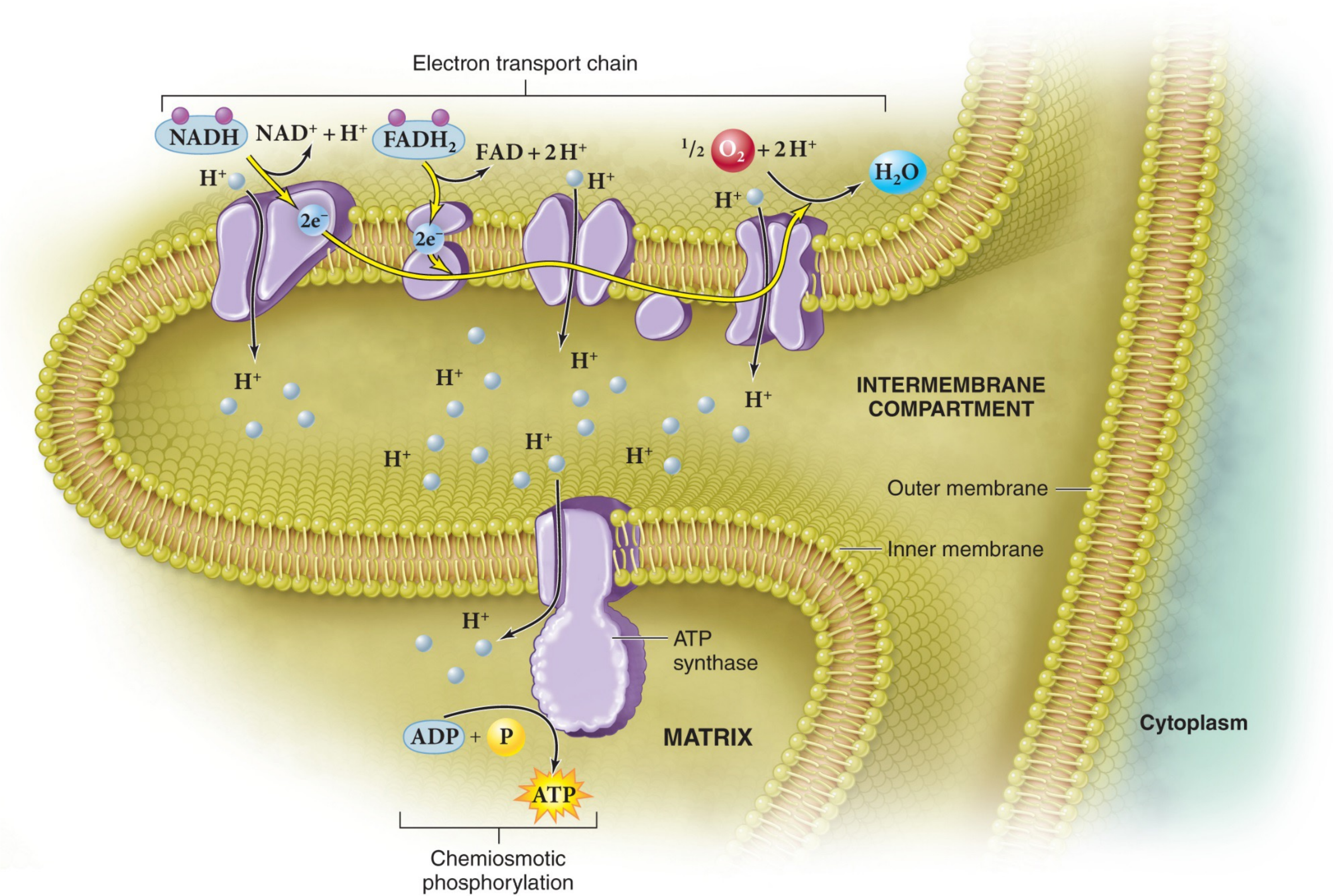
Electron Transfer Phosphorylation

- NADH and FADH2 release electrons to electron transport chain
- Electron transport chain – series of electron carrier proteins
  - In eukaryotes – embedded in inner mitochondrial membrane
  - In prokaryotes – embedded in plasma membrane
  - High-energy electrons passed successively from one protein to another, losing small amounts of energy at each step



Electron Transfer Phosphorylation

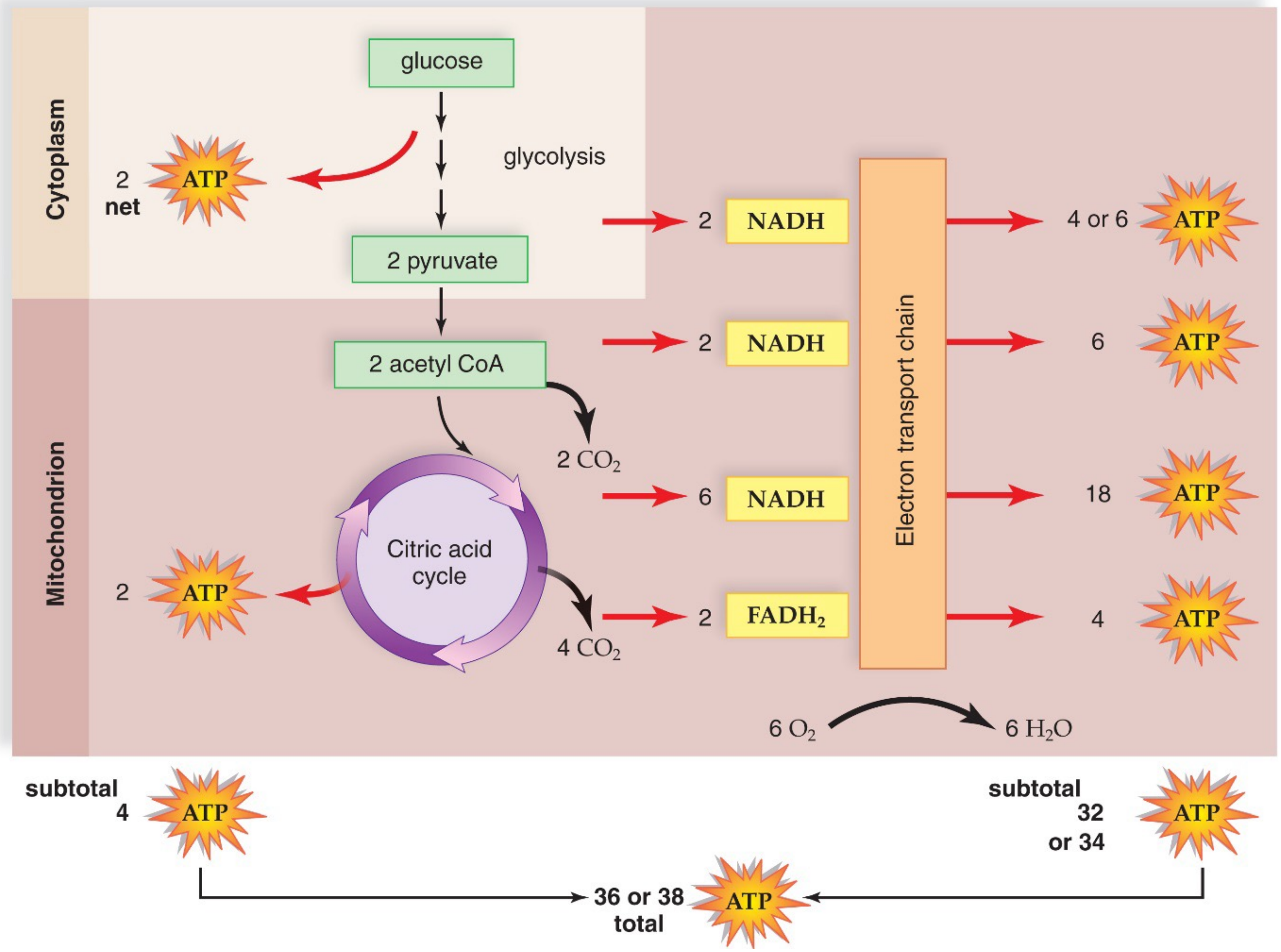
- Energy lost by electrons harnessed by electron transport chain proteins to pump H+ from matrix into inter-membrane space
- Higher H+ concentration in inter-membrane space
  - Gradient created
- H+ flows down its gradient through ATP synthase, which drives synthesis of ATP from ADP and phosphate
  - Chemiosmosis – ATP production linked to establishment of H+ gradient
- Oxygen accepts electrons and combines with H+ to form water
  - Final electron acceptor – oxygen



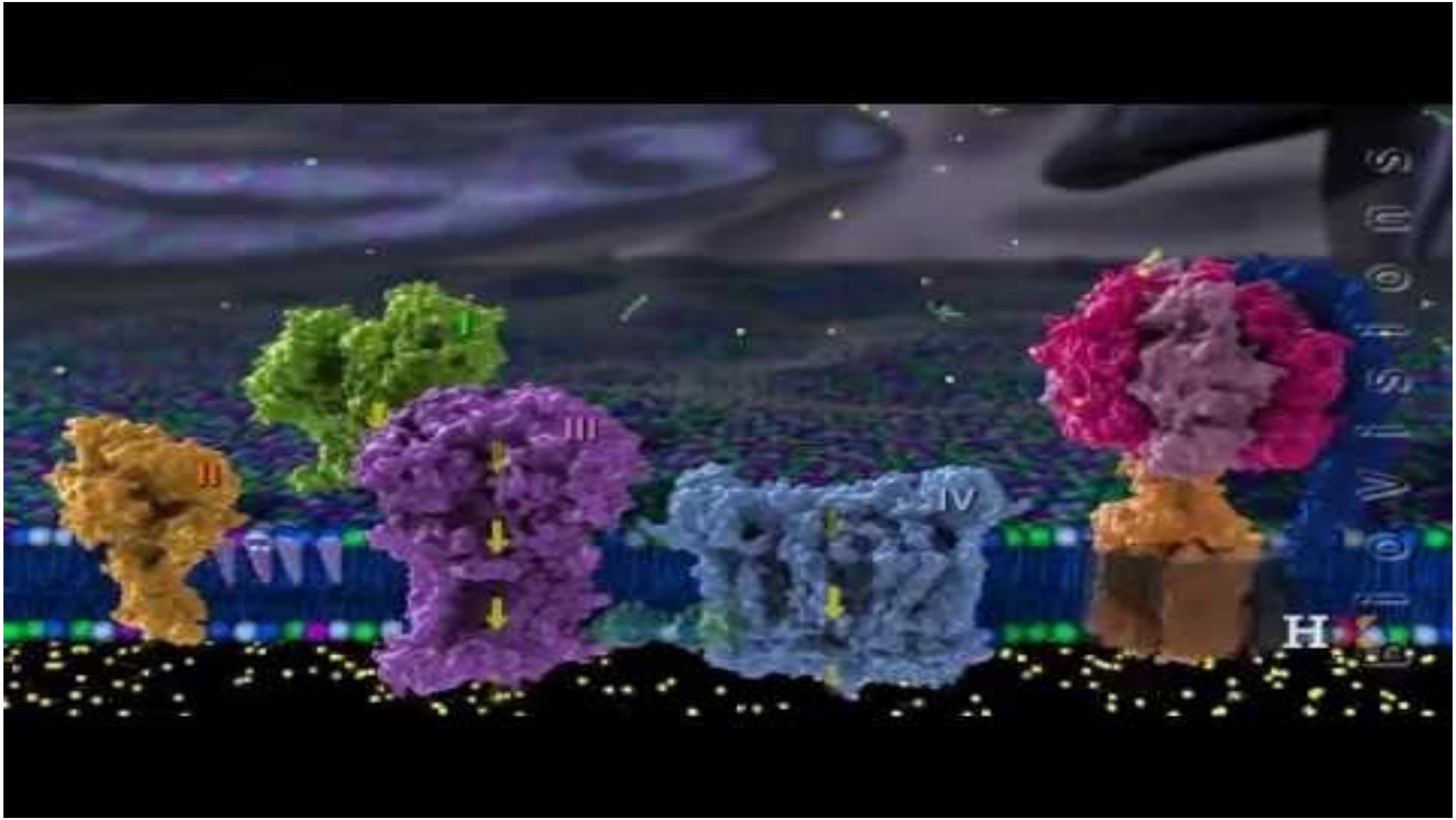
Electron transport chain
NADH
$NAD^+ + H^+$
$FADH_2$
$FAD + 2H^+$
$^1/_2\ O_2 + 2H^+$
H_2O
H^+
$2e^-$
$2e^-$
INTERMEMBRANE COMPARTMENT
Outer membrane
Inner membrane
ATP synthase
MATRIX
Cytoplasm
ADP + P
ATP
Chemiosmotic phosphorylation

Electron Transfer Phosphorylation

- Net yield per molecule of glucose
  - Glycolysis – 2 ATP
  - Citric acid cycle – 2 ATP
  - Electron transfer phosphorylation – 32 or 34 ATP

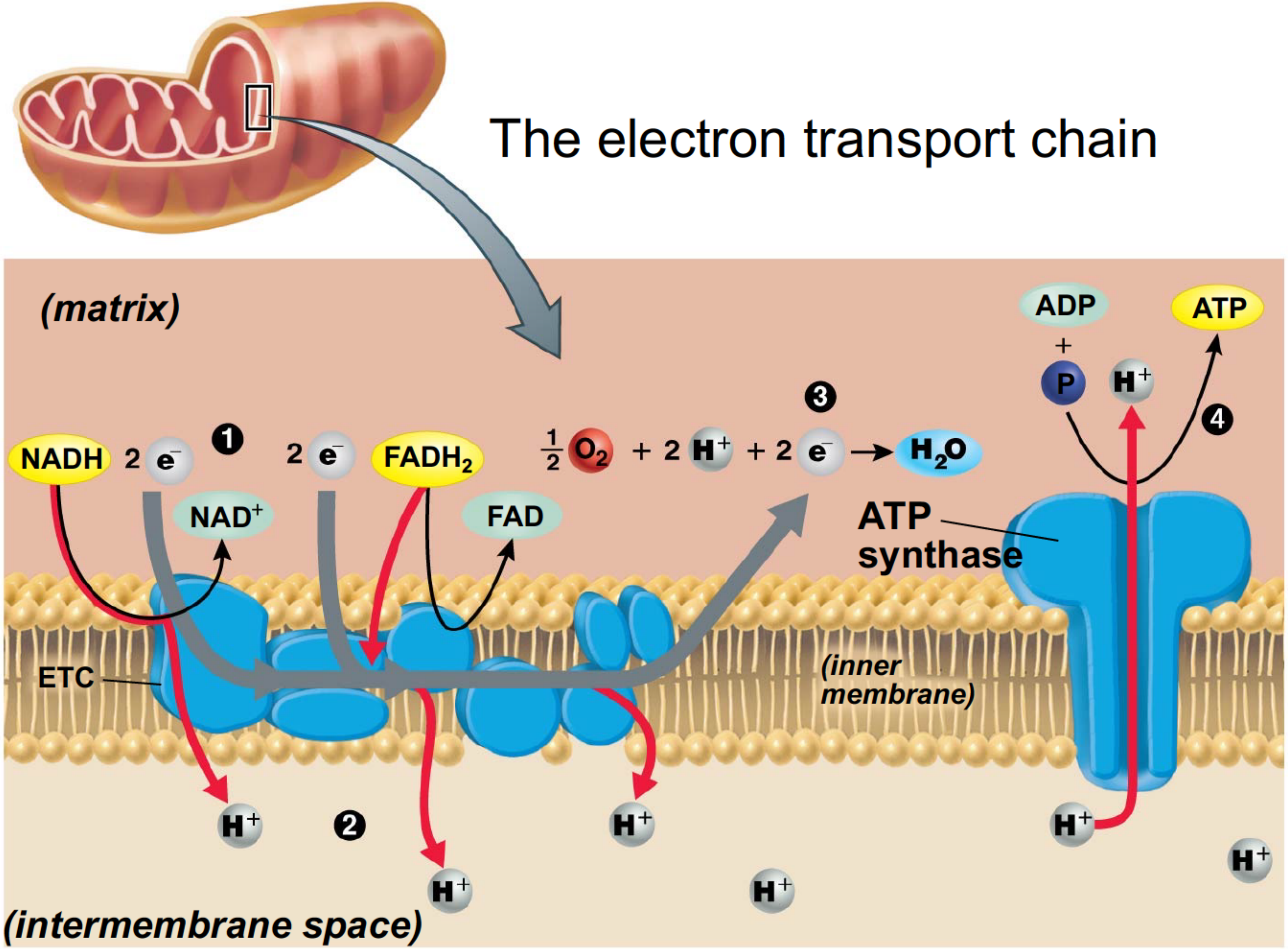


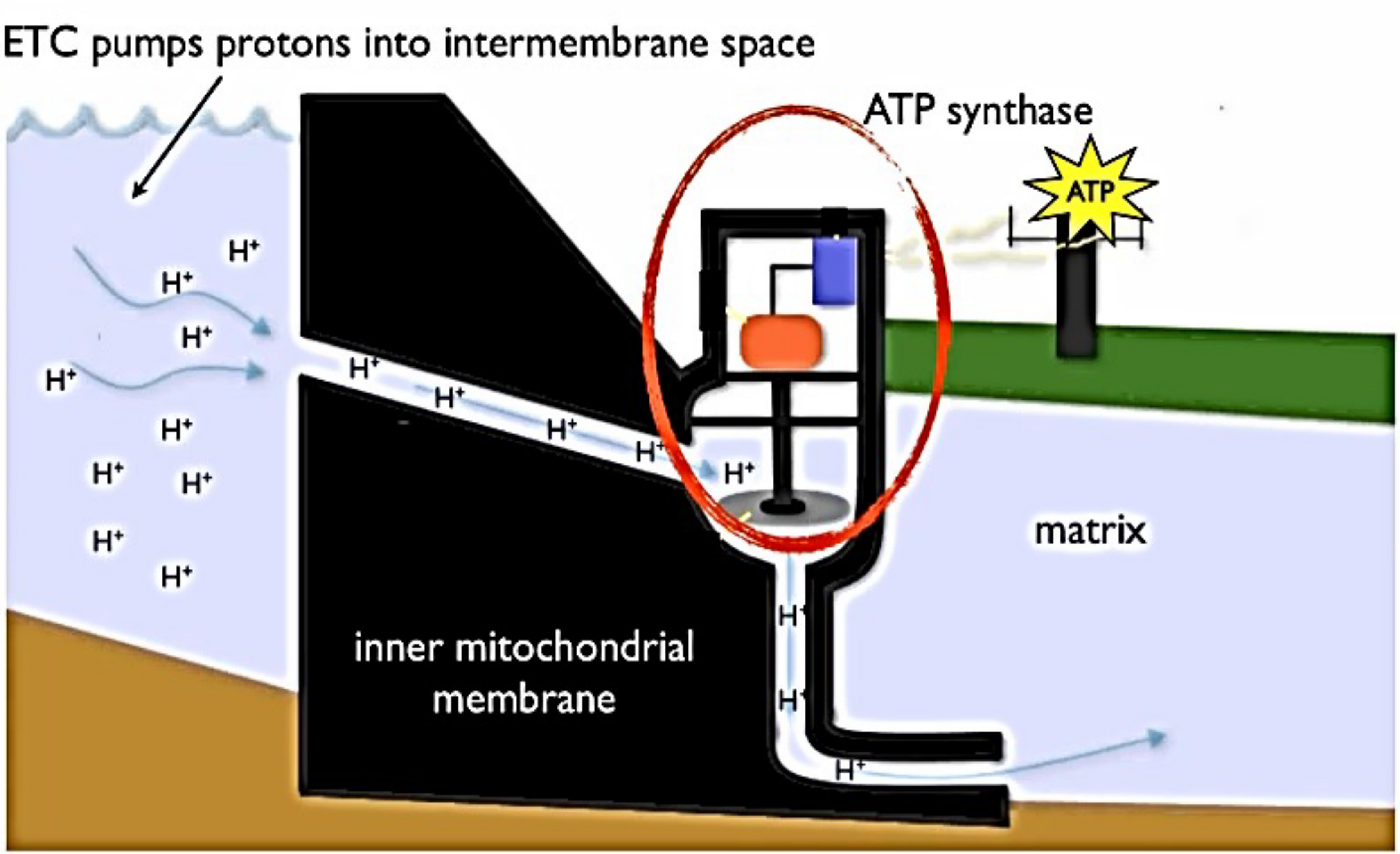
Electron Transport Phosphorylation (Video)



https://www.youtube.com/watch?v=LQmTKxI4Wn4

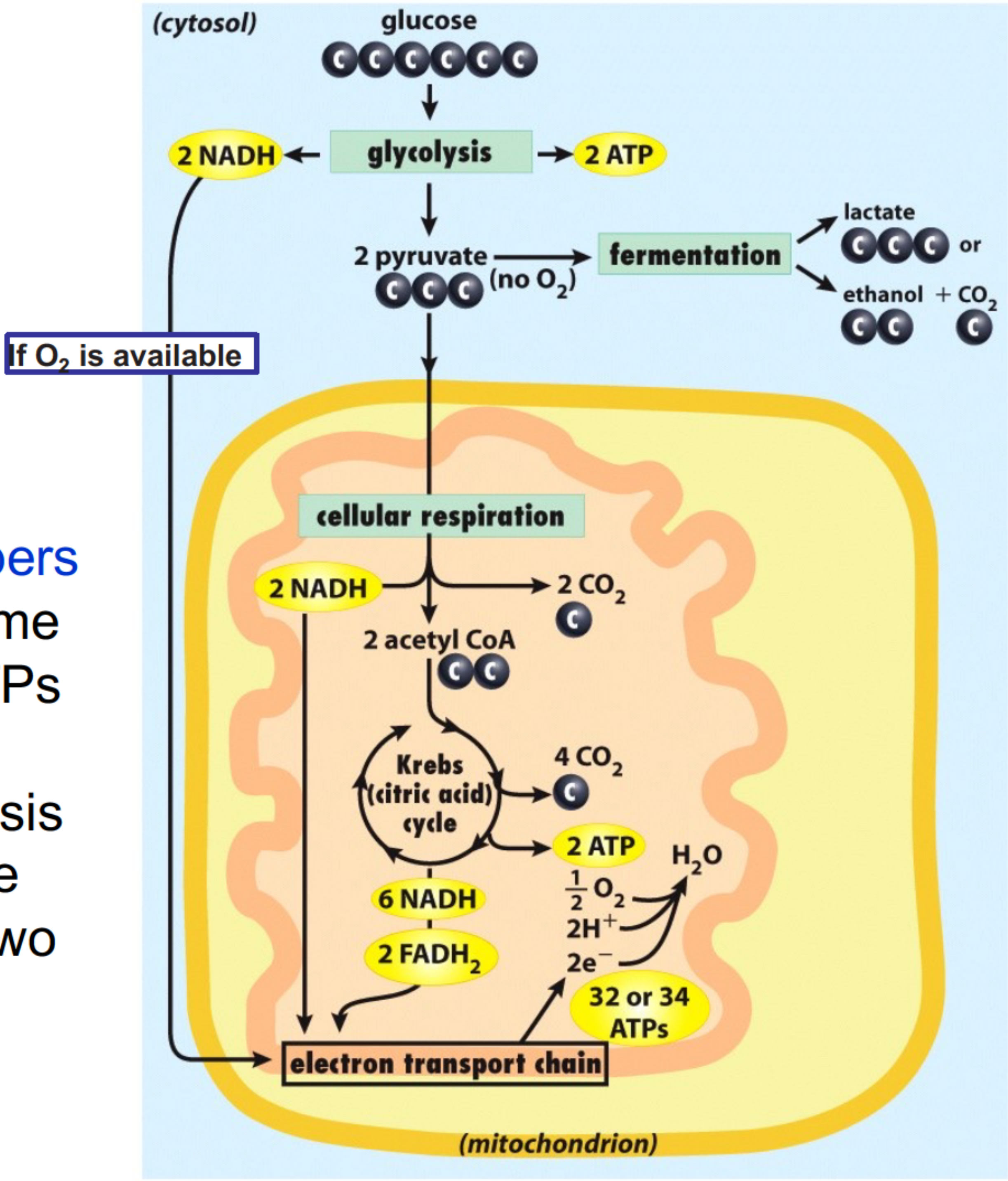
The electron transport chain





The ATP synthase enzyme complex acts like a proton-powered turbine

Summary of Glucose Breakdown



- The reason of two different numbers exist for ATP synthesis is that some cell types have to expend two ATPs to transport the two NADH molecules created during glycolysis into the mitochondrion; others are more efficient and don't require two

Step	coenzyme yield	ATP yield	Source of ATP
Glycolysis preparatory phase		-2	Phosphorylation of glucose and fructose 6-phosphate uses two ATP from the cytoplasm.
		4	Substrate-level phosphorylation
Glycolysis pay-off phase	2 NADH	4 (6)	Oxidative phosphorylation. Only 2 ATP per NADH since the coenzyme must feed into the electron transport chain from the cytoplasm rather than the mitochondrial matrix. If the malate shuttle is used to move NADH into the mitochondria this might count as 3 ATP per NADH.
Oxidative decarboxylation of pyruvate	2 NADH	6	Oxidative phosphorylation
		2	Substrate-level phosphorylation
Krebs cycle	6 NADH	18	Oxidative phosphorylation
	2 $FADH_2$	4	Oxidative phosphorylation
Total yield		36 (38) ATP	From the complete oxidation of one glucose molecule to carbon dioxide and oxidation of all the reduced coenzymes.

Outline

- Energy
  - Laws of thermodynamics
- Metabolic Reactions
  - Energy carrier molecules
  - Energy release
- Aerobic Cellular Respiration
  - Glycolysis
  - Acetyl-CoA formation
  - Citric acid cycle
  - Electron transfer phosphorylation
- Fermentation
- Food and Energy

Fermentation

- When there is no oxygen after glycolysis, fermentation will occur
  - Processes that **use an organic molecule to regenerate NAD+ from NADH are collectively referred to as fermentation**.
  - Do not break glucose down completely to carbon dioxide and water
  - Yield only 2 ATP from glycolysis

- **Lactate fermentation**
  - In animals or bacteria – produces lactic acid
- **Alcoholic fermentation**
  - In yeast – produces ethanol

Lactate fermentation

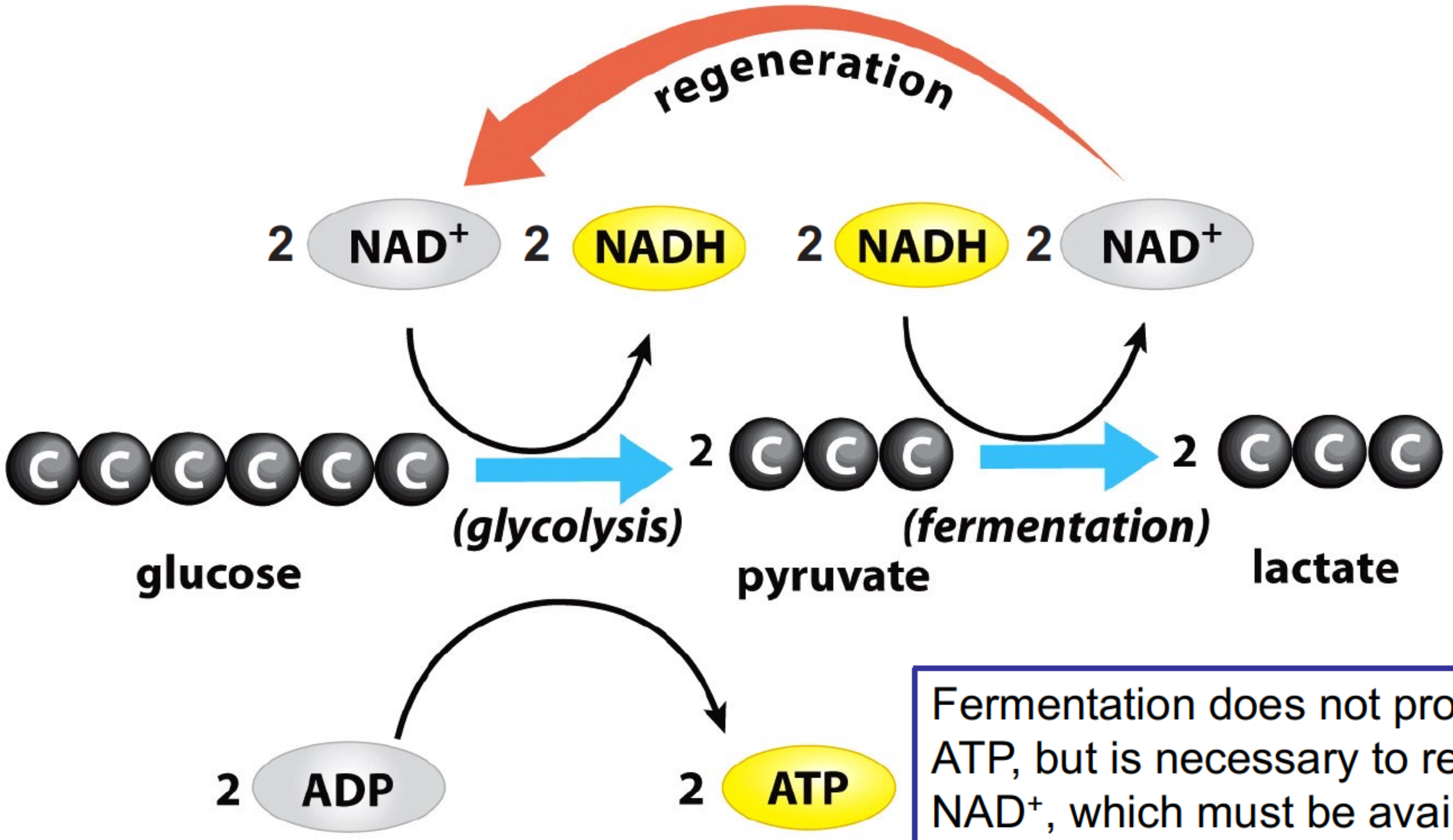
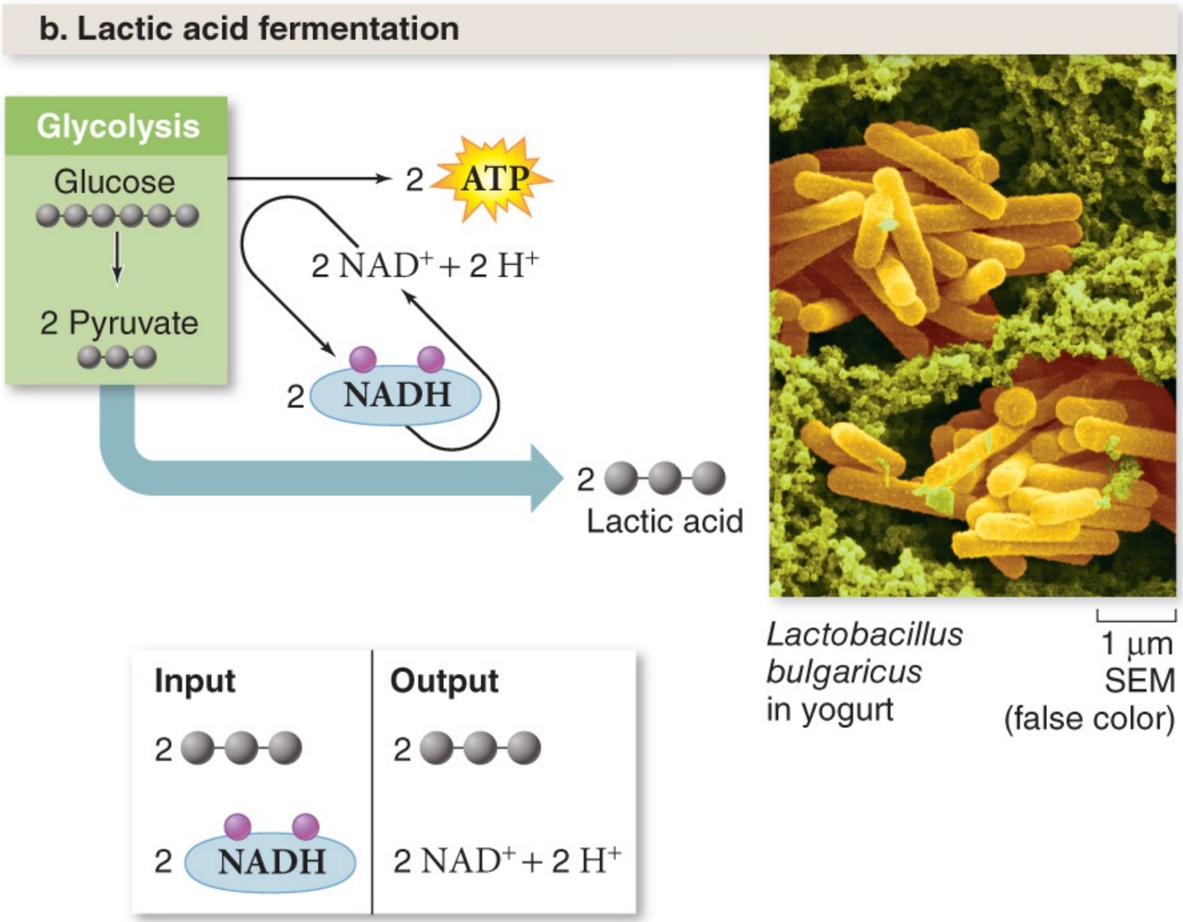


Figure 8-4 Biology: Life on Earth, 8/e

Fermentation does not produce more ATP, but is necessary to regenerate NAD^+, which must be available for glycolysis to continue

What Happens During Lactate Fermentation?

- Carried out by muscle cells, certain bacteria and fungi
- Produces lactic acid
- NAD+ regenerated after NADH transfers electrons to pyruvate
- Used in production of cheese, yoghurt, sour cream and sauerkraut

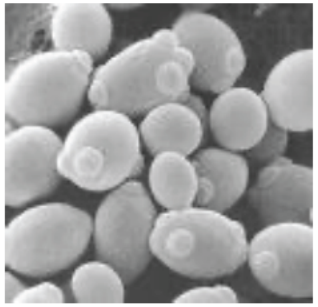


(right): © Scimat/SPL/Photo Researchers

Alcoholic fermentation

Starch

Malting



Yeast

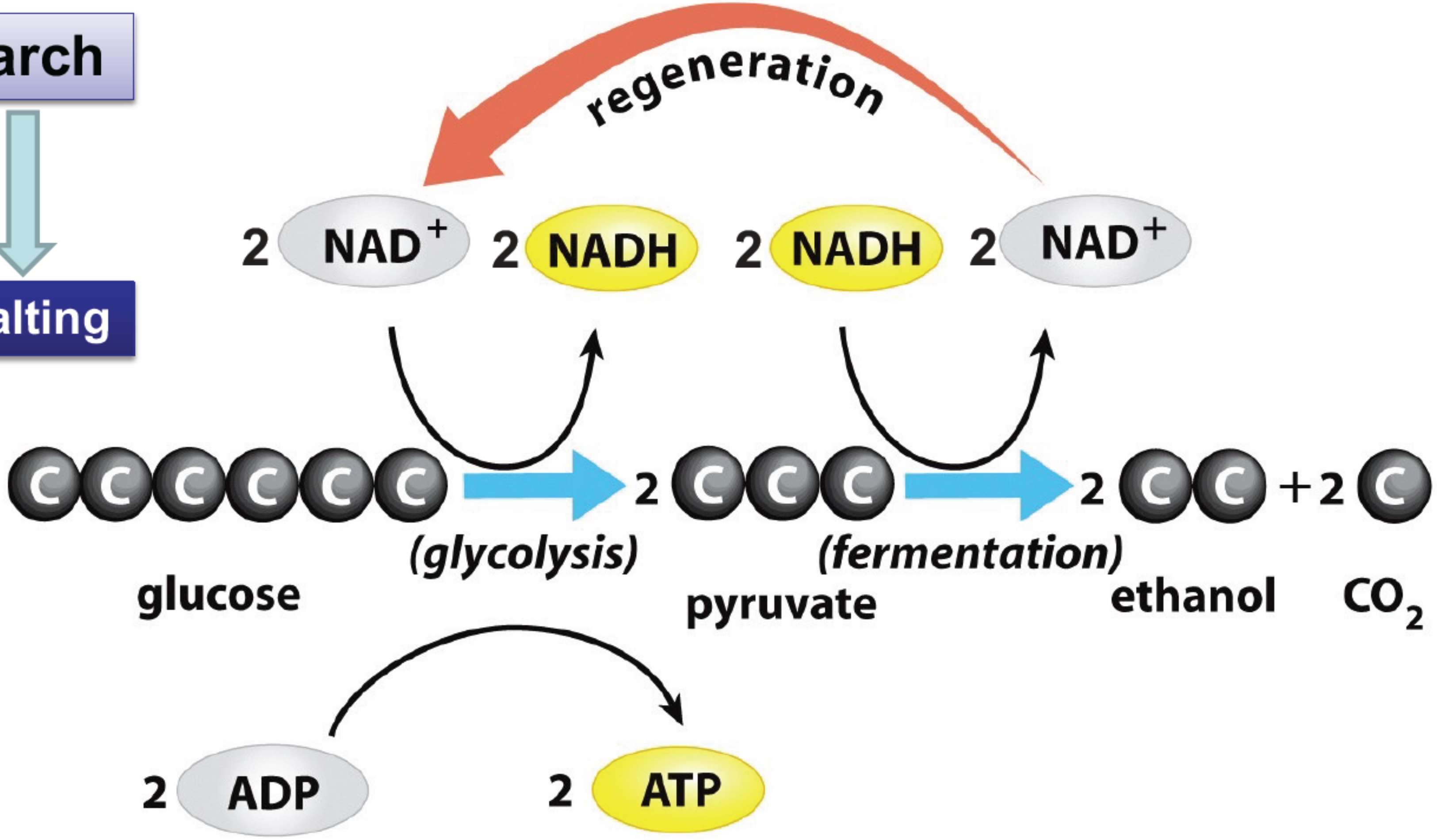
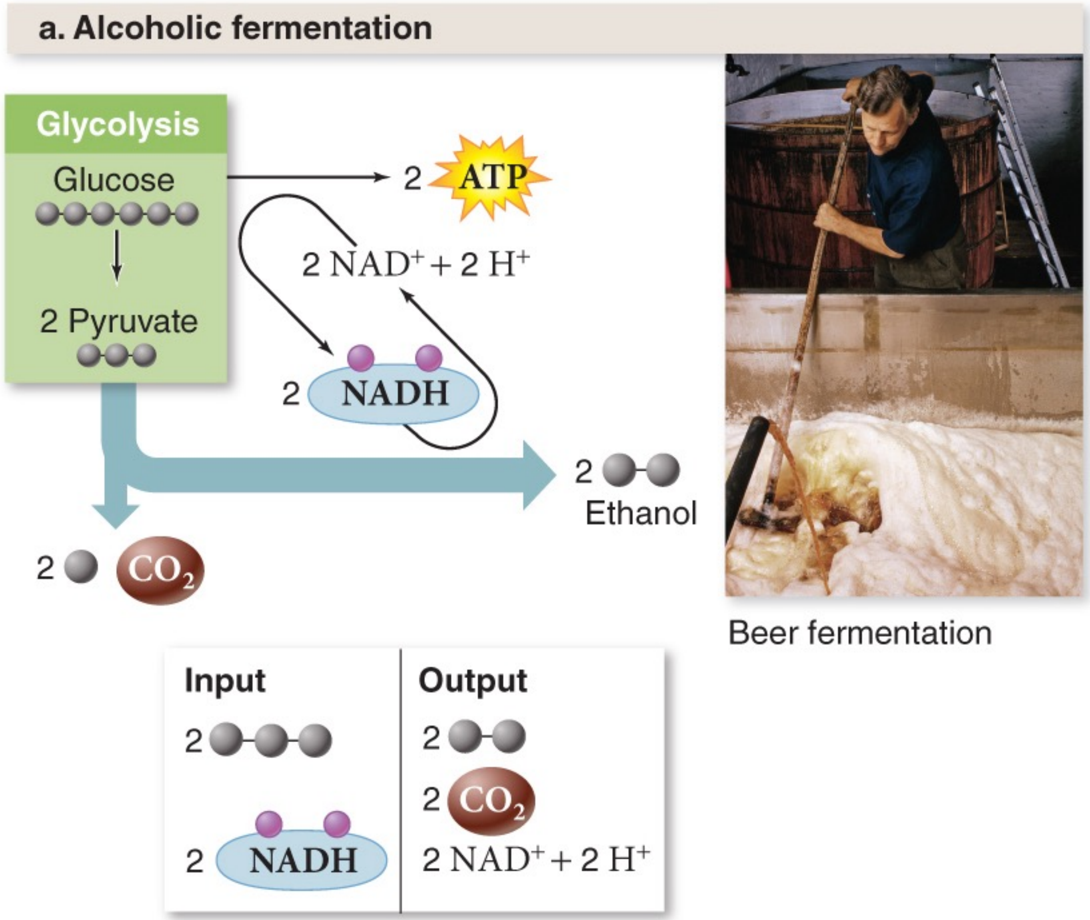


Figure 8-5 Biology: Life on Earth, 8/e

What Happens During Alcohol Fermentation?

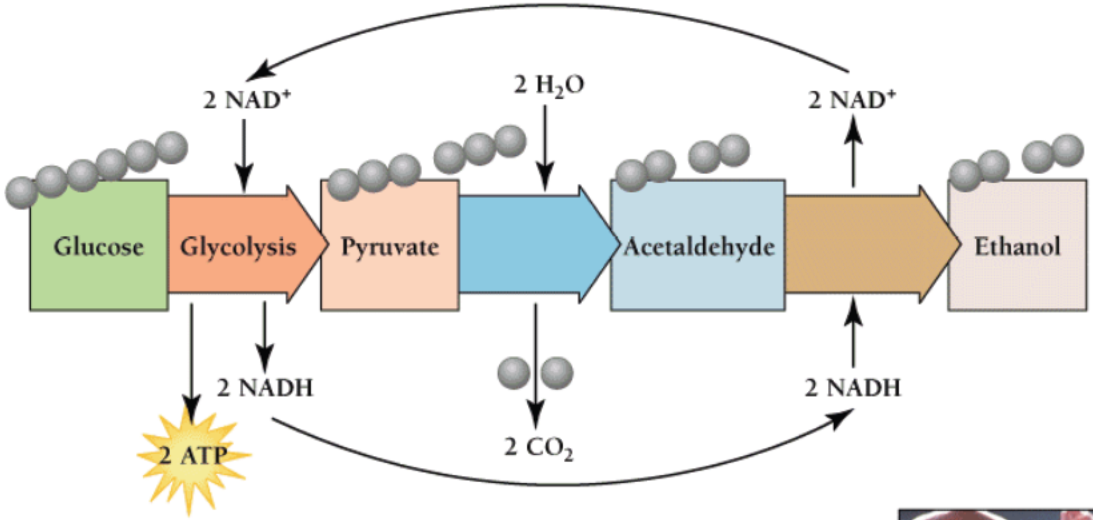
- Carried out by microorganisms such as yeasts under anaerobic conditions
- Produces CO2 and ethanol
- NAD+ regenerated to accept more high-energy electrons during glycolysis
- Used in production of alcoholic spirits and breads



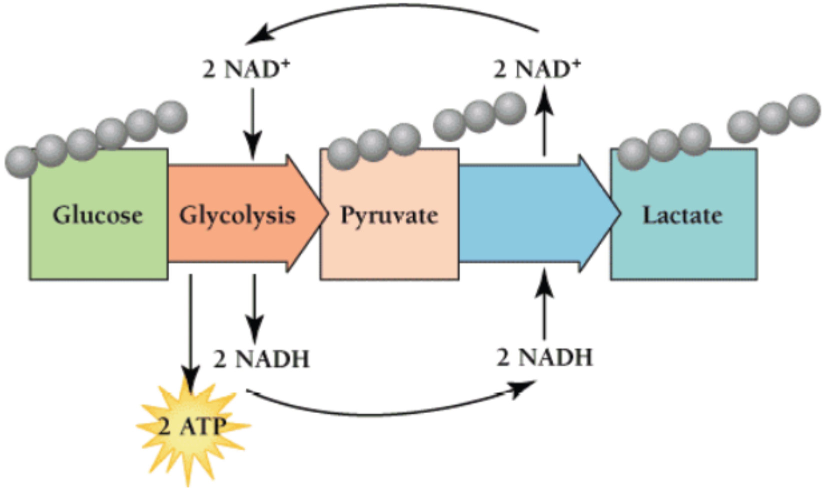
Fermentation

Fermentation keeps ATP production going when oxygen is unavailable

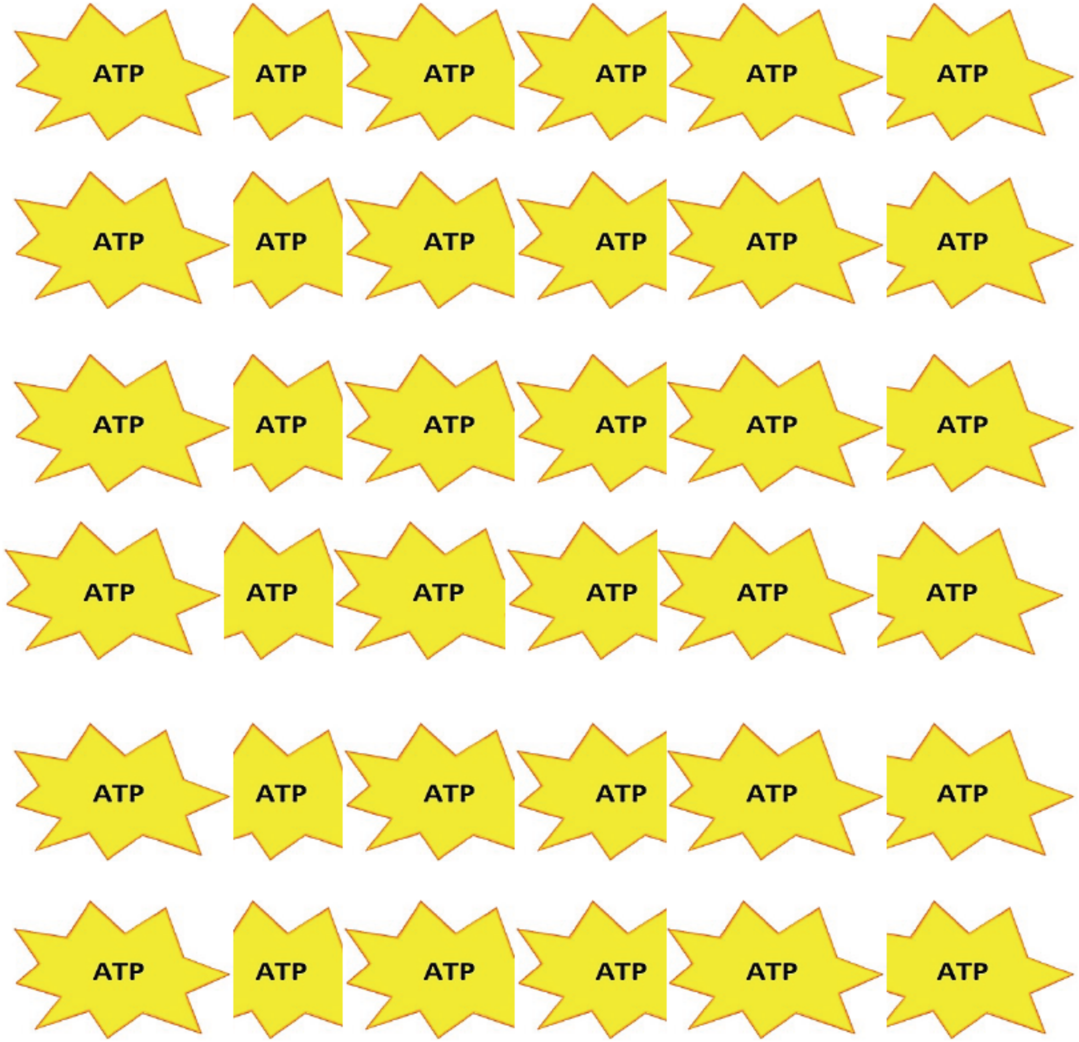
Yeast



Animal



Aerobic Respiration



Lactate/Alcoholic Fermentation

FYI only: This yields approximately 380,000 calories (cal) per mole of glucose (ATP ~ 10,000 cal/mole). Thermodynamically, the complete oxidation of one mole of glucose should yield approximately 688,000 cal; the energy that is not conserved biologically as chemical energy (or ATP formation) is liberated as heat (308,000 cal). Thus, the cellular respiratory process is at best about 55% efficient.

https://www.ncbi.nlm.nih.gov/books/NBK7919/

Outline

- Energy
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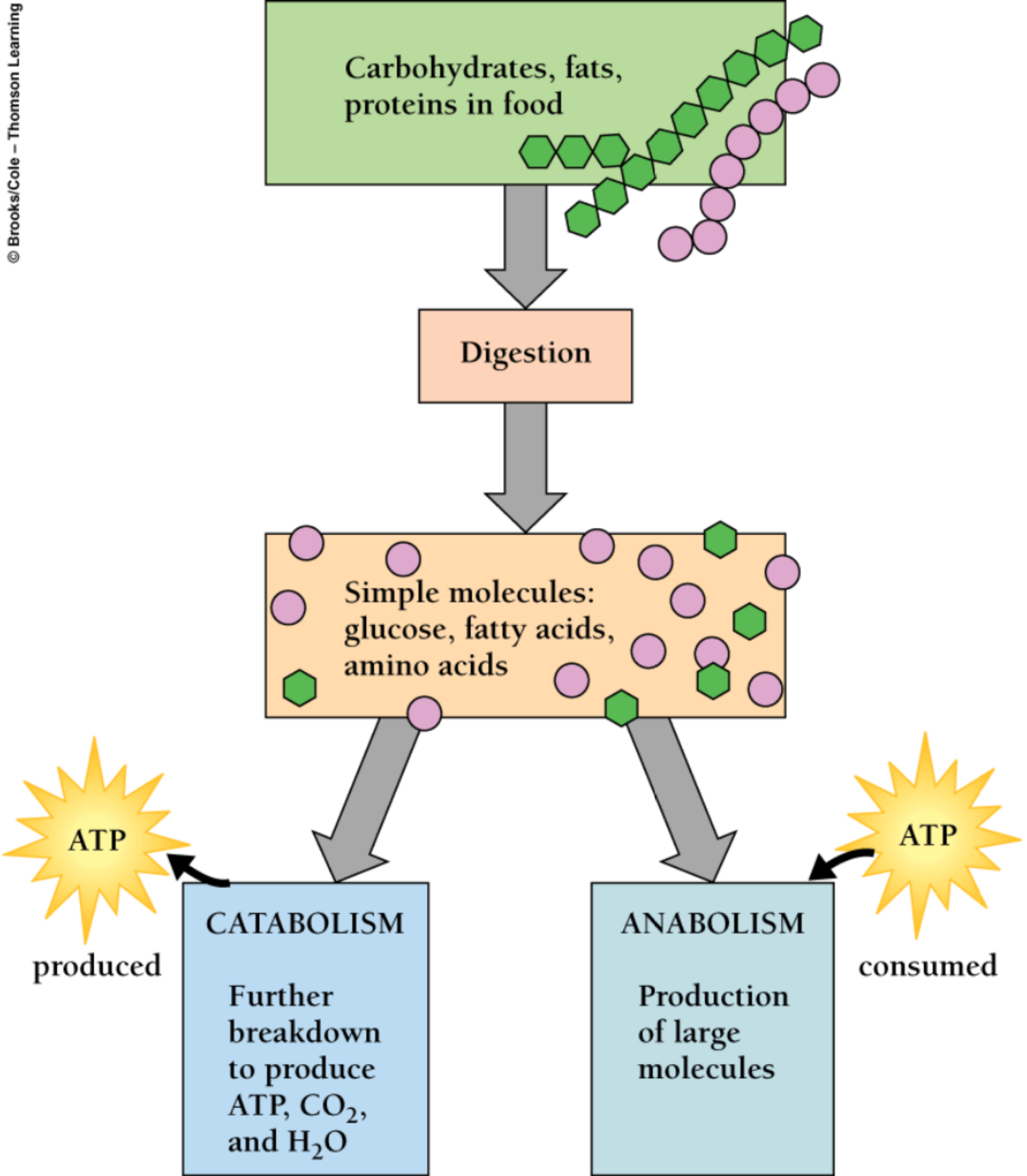
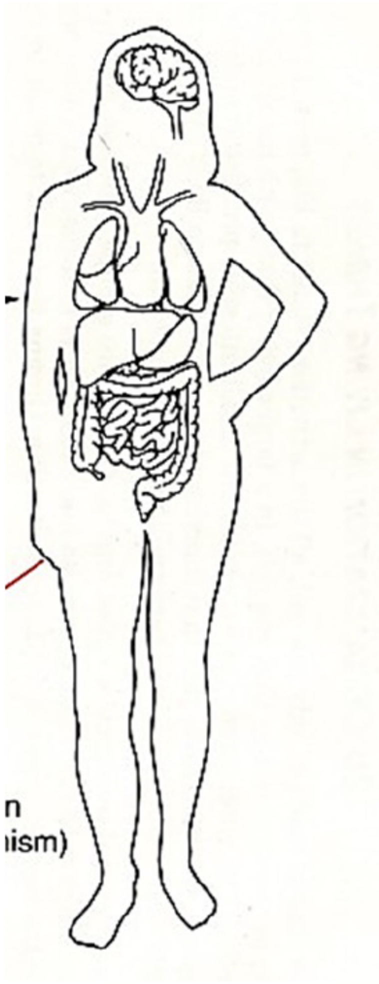
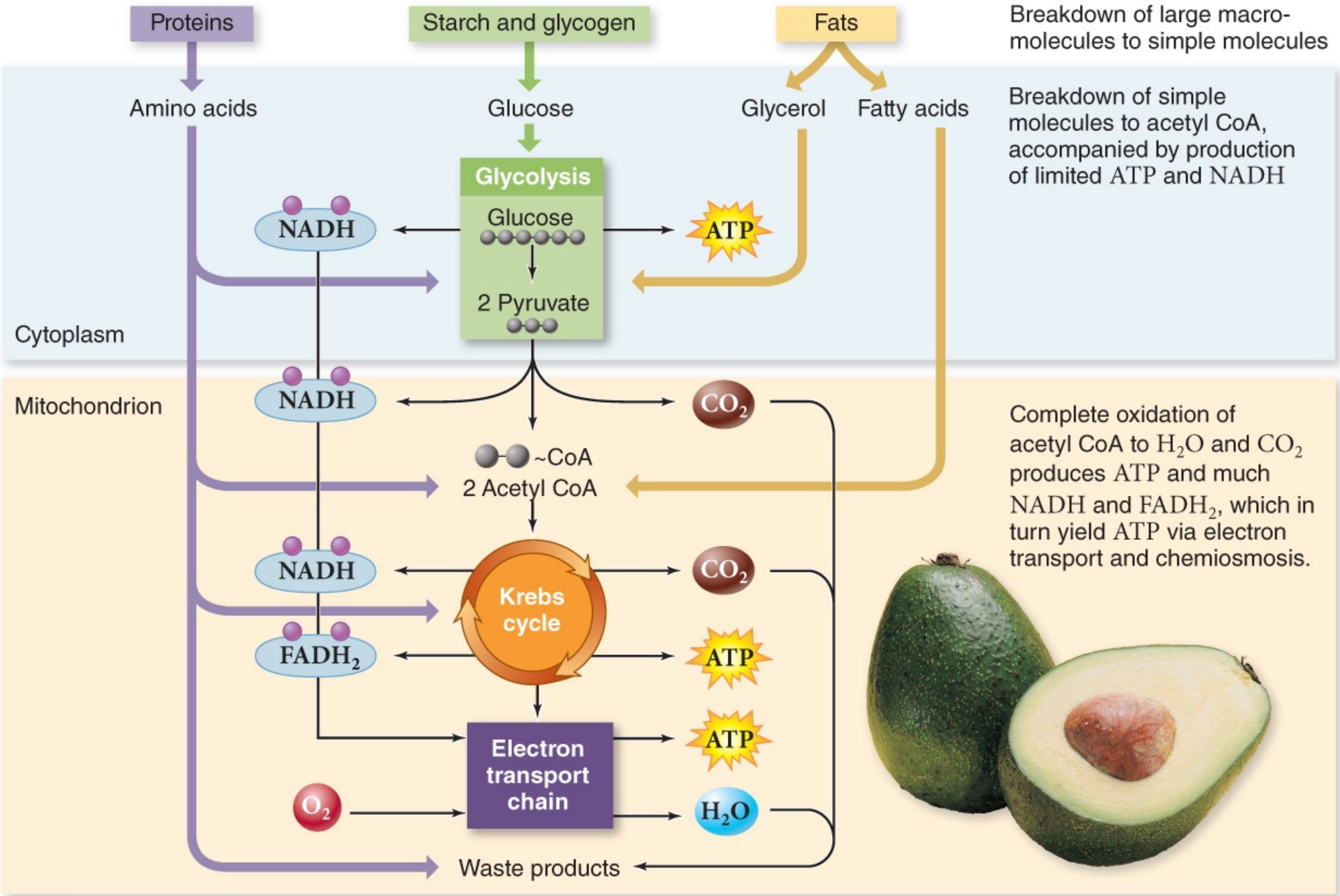
Food and Energy

- Starch and other complex carbohydrates
  - Broken down to monosaccharide subunits that enter glycolysis
- Fats (triglycerides) broken down to glycerol and fatty acids
  - Glycerol enters glycolysis
  - Fatty acids converted to acetyl-CoA that enter citric acid cycle
- Proteins broken down to amino acid subunits
  - Usually used to build proteins but may be used as energy source
  - Amino group removed and converted into waste product eliminated in urine
  - Remaining carbon groups converted to acetyl-CoA, pyruvate or intermediates of citric cycle, depending on amino acid



Carbohydrates, fats, proteins in food
Digestion
Simple molecules: glucose, fatty acids, amino acids
ATP
produced
CATABOLISM
Further breakdown to produce ATP, CO_2, and H_2O
ANABOLISM
Production of large molecules
ATP
consumed





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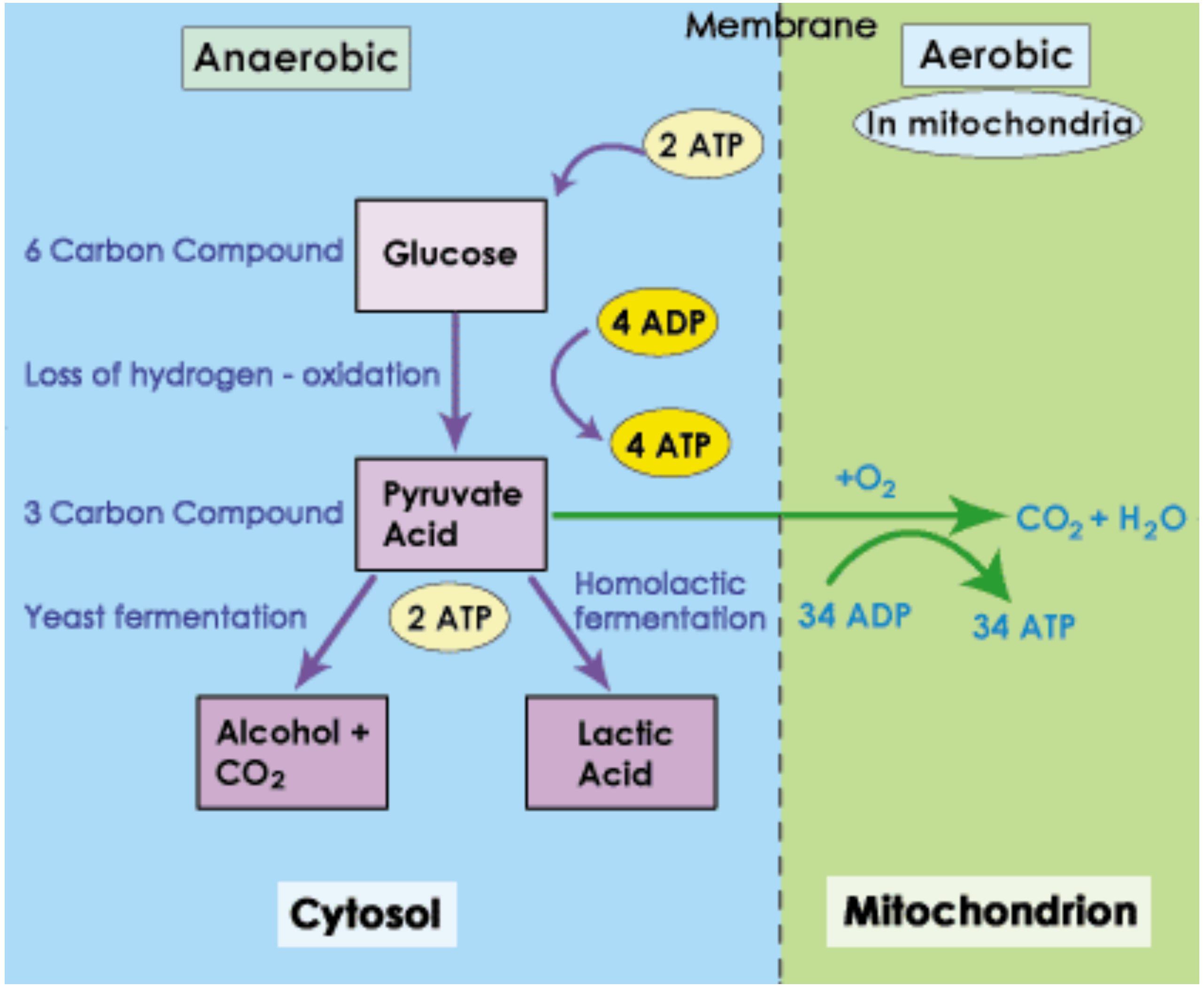
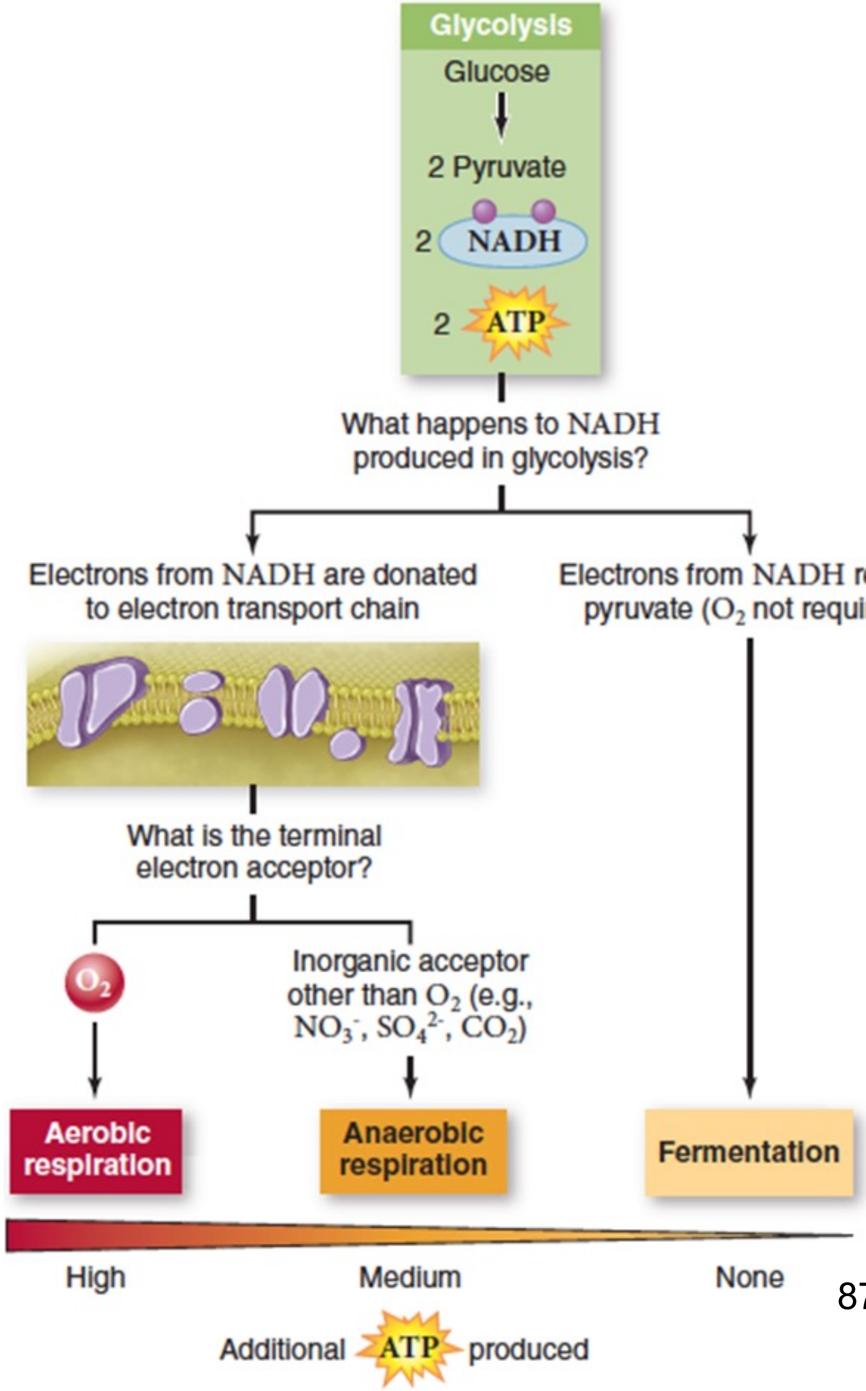
Summary


Membrane
Anaerobic
Aerobic
In mitochondria
2 ATP
6 Carbon Compound
Glucose
4 ADP
Loss of hydrogen - oxidation
4 ATP
+O2
3 Carbon Compound
Pyruvate Acid
CO2 + H2O
Homolactic fermentation
Yeast fermentation
2 ATP
34 ADP
34 ATP
Alcohol + CO2
Lactic Acid
Cytosol
Mitochondrion


Glycolysis
Glucose
2 Pyruvate
2 NADH
2 ATP
What happens to NADH produced in glycolysis?
Electrons from NADH are donated to electron transport chain
Electrons from NADH reduce pyruvate (O2 not required)
What is the terminal electron acceptor?
O2
Inorganic acceptor other than O2 (e.g., NO3-, SO4 2-, CO2)
Aerobic respiration
Anaerobic respiration
Fermentation
High
Medium
None
Additional ATP produced

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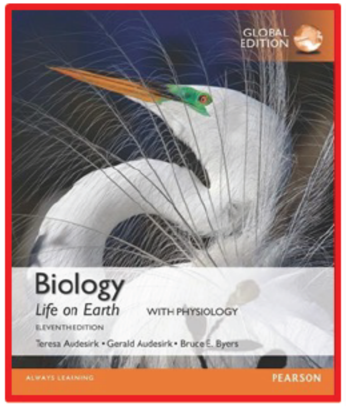
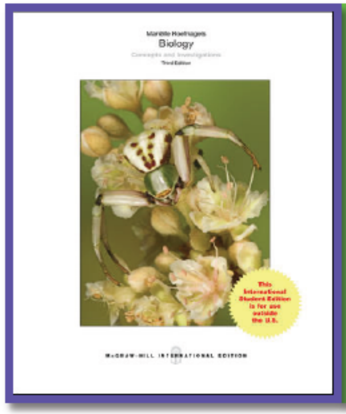
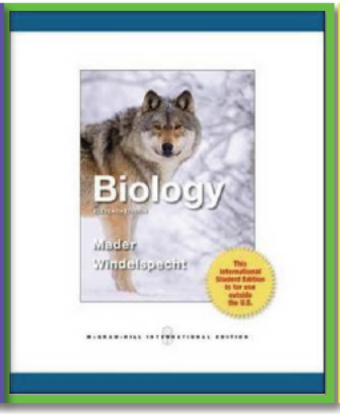
Text Books/References



This Lecture: Energy of Life

Chapters 6,8	Chapter 4,6	Chapters 6,8	Chapter 5, 7

Next Lecture: DNA and heredity

Chapter 12	Chapters 7,8	Chapters 12	Chapters 8

Further questions

- Many microorganisms in lakes use cellular respiration to generate energy. Dumping large amounts of raw sewage into rivers or lakes typically leads to massive fish kills, even if the sewage itself is not toxic to fish.
  - What kills the fish?
  - How might you reduce fish mortality after raw sewage is accidentally released into a small pond?

- How does the ratio of isotopes of minerals and oxygen found in teeth and bones help us understand the types of food consumed and the origin of these foods?