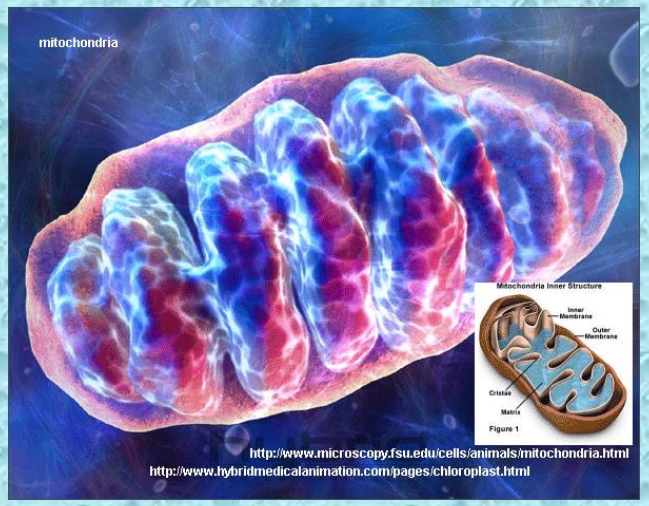
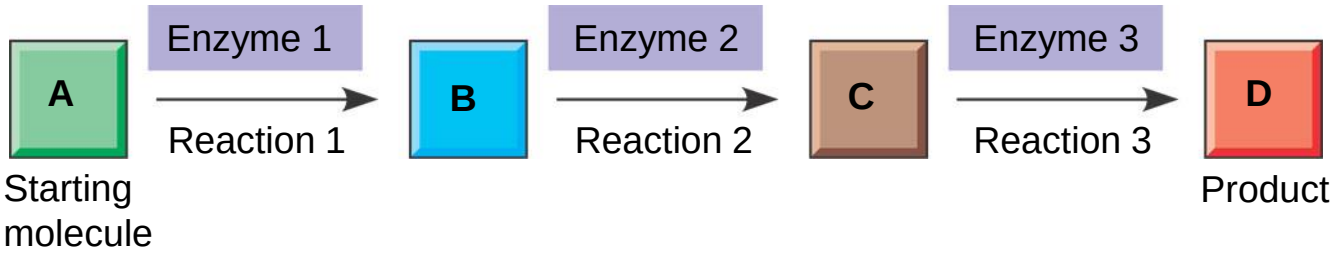
AN INTRODUCTION TO METABOLISM



Metabolism
Dr. Loay H. Ali

Organization of the Chemistry of Life into Metabolic Pathways

- A metabolic pathway has many steps
  - That begin with a specific molecule and end with a product
  - That are each catalyzed by a specific enzyme



2 metabolic pathways in our bodies

Catabolic Pathways

- Breaks down complex molecules into simpler compounds.
- EX:
- amylase breaks complex starches into simple sugars.
- The process of cellular respiration.

Anabolic Pathways

- Consume energy to build complicated molecules.
- EX:
- Anabolic steroids = to build muscle.
- The building of a protein from amino acids.

- **Catabolic pathways** release energy by breaking down complex molecules to simpler compounds.
- This energy is stored in organic molecules until it needs to do work in the cell.
- **Anabolic pathways** consume energy to build complicated molecules from simpler compounds.
- The energy released by catabolic pathways is used to drive anabolic pathways.

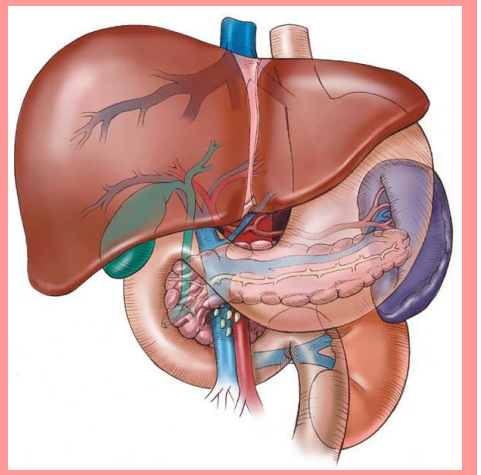
Organisms transform energy

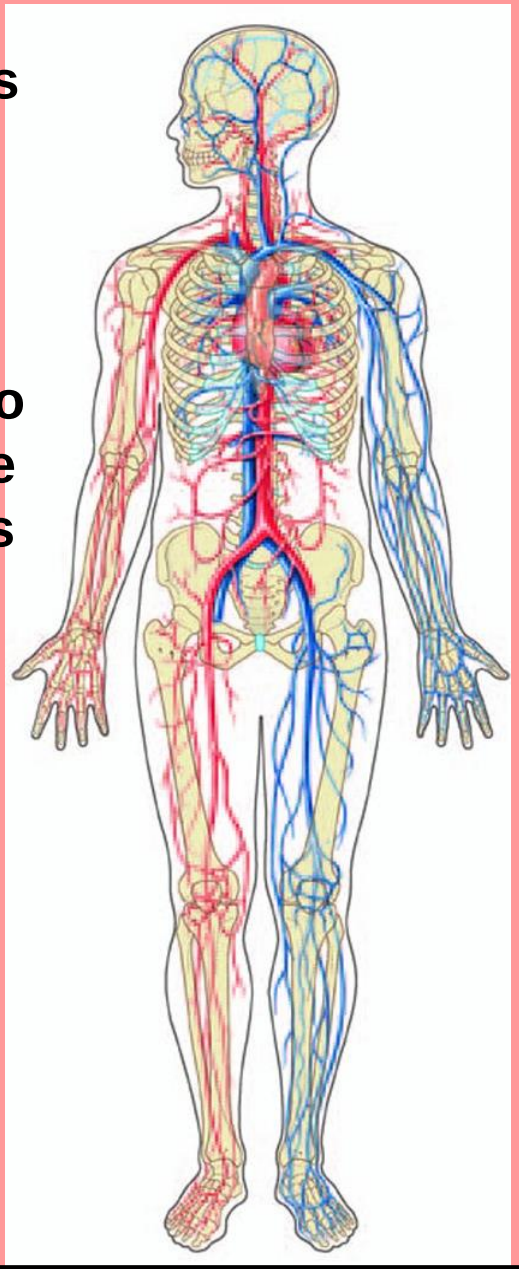
- The energy released by catabolic pathways is used to drive anabolic pathways.
- Energy is fundamental to all metabolic processes, and therefore to understanding how the living cell works.
- Energy can be converted from one form to another.
- **Kinetic energy** , **Potential energy** , **Chemical energy**

- Cellular respiration and other catabolic pathways unleash energy stored in sugar and other complex molecules.
- The chemical energy stored on these organic molecules was derived primarily from light energy by plants during photosynthesis.
- A central property of living organisms is the ability to transform energy.

Through the bloodstream and to the liver...

Once the nutrients enter the bloodstream by passing through the walls of the small intestine into the capillaries, the blood then carries most of the nutrients to the liver.





The liver removes the glucose, converts it to glycogen, and stores it. It is released again as the body needs it.

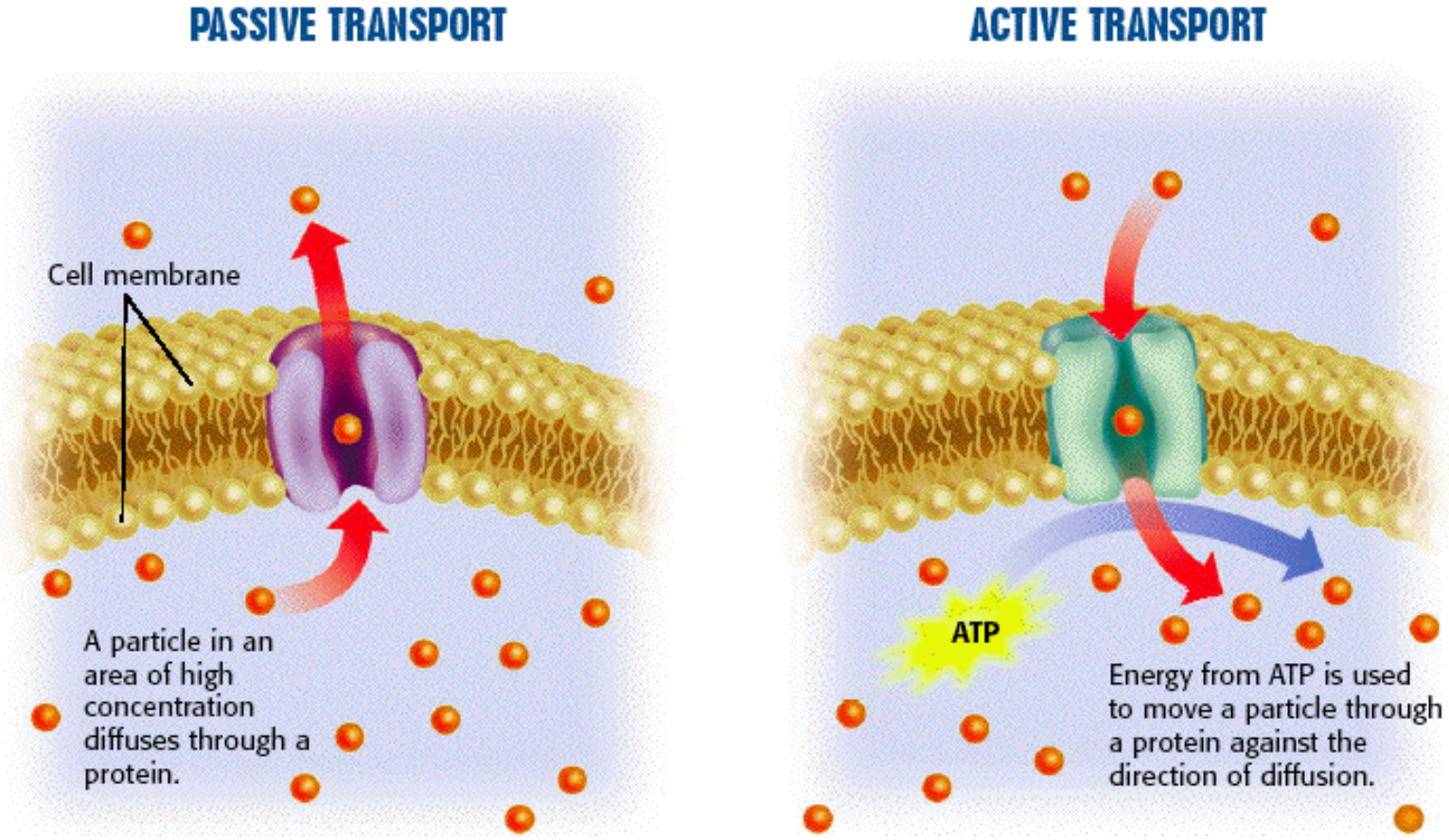
The amino acids are either released by the liver and sent to the muscle cells or are converted to urea for excretion.

The bile from the liver takes care of the fatty acids, making them absorbable into the blood stream and sent to the cells for use or storage.

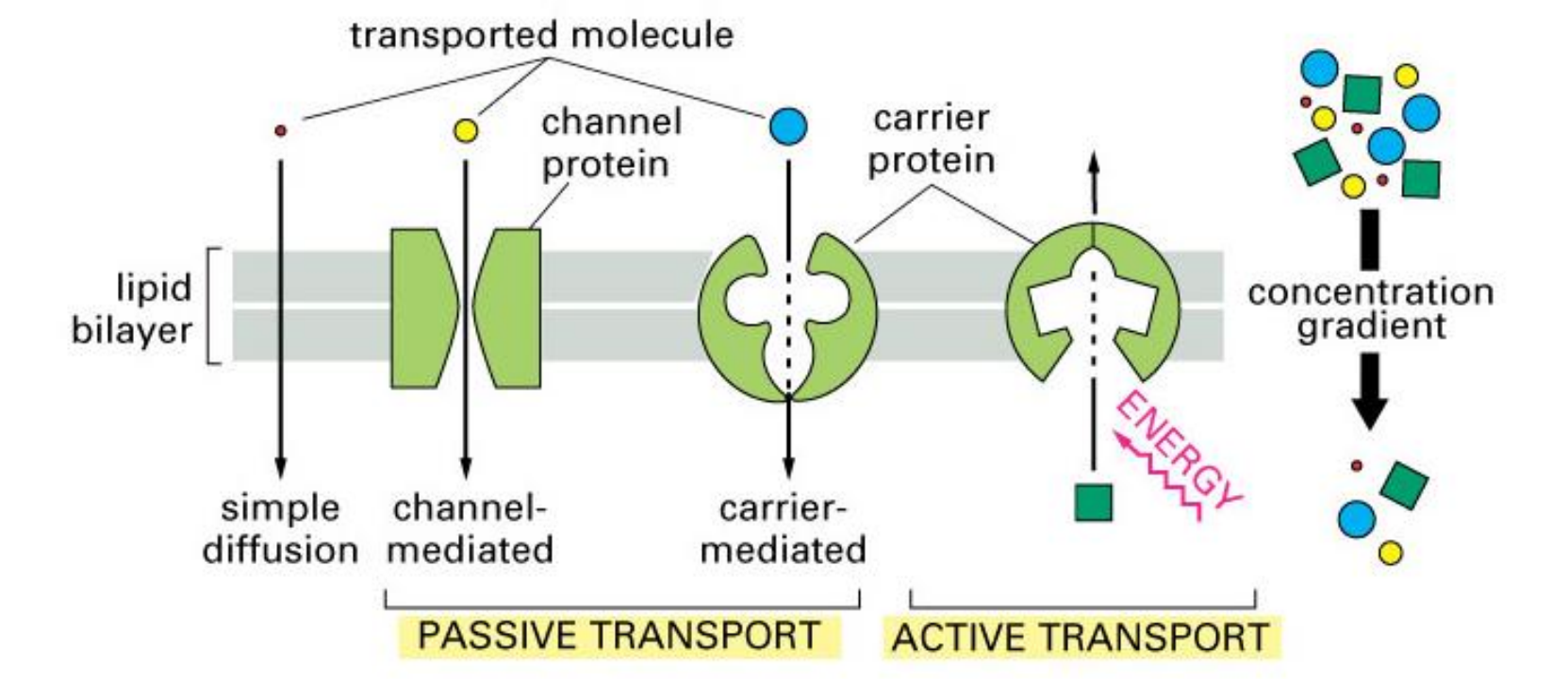
From the liver, the nutrients go back into the bloodstream for delivery all over the body to the cells.

Transport of molecules...

The movement or 'transport' of nutrient molecules through intestinal wall, blood vessel wall, or cell membrane may be either PASSIVE or ACTIVE.



Passive transport does not require energy, moving materials into an area of lower



The four main kinds of passive transport are diffusion, facilitated diffusion, filtration, and osmosis. Some type of *Passive transport* is used in absorbing fats, the fat soluble vitamins A, D, E, and K, and water.

Active transport **(energy required) is used in absorption of glucose, amino acids, calcium, iron, folic acid, ascorbic acid, thiamin, and some B vitamins.**

Overview: The Energy of Life

- The living cell is a miniature chemical factory where thousands of reactions occur
- The cell extracts energy and applies energy to perform work
- Some organisms even convert energy to light, as in bioluminescence

Energy and human life

Chemical energy
- Carbohydrates
- Fats
- Others

Chemical waste
- Carbon dioxide
- Water

Heat

ATP
- body's "energy currency"

metabolism

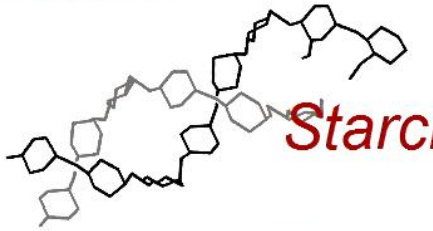
Heat

An organism's metabolism transforms matter and energy, subject to the laws of thermodynamics

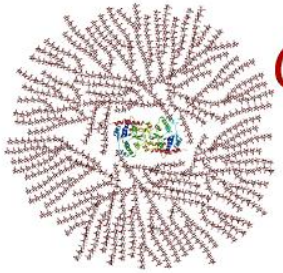
- **Metabolism** is the totality of an organism's chemical reactions
- Metabolism is an emergent property of life that arises from interactions between molecules within the cell
- A **metabolic pathway** begins with a specific molecule and ends with a product
- Each step is catalyzed by a specific enzyme

Glucose metabolism

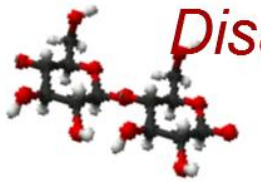
Intake:



Starch

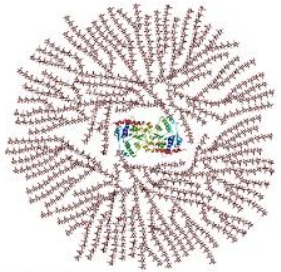


Glycogen



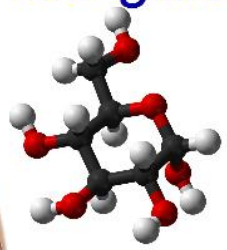
Disaccharides

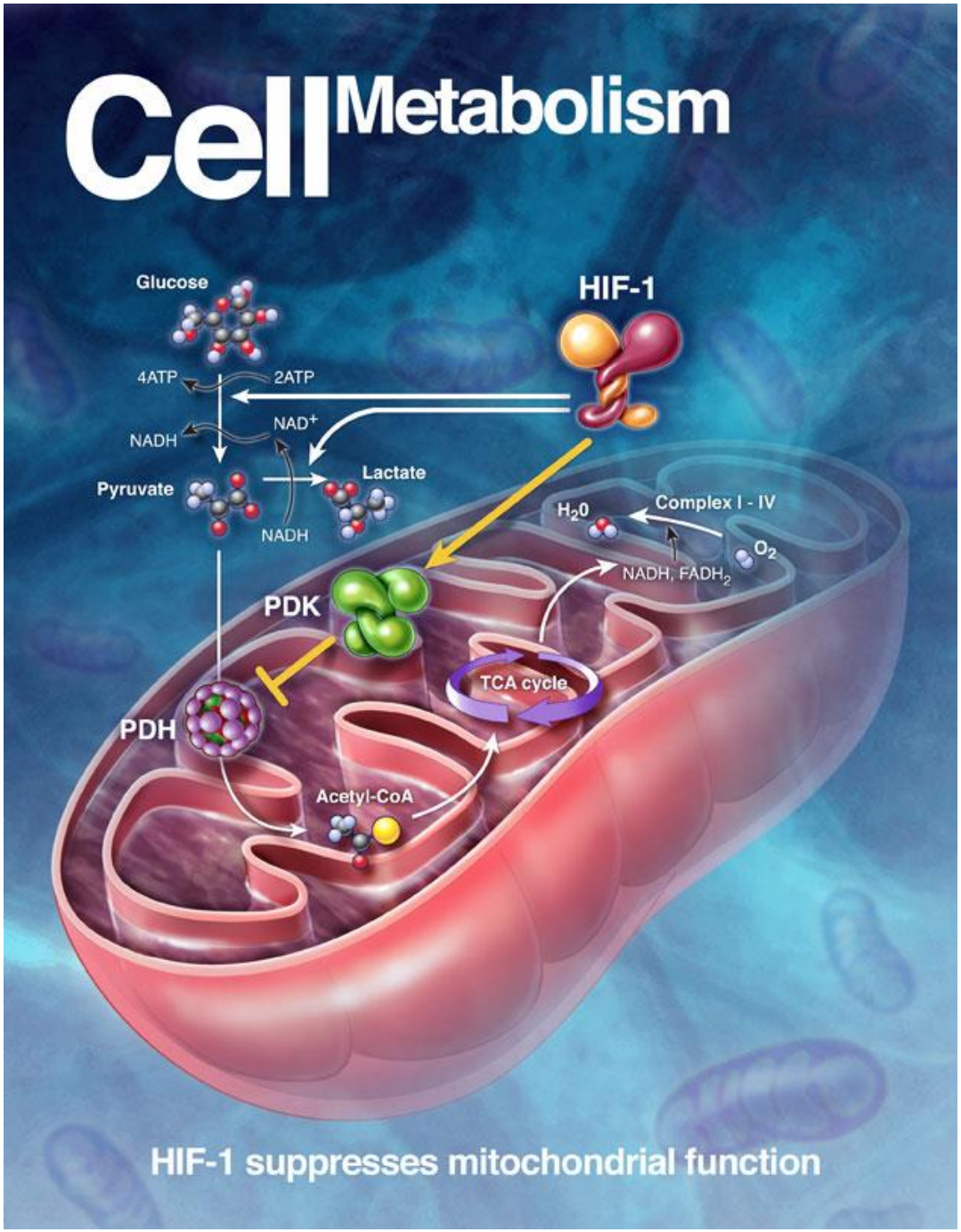
Monosaccharides (glucose, fructose, galactose)



Storage:
Glycogen

Distribution and utilization:
Free glucose

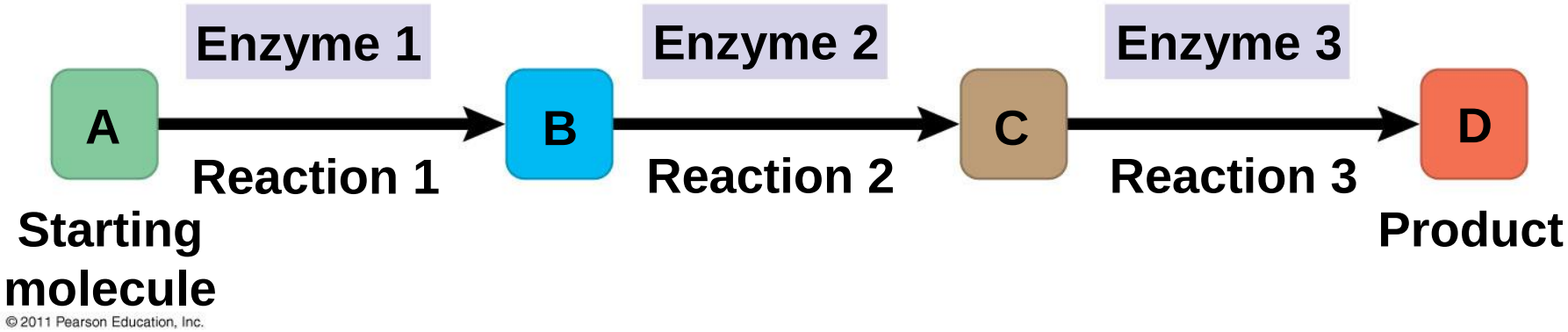


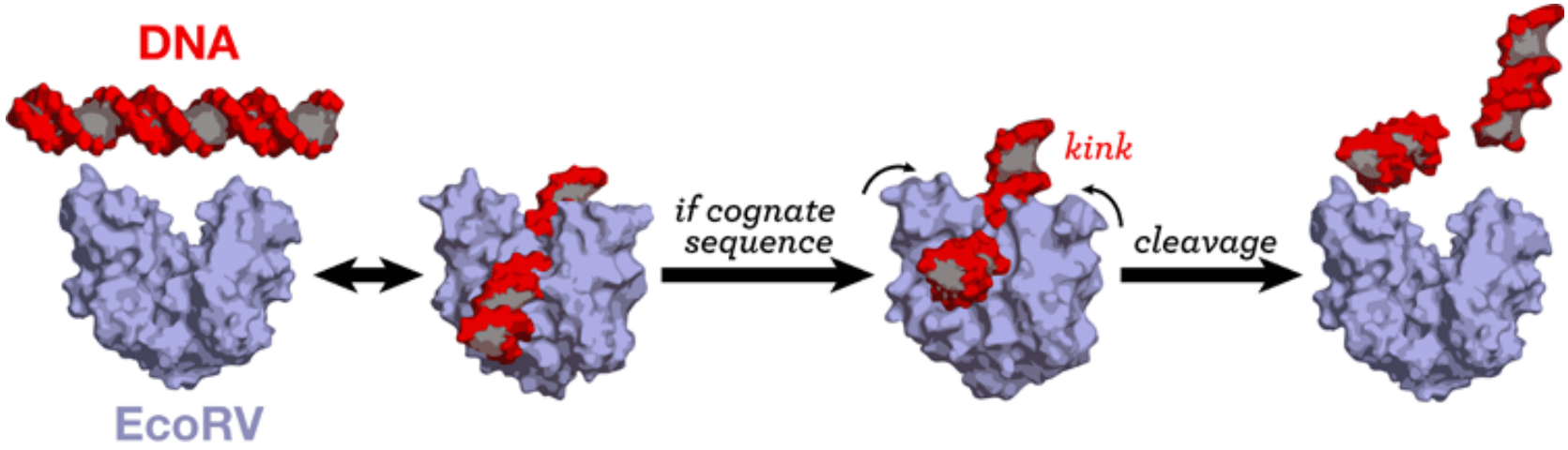

Cell Metabolism
Glucose
HIF-1
4ATP
2ATP
NAD+
NADH
Pyruvate
Lactate
NADH
H20
Complex I - IV
O2
NADH, FADH2
PDK
TCA cycle
PDH
Acetyl-CoA
HIF-1 suppresses mitochondrial function

Enzymes speed up metabolic reactions by lowering energy barriers

- A **catalyst** is a chemical agent that changes the rate of a reaction without being consumed by the reaction.
- An **enzyme** is a catalytic protein.
- Enzymes regulate the movement of molecules through metabolic pathways.
- Chemical reactions between molecules involve both bond breaking and bond forming.

Figure 8.UN01





- **Catabolic pathways** release energy by breaking down complex molecules into simpler compounds

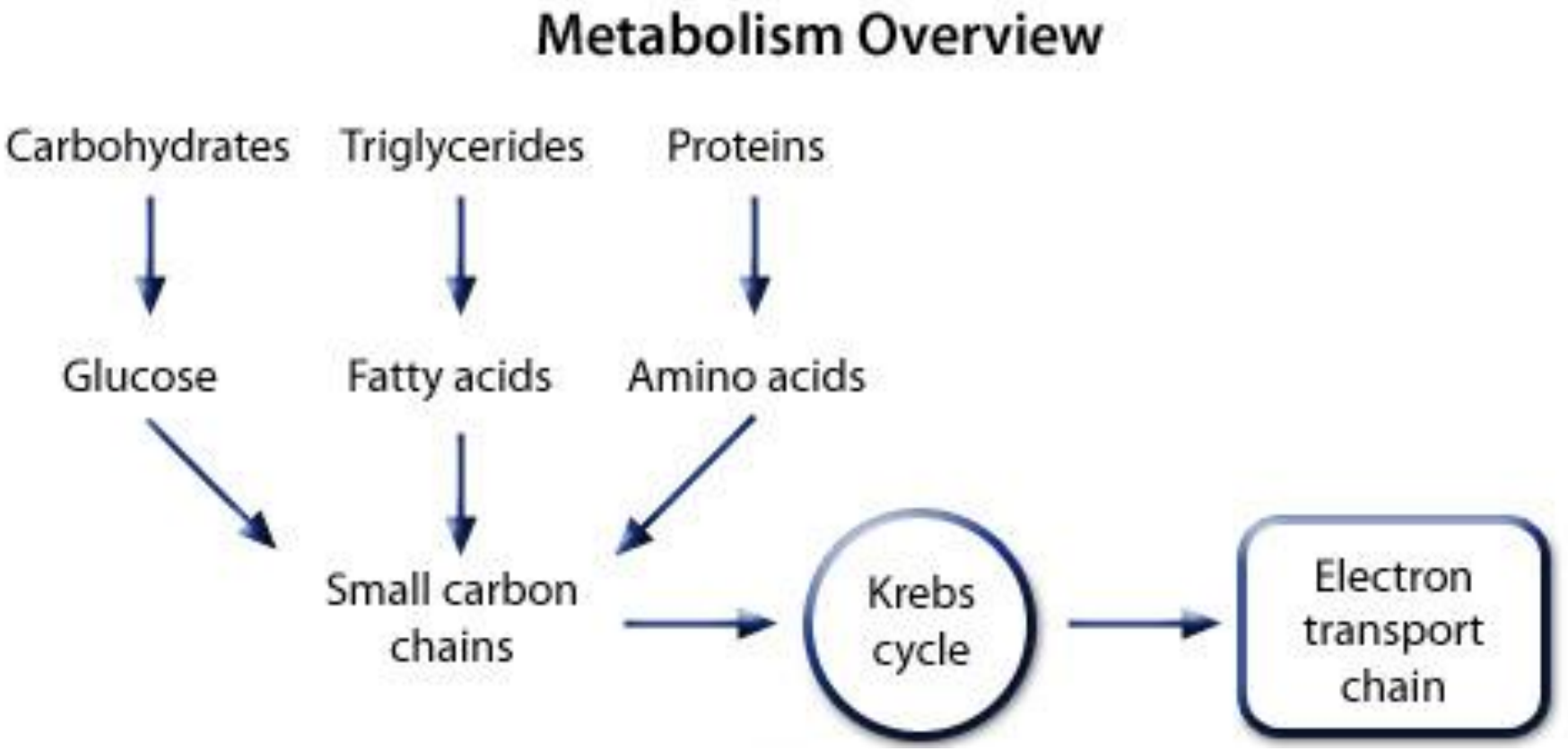
- Cellular respiration, the breakdown of glucose in the presence of oxygen, is an example of a pathway of catabolism

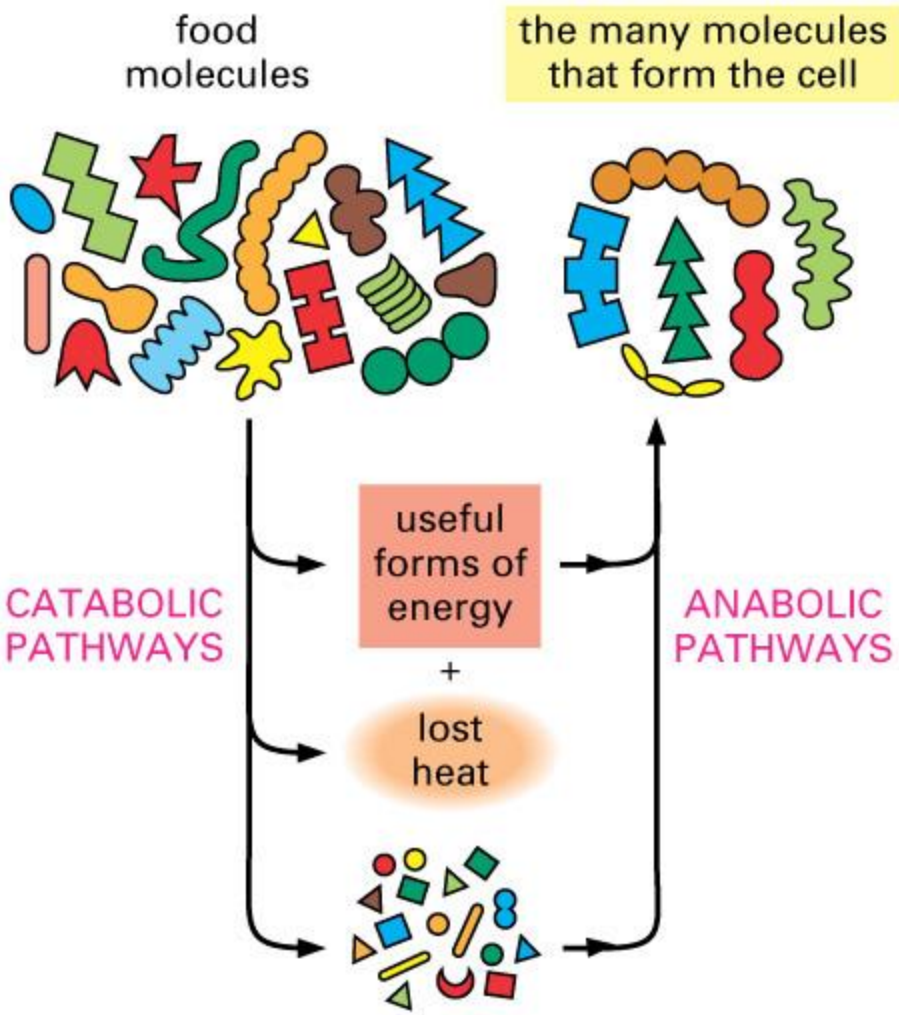
- **Anabolic pathways** consume energy to build complex molecules from simpler ones

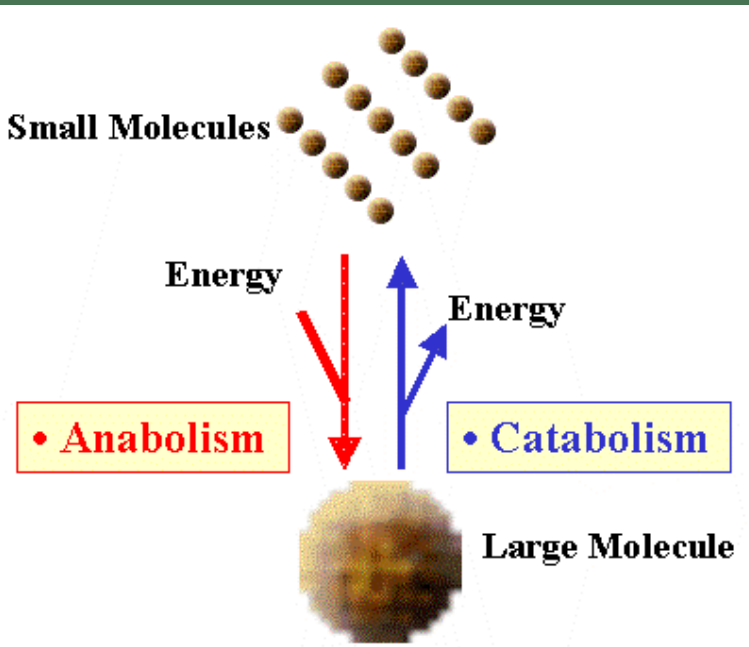
- The synthesis of protein from amino acids is an example of anabolism

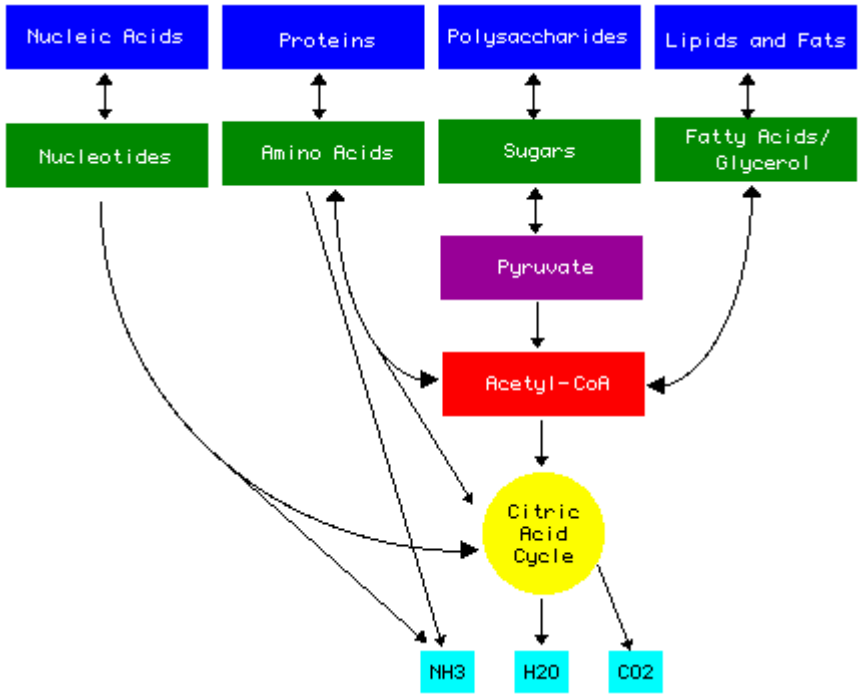
- **Bioenergetics** is the study of how organisms manage their energy resources

Metabolism is carried out by proteins/enzymes with the ultimate goal to extract energy!

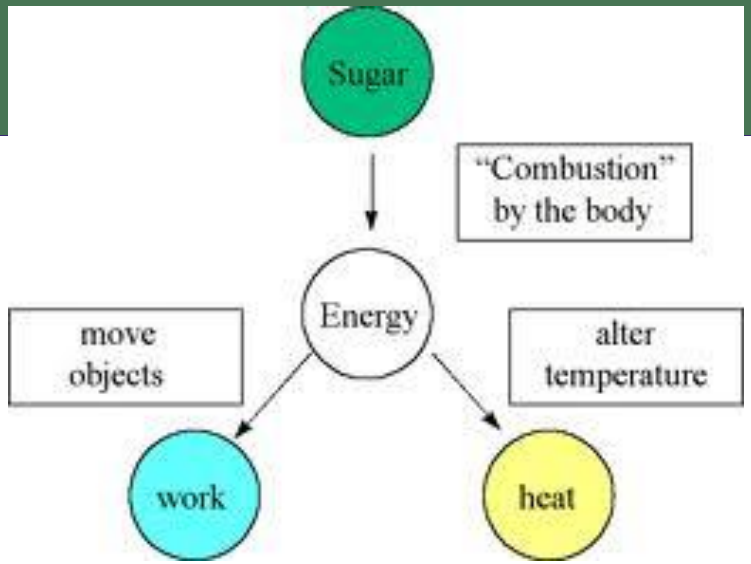



food molecules
the many molecules that form the cell
CATABOLIC PATHWAYS
useful forms of energy
+
lost heat
ANABOLIC PATHWAYS
the many building blocks for biosynthesis


Small Molecules
Energy
Energy
• Anabolism
• Catabolism
Large Molecule


Nucleic Acids
Proteins
Polysaccharides
Lipids and Fats
Nucleotides
Amino Acids
Sugars
Fatty Acids/ Glycerol
Pyruvate
Acetyl-CoA
Citric Acid Cycle
NH3
H2O
CO2

Life Runs on Energy



- **Energy**
  - capacity to do work

- Energy can be converted from one form to another, but cannot be created or destroyed – energy disperses spontaneously
- There are various forms of energy: chemical, heat, electromagnetic, gravitational, electric, elastic, nuclear, rest
- Categorized in two main classes: potential energy and kinetic energy.

What Physical Principles Underlie Biological Energy Transformations?

Transformation of energy is a hallmark of life.

- plant uses light energy to produce carbohydrates.
- Animal cell extract energy from nutrients consumed for all cellular activities

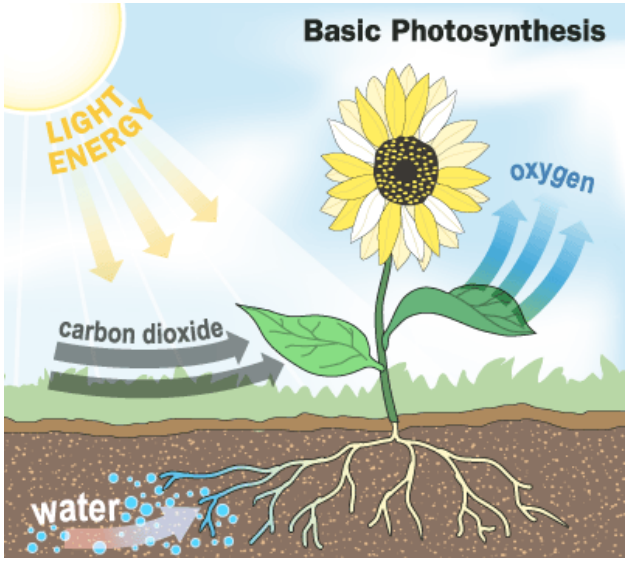
Physicis define **energy** as the capacity to do work.

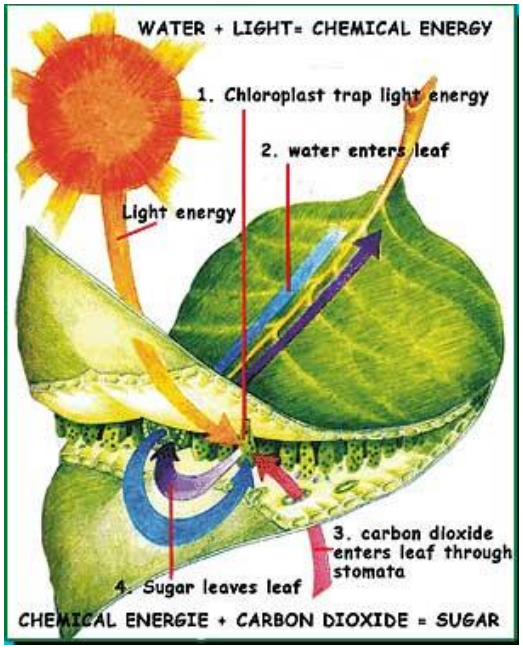
Biochemistry defined as the *capacity for change*.

- changes are associated with the chemical composition and properties of molecules.

<u>Energy transformations are linked to chemical transformations in cells.</u>

<u>No cell creates energy; all living things must obtain energy from the environment.</u>





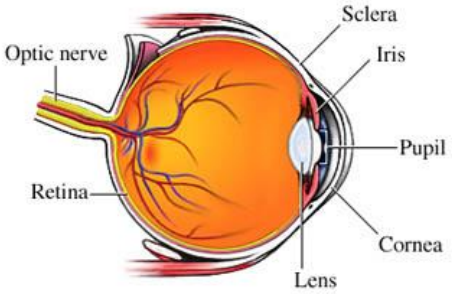
What Physical Principles Underlie Biological Energy Transformations?

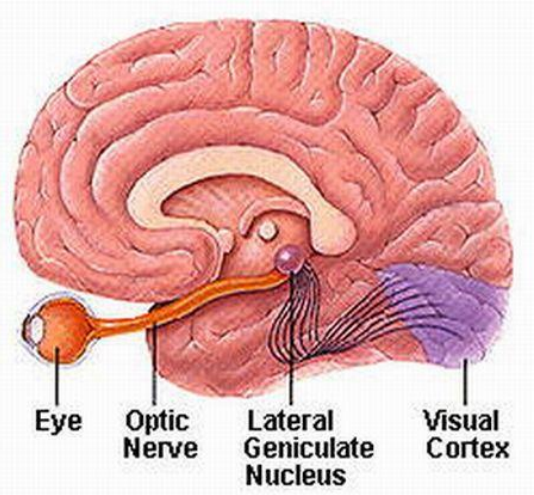
All energy can be placed in 2 categories:

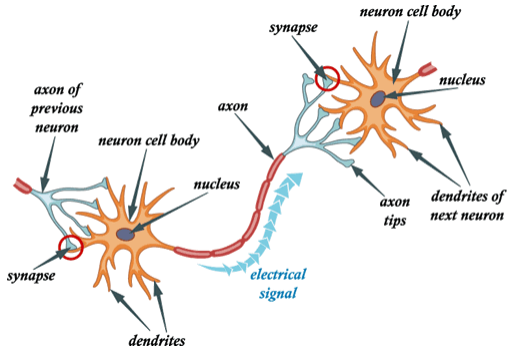
- *Potential energy* - stored energy - chemical bonds, concentration gradient, charge imbalance
- *Kinetic energy* - energy of movement - stored energy in muscles is converted into the kinetic energy of muscle contractions

Potential energy can be converted into kinetic energy and vice versa.

- **EXAMPLE**: Light energy is converted into chemical energy in your eyes, and then is converted into electric energy in the nerve cells that carry messages to your brain.







One way flow of energy

The sun provides energy in the form of heat and light

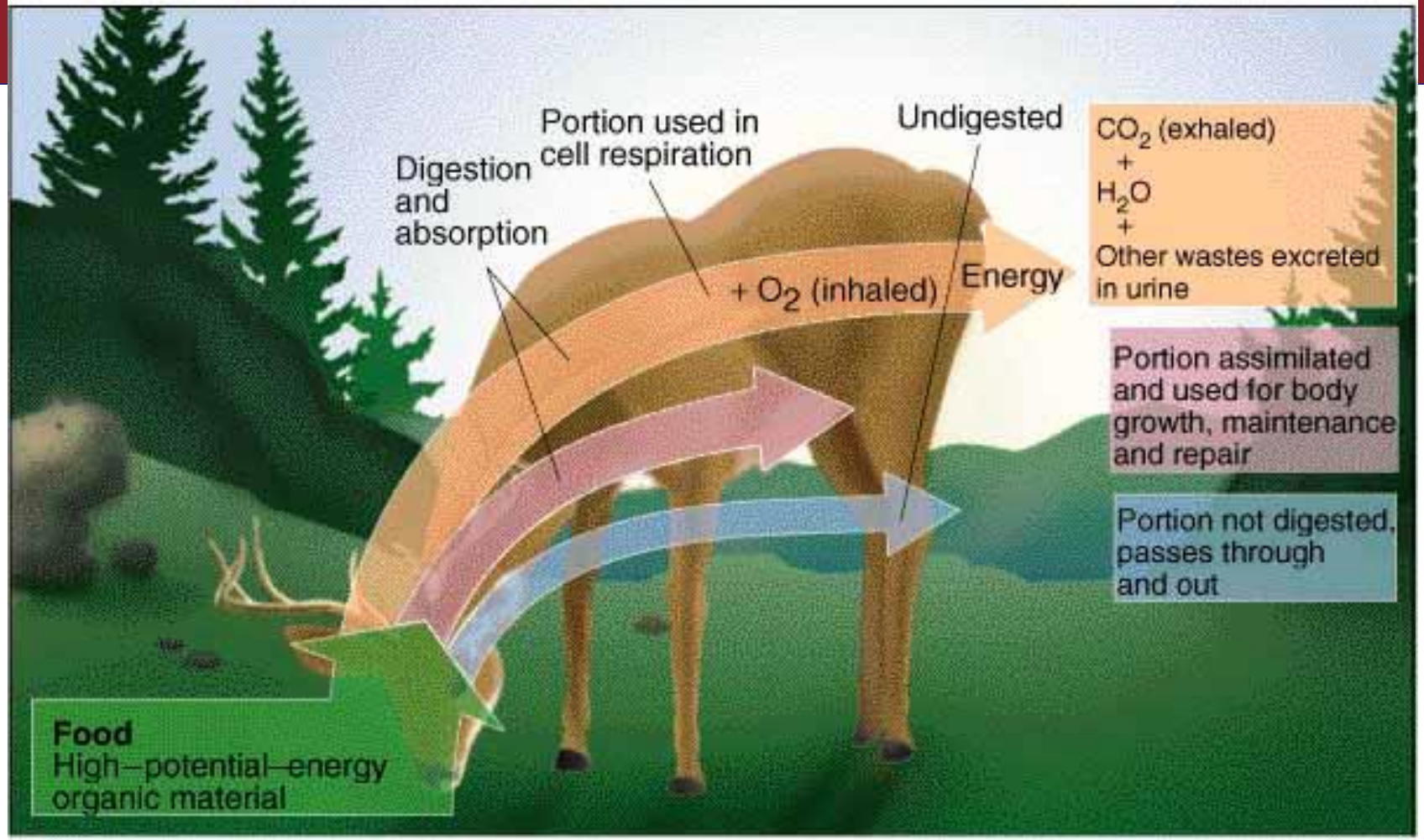
Absorbed by plants to go through cell respiration (metabolic reactions to convert biochemical energy from nutrients into ATP)

The energy is then transferred to a herbivore, and then a carnivore after

Eventually the animal dies and is broken down chemically by decomposers

These decomposers then return the energy as compounds and essential nutrients, which are then used by the plants

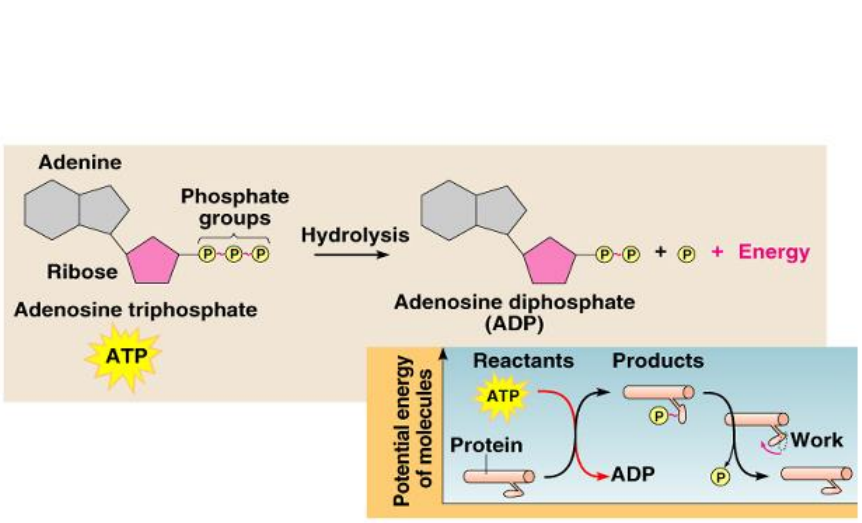
the cycle starts over

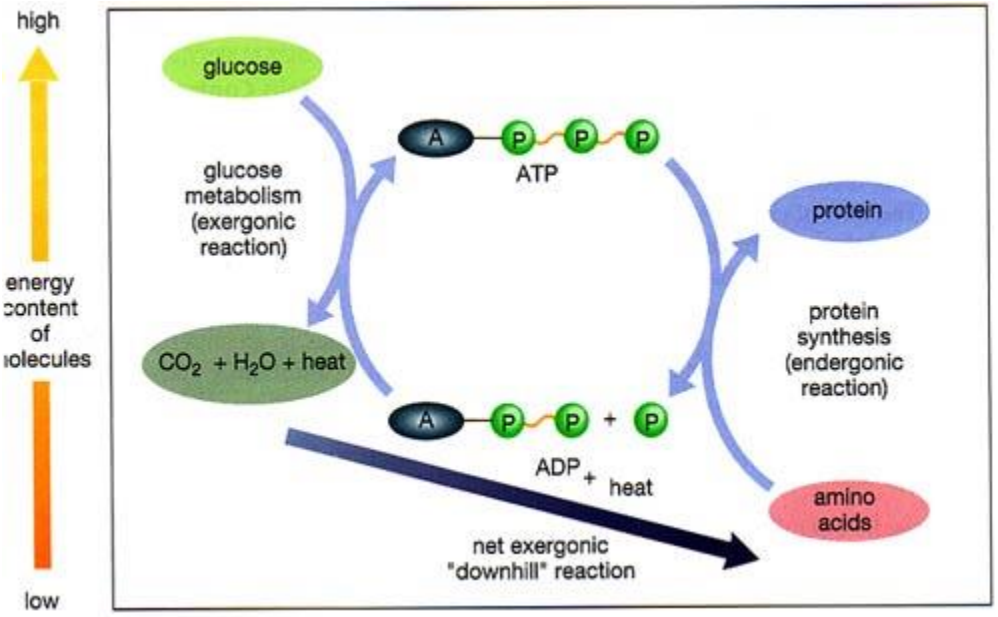


Only a small portion of ingested food is used for growth and repair. A larger amount is used in cell respiration to provide energy.

Exergonic and Endergonic Reactions in Metabolism

- An **exergonic reaction** proceeds with a net release of free energy and is spontaneous
- An **endergonic reaction** absorbs free energy from its surroundings and is nonspontaneous

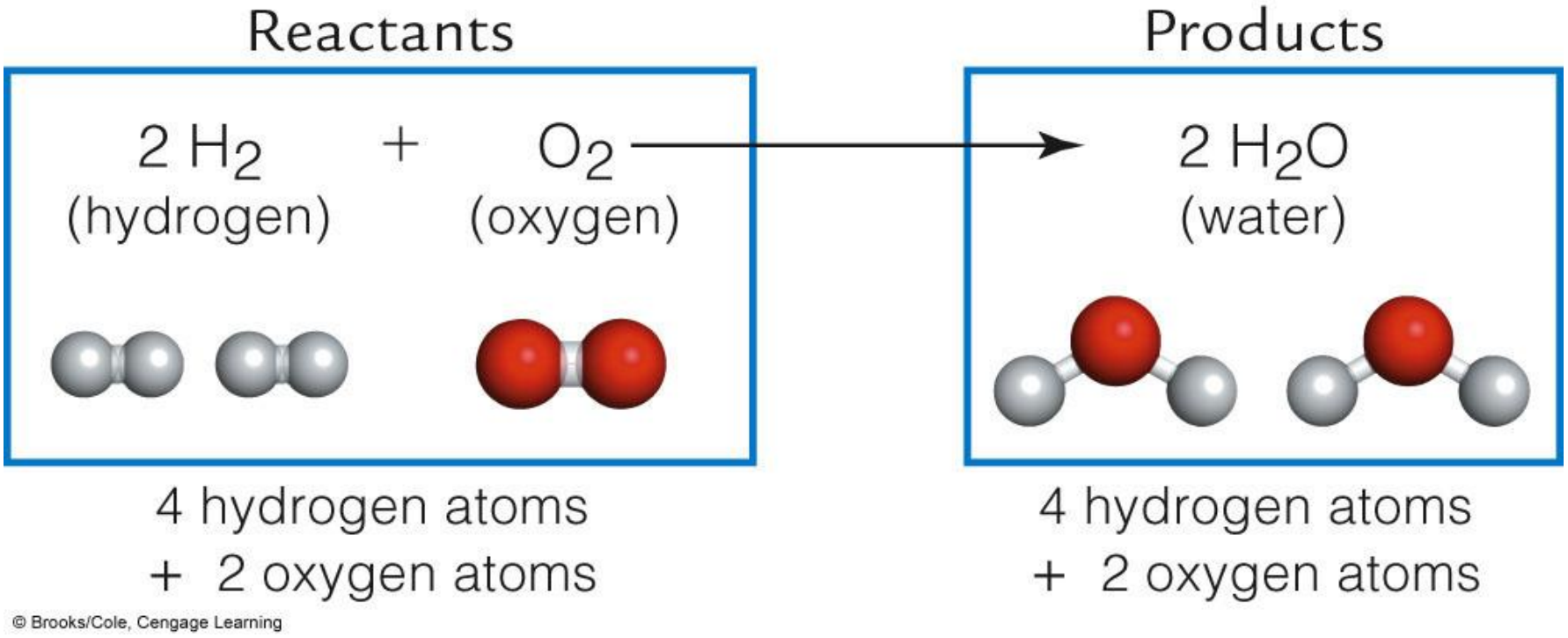




- **Reaction**
  - Process of chemical change
  - Chemical reactions can be either spontaneous, requiring no input of energy, or non-spontaneous, often coming about only after the input of some type of energy: heat, light or electricity.
  - Chemical reactions encompass changes that strictly involve the motion of electrons in the forming and breaking of chemical bonds,
- **Reactant**
  - Molecule that enters a reaction
- **Product**
  - A molecule remaining at the end of a reaction

- **One or more reactants can become one or more products!**
- **Also, intermediate molecules may form between reactants and products!**

The covalent bond between an O and a H in water holds a specific amount of energy which differs from the amount of energy held by a covalent bond in molecular oxygen (O_2)



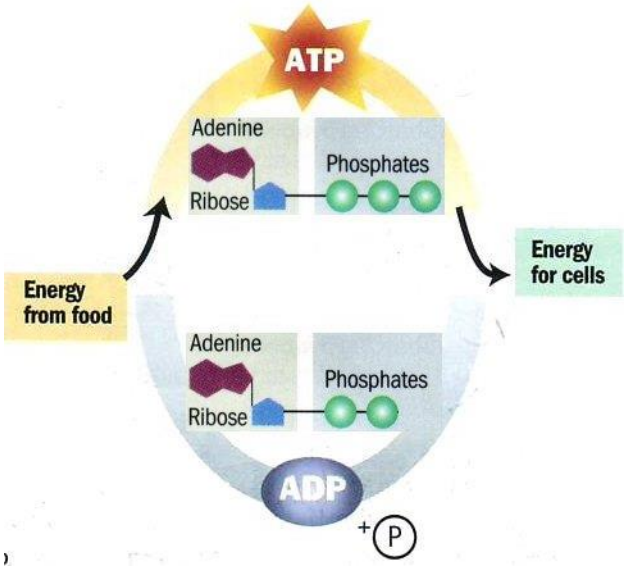
Thus, in most reactions, the energy of the reactants differs from the energy of the products!!!

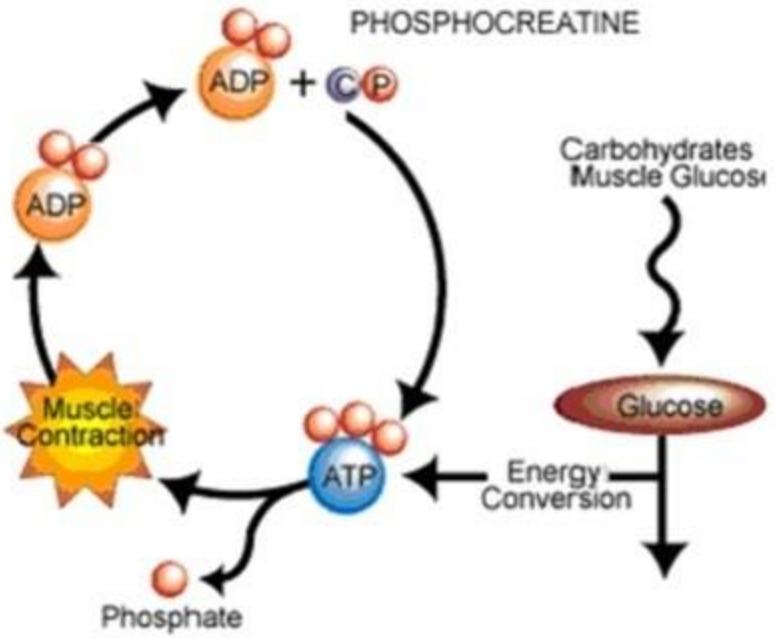
What Is the Role of ATP in Biochemical Energetics?

ATP (adenosine triphosphate) captures and transfers free energy.

ATP releases a large amount of energy when hydrolyzed.

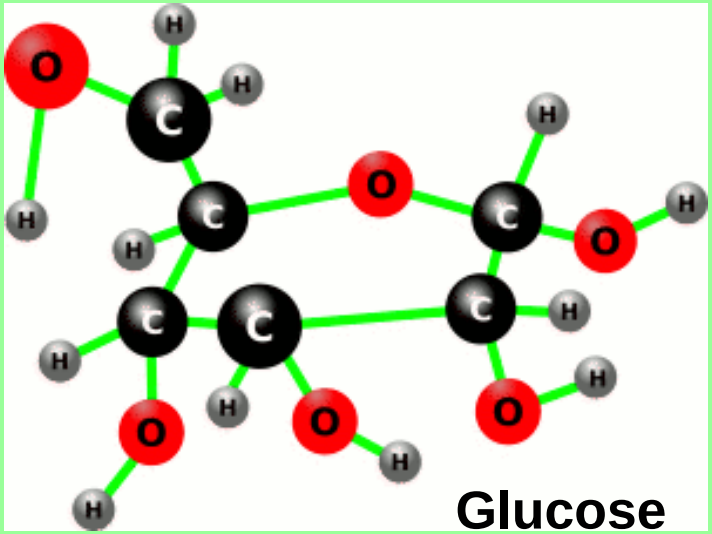
ATP can phosphorylate, or donate phosphate groups to other molecules.



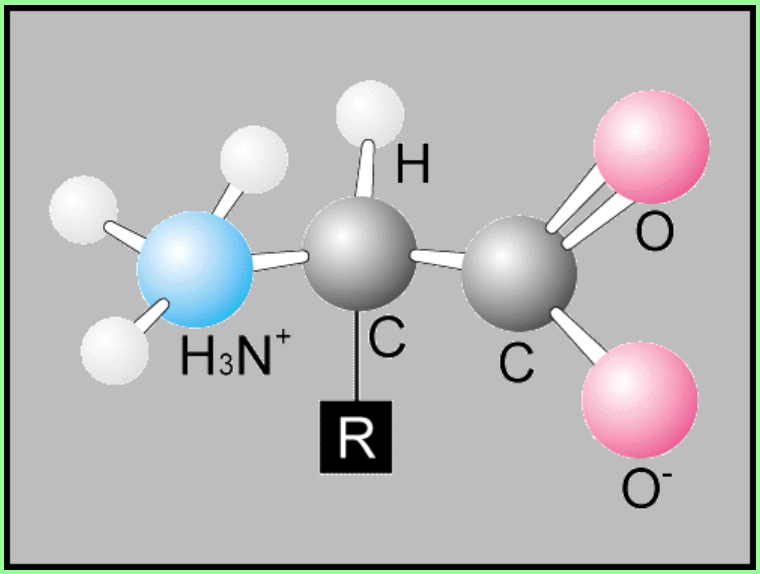


Nutrients are now in molecular form...

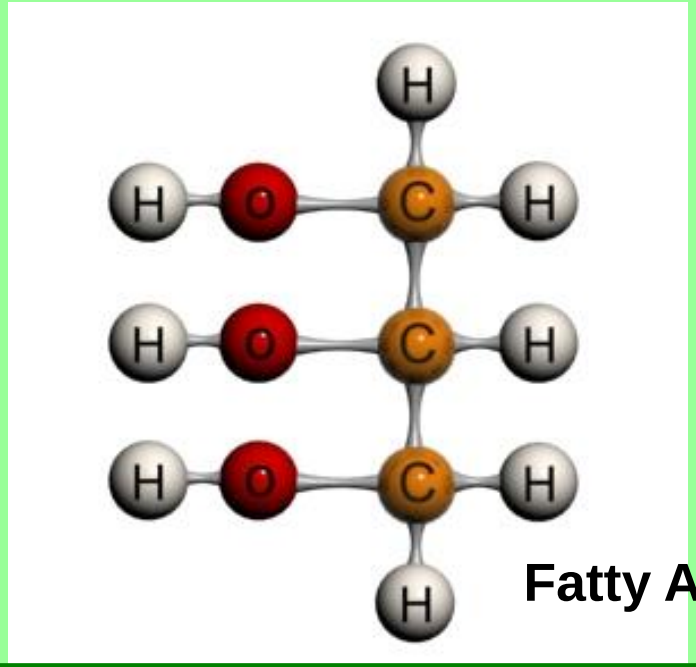
The amino acids that form proteins, the glucose that forms sugars and starches found in carbohydrates, and the fatty acids that form lipids are now reduced to even smaller molecules made of… carbon (C), oxygen (O), hydrogen (H), and sometimes nitrogen (N).



Glucose



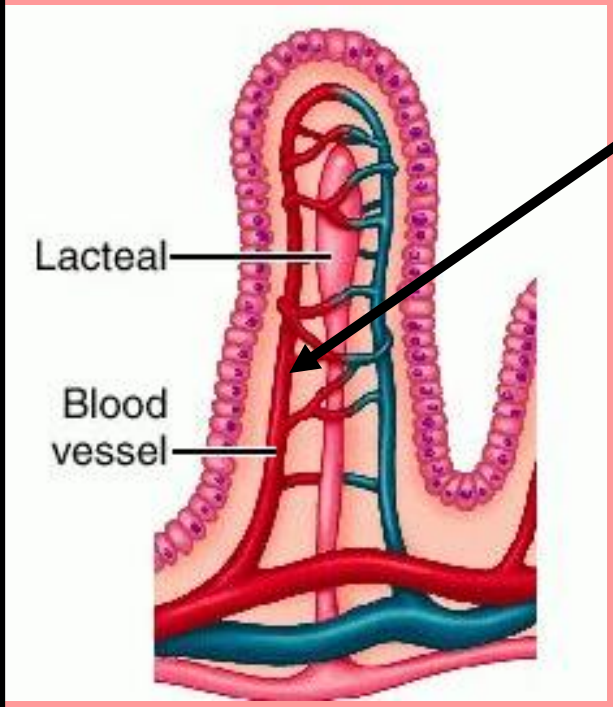
Amino Acid



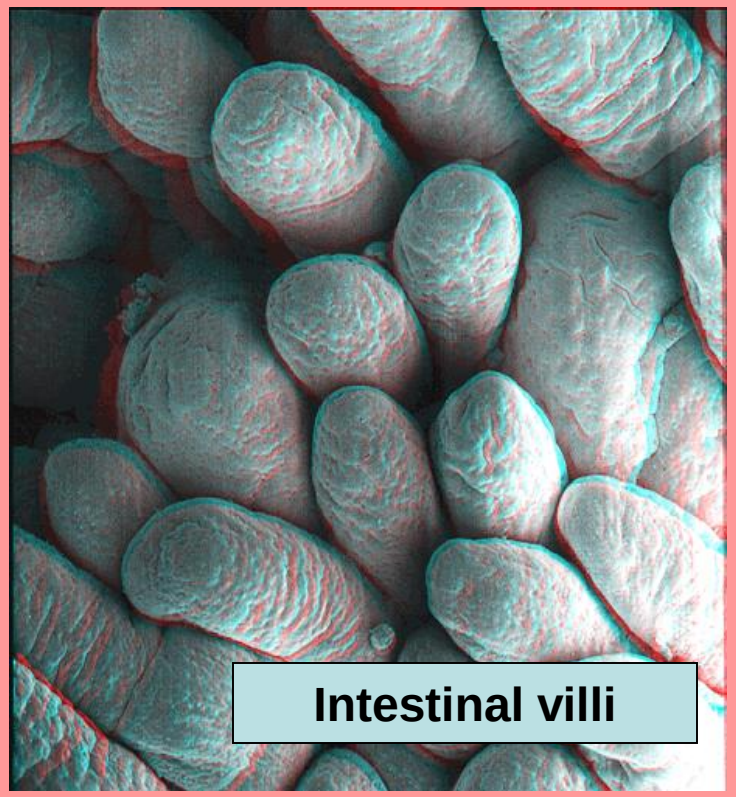
Fatty Acid

Absorption...

The surface area of the intestine is well suited to its function of nutrient absorption. The mucosal folds called villi and microvilli give a total absorptive area for the small intestine a 600-fold increase over the projected surface area of a smooth-surfaced tube of equivalent length. Total surface area is roughly about the size of a tennis court.



In addition to nutrients, the water in our food and drink is also absorbed from the small intestine into the bloodstream to provide the body with the fluid it needs.

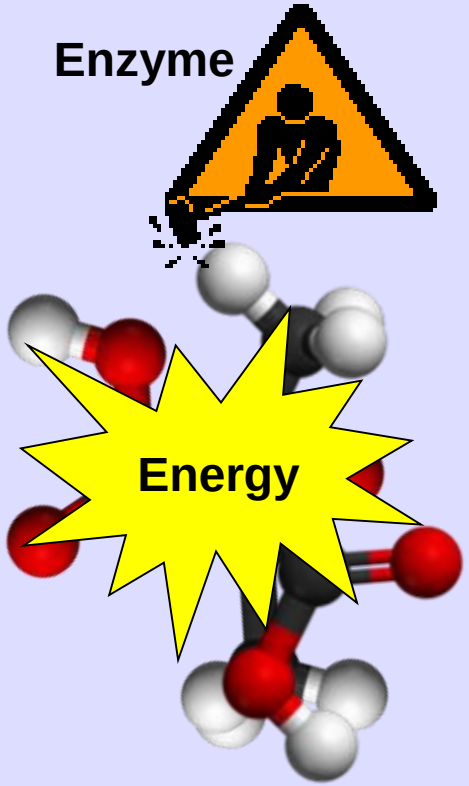


Intestinal villi

Step 1 of the metabolic process... glycolysis

Enzymes are proteins, synthesized in cells. They act as catalysts, causing all the body's chemical processes to take place quickly and completely.

They break the glucose molecule in half, forming two 3-carbon molecules. These molecules are called pyruvic acid or pyruvate. This process is called glycolysis and occurs in the cytoplasm of the cell.



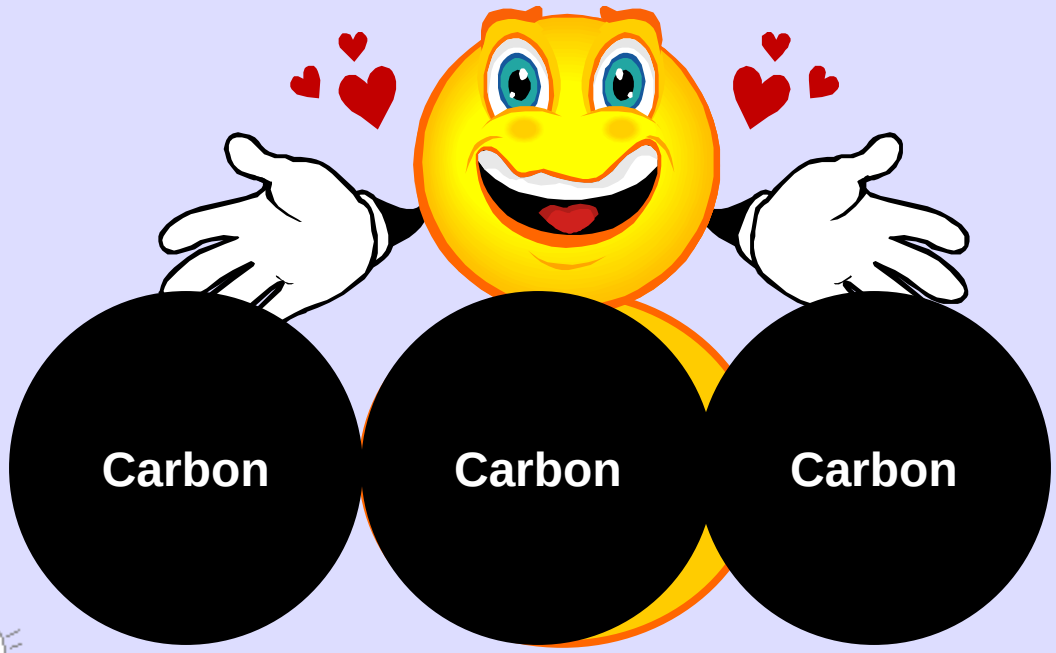
A small amount of energy is released during this process, as the bonds within the molecule are broken. This is a CATABOLIC reaction.

Black spheres are carbon atoms, white are hydrogen, and red are oxygen.

Step 2 of the metabolic process... acetyl group formation

A co-enzyme made of Vitamin B and called ‘CoA’ bonds with 2 of the carbon atoms in pyruvate, forming an <u>acetyl</u> (ə-sēt'l) <u>molecule group.</u>

CoA kicks out the 3rd carbon atom of pyruvate. This formation occurs within the mitochondria of the cell.



Oxygen

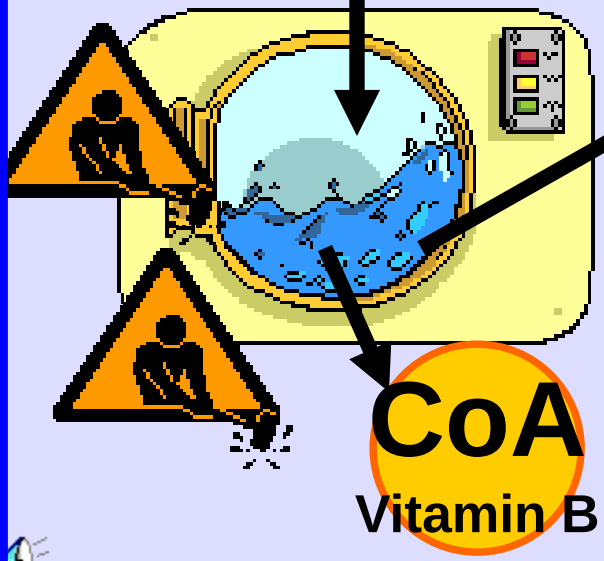
Exhaled as CO2

Oxygen

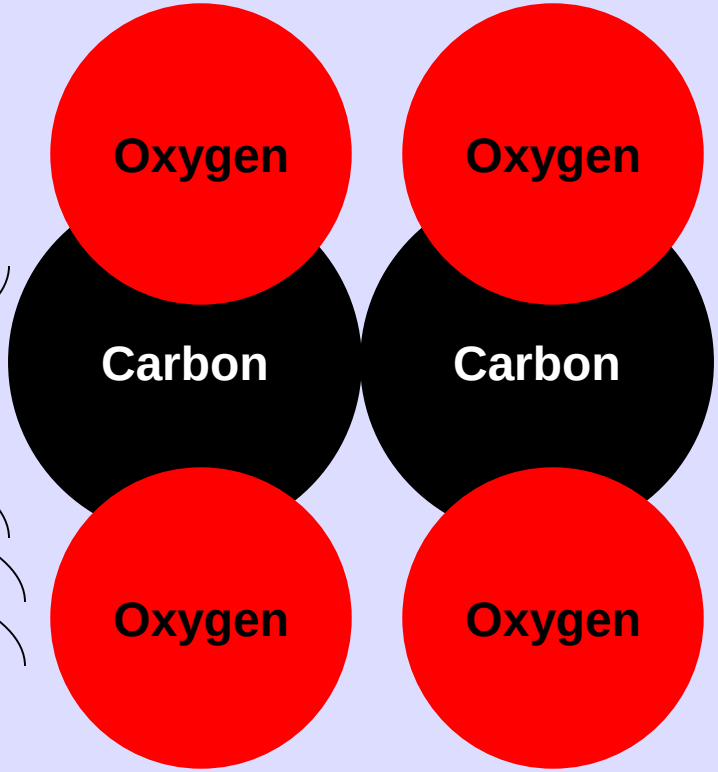
That 3rd carbon atom bonds with 2 free-floating oxygen atoms to form CO2, carbon dioxide, and is exhaled.

Step 3 of the metabolic process… Krebs Cycle

Step 3 occurs within the mitochondria of the cell.

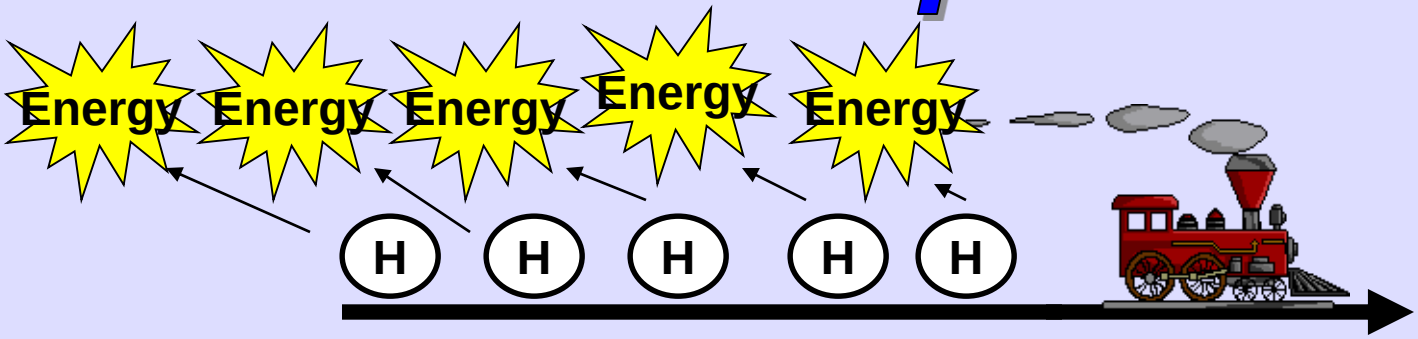


Exhale



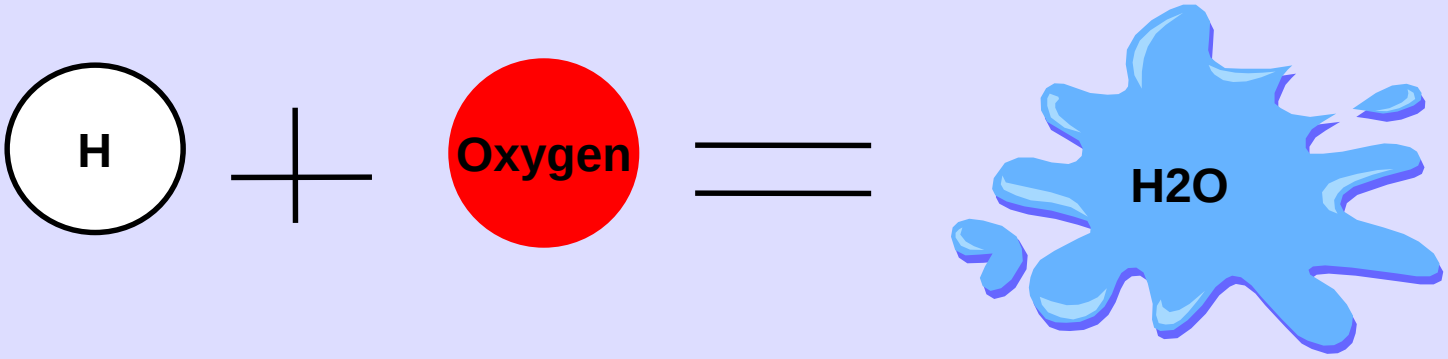
Now enzymes and co-enzymes begin to break up the acetyl group. The CoA goes back to work again in another place. The two carbon atoms are removed. They hook up with free-floating oxygen atoms and end up being exhaled as CO_2… carbon dioxide.

Step 4 of the metabolic process…
Electron transport chain



Hydrogen removed on electron transport chain

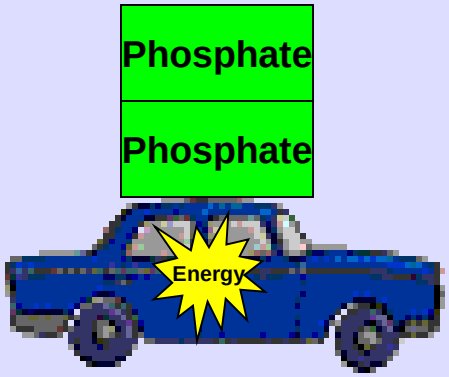
At this point, the hydrogen atoms have extra electrons attached to them. The electron transport chain strips off the extra electrons and carries their energy away. The remaining hydrogen atoms bond with oxygen atoms to form molecules of H20… water.



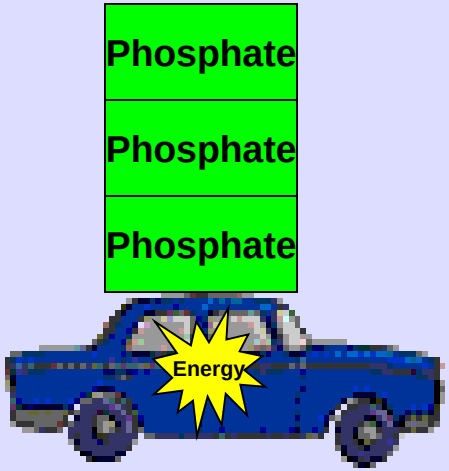
This occurs within the mitochondria of the cell and is still a catabolic reaction.

Step 5 of the metabolic process… ATP transports the energy

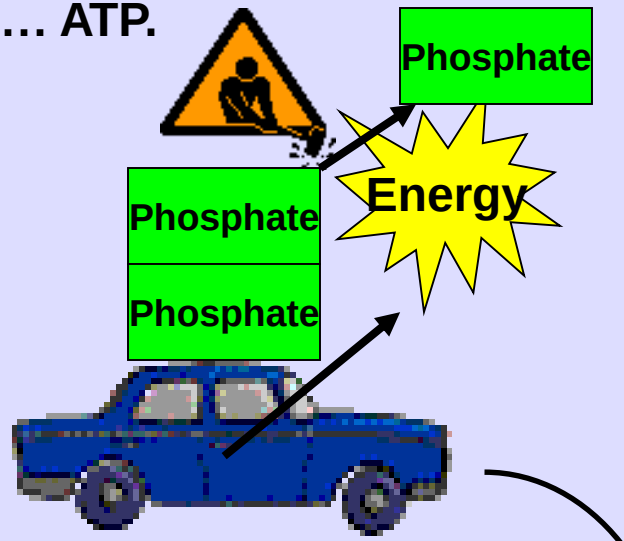
The energy cannot get to the part of the cell it needs to without assistance. It has to be transported in a vehicle called Adenosine (ə-dĕn'ə-sēn') Triphosphate… ATP.



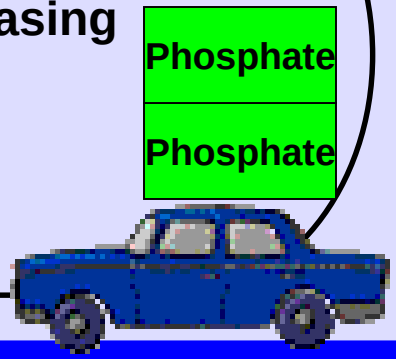
ADP… adenosine diphosphate picks up the energy



Then the ADP picks up another free floating phosphate (a salt), and becomes ATP.



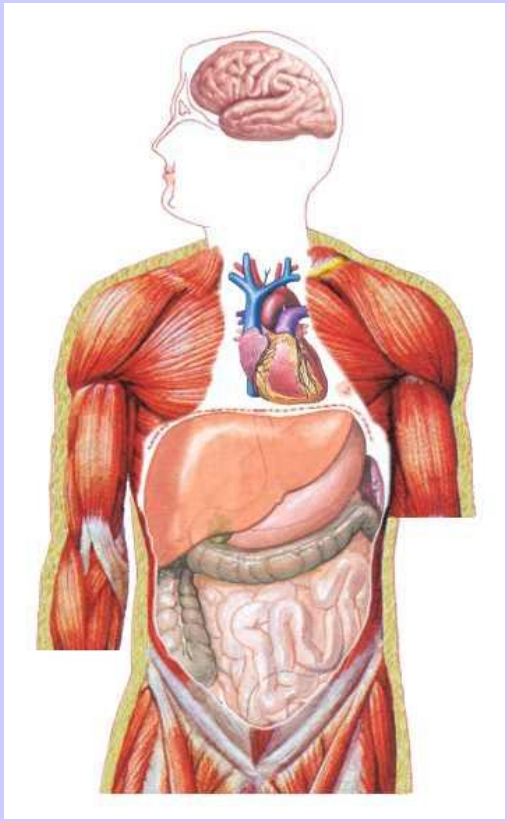
Reaching its destination, enzymes break off the extra phosphate… releasing large amounts of energy.

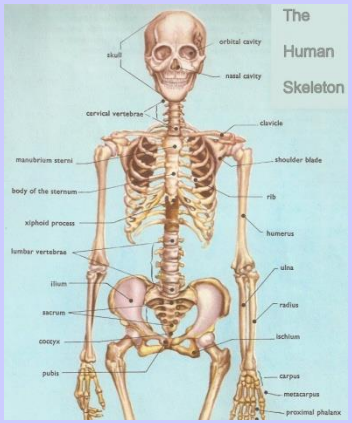


The ADP returns to pick up more energy and phosphates.

Step 6 of the metabolic process... Newly created energy is used up

The newly created energy now combines with the amino acids of protein to form new cytoplasm for the cells. This "building up" of organs and body tissues is an ANABOLIC process.





Energy + amino acids = new growth

Anabolism maintains the cells, and is responsible for growth of a variety of compounds and tissues. It creates muscle, hair, skin, organs, flesh, bone, chemicals such as hormones and enzymes, nails, and muscle. Some hormones, referred to as anabolic steroids, help the body grow muscle.