Unit-1
Zoo CC410
B.Sc-2nd Year; Sem-IV

Overview of Metabolism-I

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Overview of Metabolism

Metabolism is a biochemical process that allows an organism to live, grow, reproduce, heal, and adapt to its environment.

Or

Metabolism is defined as the entire set of life sustaining chemical reactions that occur in organisms.

*These reactions number in the thousands and include reactions such as those responsible for getting energy from food, processing and removal of waste, building up muscles, growth, photosynthesis in plants, cell division, and reproduction.

* The entire set of metabolic reactions is organized into smaller sets of sequential reactions called **metabolic *pathways*.**

Overview of Metabolism

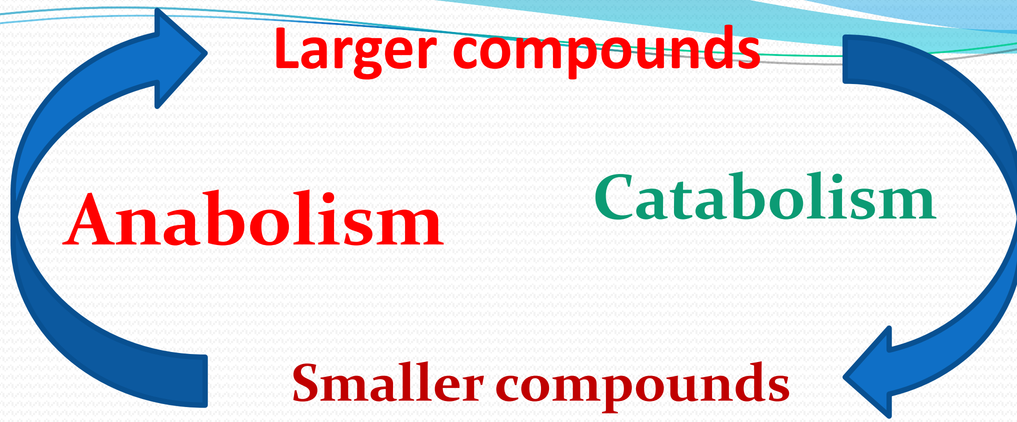
The species produced in the various reactions of a metabolic pathway are sometimes referred to as ***metabolites.***

Many of the reactions in metabolic pathways require enzymes; therefore organisms can control (accelerate or suppress) metabolic pathways, according to their current needs, by *upregulating, downregulating, inhibiting, or activating one or* more of the enzymes involved in the pathway.

Metabolic pathways can usually be classified as **catabolic (catabolism)** or **anabolic (anabolism).**

Anabolism refers to the process which *builds* molecules the body needs; it usually *requires energy* for completion.

Catabolism refers to the process that *breaks down* complex molecules into smaller molecules; it usually *releases energy* for the organism to use.



. ***Anabolic pathways involve building up of larger organic compounds*** from smaller ones.

• ***Catabolic pathways involve the breakdown of larger organic*** compounds into smaller compounds.

* **Pathways that are involved in the metabolism of carbohydrates, proteins, and fats.**

* An ultimate goal of these reactions is to convert the chemical potential energy contained in food into chemical potential energy in the form of ***ATP.***

	Anabolism	Catabolism
Introduction	Metabolic process that builds molecules the body needs.	Metabolic process that breaks down large molecules into smaller molecules.
Energy	Requires energy	Releases energy
Hormones	Estrogen, testosterone, insulin, growth hormone.	Adrenaline, cortisol, glucagon, cytokines.
Effects on Exercise	Anabolic exercises, which are often anaerobic in nature, generally build muscle mass.	Catabolic exercises are usually **aerobic** and good at burning fat and calories.
Example	: amino acids becoming polypeptides (proteins), glucose becoming glycogen, fatty acids becoming triglycerides.	Proteins becoming amino acids, proteins,. becoming glucose, glycogen becoming glucose or triglycerides becoming fatty acids

The Coenzymes Involved in Metabolism

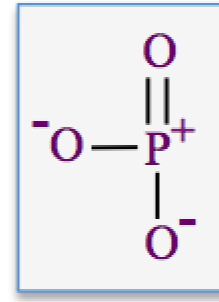
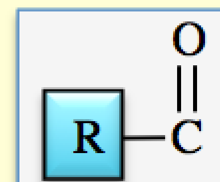
A coenzyme that must bind to an enzyme in order for the enzyme to function.

In most cases, a coenzyme is actually one of the *substrates (reactants) in* the catalyzed reaction.

The reason that certain substrates are also referred to as coenzymes is that these substrates are common substrates in many different enzymatic reactions in which they donate electrons, atoms, or groups of atoms to other substrates, or accept electrons, atoms or groups of atoms from other substrates.

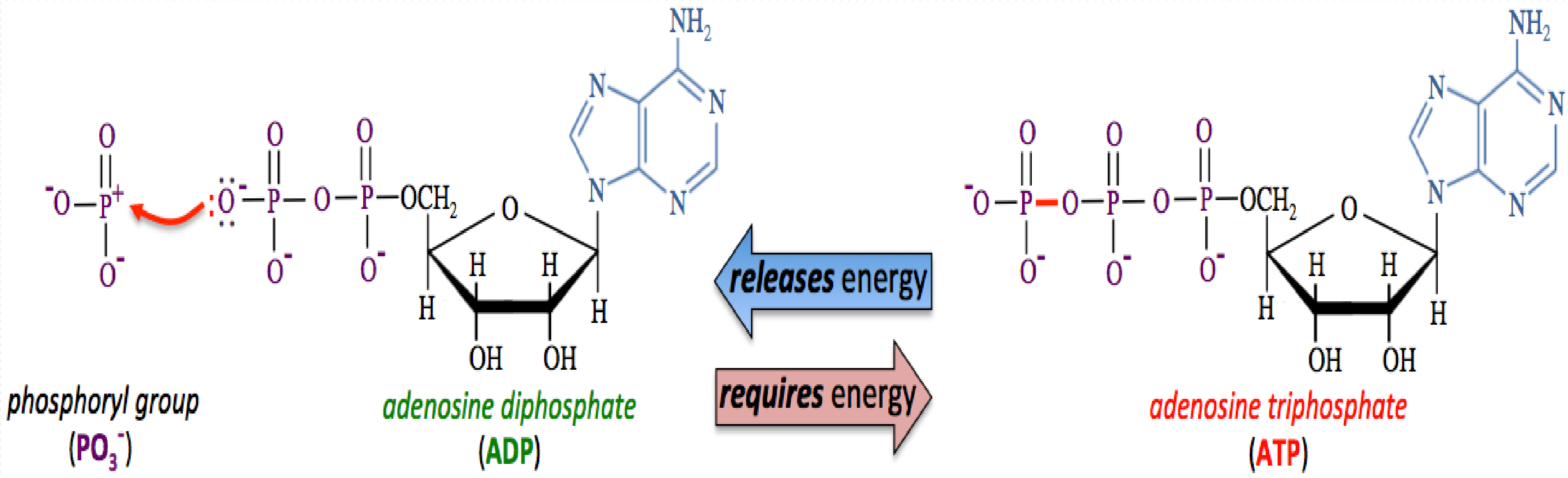
The Coenzymes Involved in Metabolism

The five group-transfer coenzymes that are central to the metabolism of food, along with the species each transfers are listed in the table.

Coenzyme	Species that is Transferred
ADP/ATP	phosphoryl group = 
NAD^+/NADH	hydride ion ($H:^-$) **or** electrons
FAD/$FADH_2$	hydride ion ($H:^-$) **or** electrons
coenzyme A	acyl group = 
coenzyme Q	hydride ion ($H:^-$) **or** electrons

Phosphoryl Group-Transfer Coenzymes: ATP and ADP

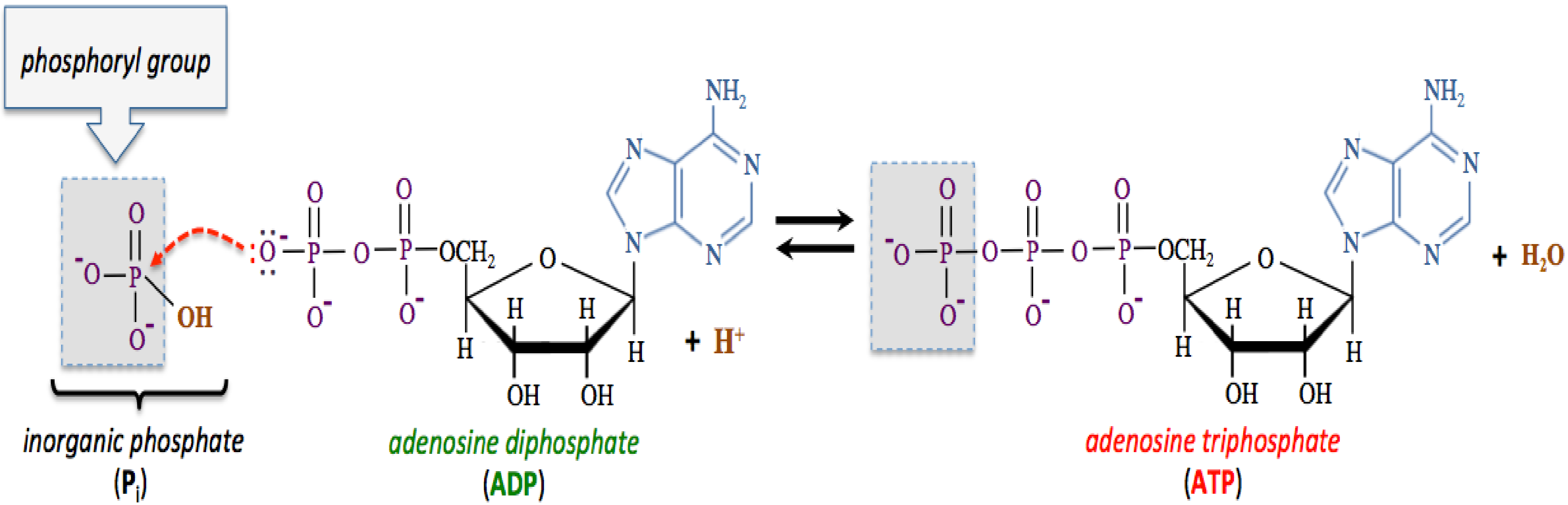
ATP and ADP are classified as coenzymes because they are involved in the *transfer* of ***phosphoryl groups (PO3 -) in many different enzymatically catalyzed reactions.***



- Adding a *phosphoryl group to* ***ADP requires energy.***

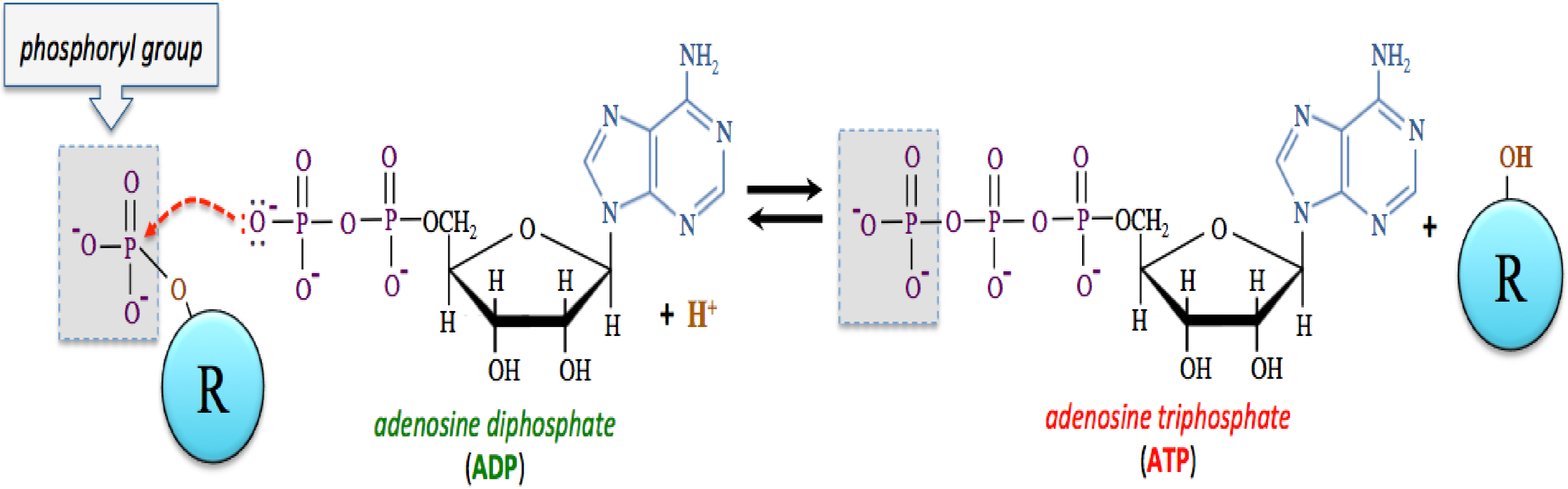
- Removing a *phosphoryl group from* ***ATP releases energy.***

ATP is often formed by the reaction of ADP with *hydrogen phosphate* (HPO4 2-) and an **H+ ion, as shown below.**



Biological literature refers to *hydrogen phosphate* as "***inorganic phosphate***" ***(abbreviated as Pi)***

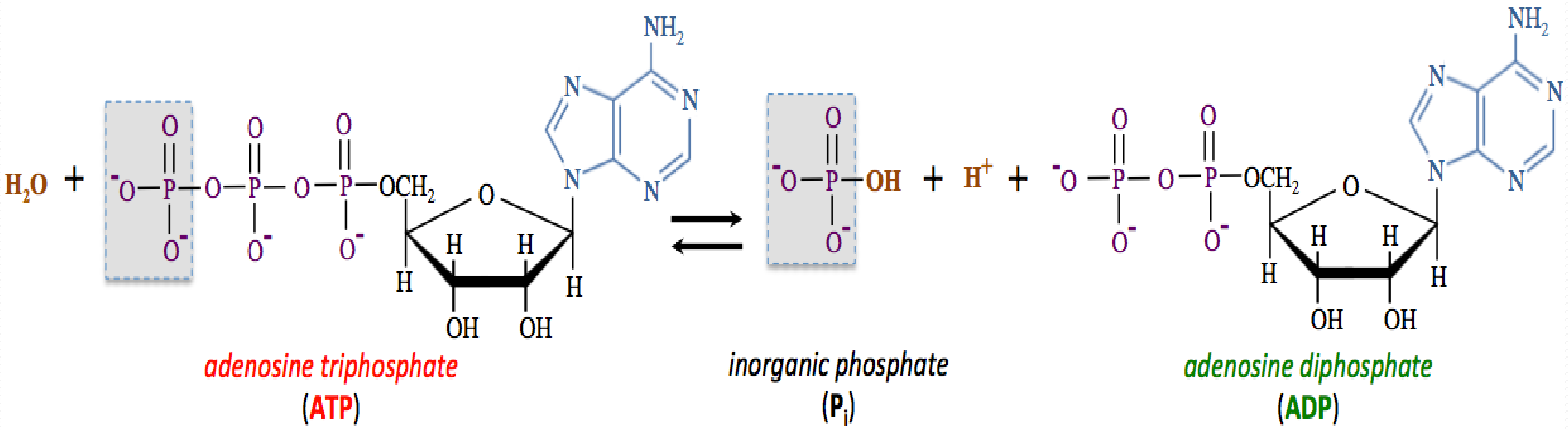
Another way that organisms convert ADP to ATP is by the reaction of ADP with an *organic molecule that contains a phosphoryl group.*



You will see hydrogen ions (**H+**) **as reactants *in many of the reactions in*** *this chapter. Because these reactions occur in aqueous solutions,* ***H+ is readily available from H2O, and can also come from H3O+ or the acid*** *forms of other species that are present.*

Energy is *released from ATP when it is converted to ADP.*

• *One way that energy can be released from* ***ATP is by reacting it with H2O to form ADP, inorganic phosphate, and an H+ ion. ADP, inorganic phosphate,*** and an **H+ ion.**



$\Delta G = -7300$ Joules per mole of ATP

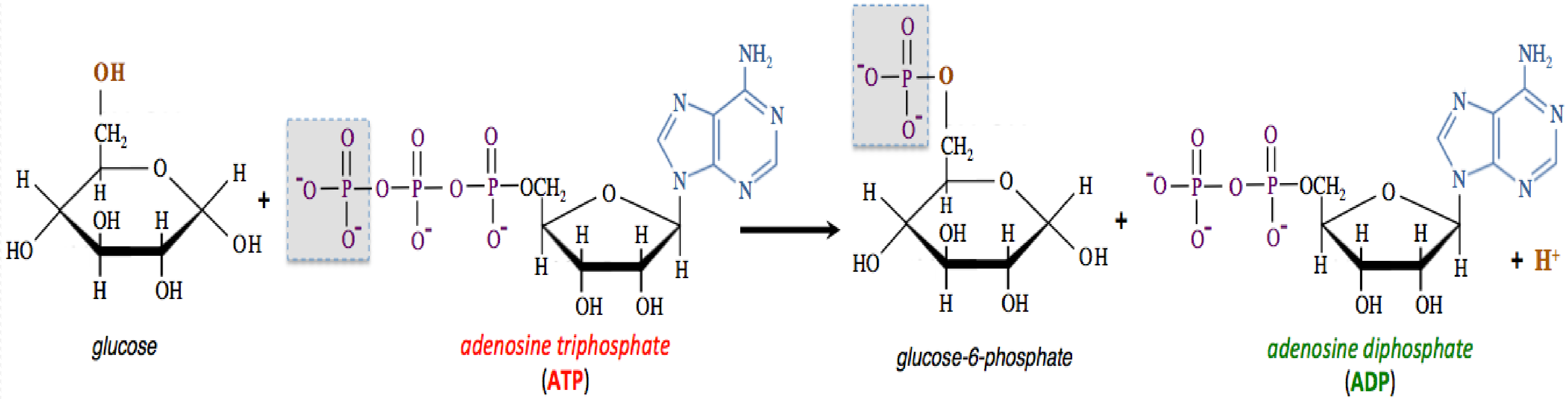
Note that **H+ is *produced in this reaction. You will see H+ ions as products in many of*** *the reactions in this chapter. Keep in mind that the* ***H+ ions that are produced in*** aqueous solutions do not remain solvated as *isolated ions; they quickly react with water* to form **H3O+ . Alternatively, H+ can react with OH- or the *base form of another species*** that is present.

Energy is ***released from ATP when it is converted to ADP.***

• Another way that organisms extract energy from **ATP is to energize" organic** compounds by transferring a phosphoryl group *directly to the compound*

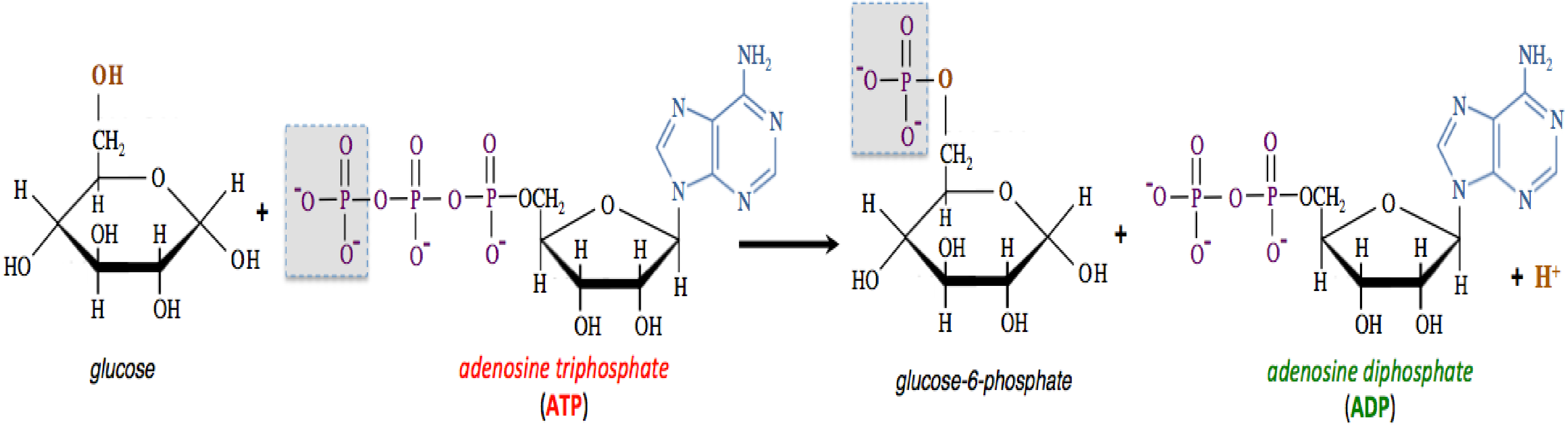
ATP + organic compound ⇄ ADP + *phosphorylated organic compound + H+*

• Example:

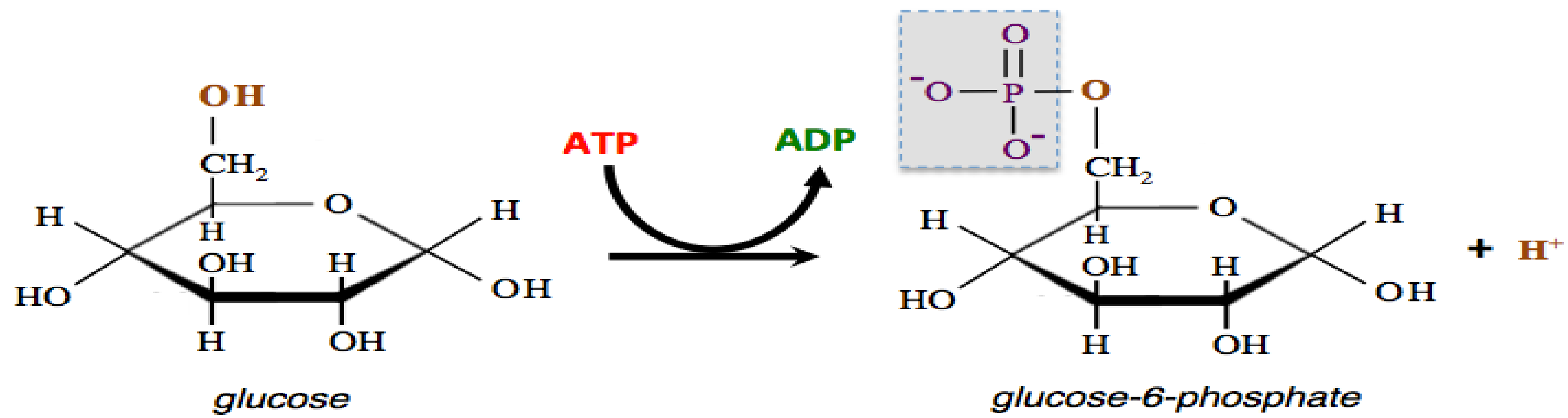


In this particular reaction, the reverse reaction occurs so slowly that it is negligible.

• In such cases, we refer to the reaction as an "***irreversible reaction.***"



When writing a chemical equation for an irreversible reaction, only a forward (left to right) arrow is used, as shown *above*. Biochemical literature often uses an *alternative chemical equation format*. For example, the reaction shown above is often written as:



Electron-Transfer Coenzymes and Their Role as Oxidizing and Reducing Agents

Oxidation-reduction reactions, which involve the transfer of one or more electrons, are quite common in organisms. Many of these reactions involve the transfer of an electron by way of the ***hydride ion (H:-).***

The principal catabolic process is digestion, where nutrient substances are ingested and broken down into simpler components for the body to use. In cells, catabolic processes break down polysaccharides such as starch, glycogen, and cellulose into monosaccharides (glucose, ribose and fructose, for example) for energy. Proteins are broken down into amino acids, for use in anabolic synthesis of new compounds or for recycling. And nucleic acids, found in RNA and DNA, are catabolized into nucleotides as part of the body's energy needs or for the purpose of healing.

Hormones

Many of the metabolic processes in an organism are regulated by chemical compounds called hormones. In general, hormones can be classified as anabolic or catabolic based on their effect within the organism

Anabolic hormones include:

Estrogen: Present in males as well as in females, estrogen is produced mainly in the ovaries. It regulates some female sexual characteristics (growth of breasts and hips), regulates the menstrual cycle, and plays a role in strengthening bone mass.

Testosterone: Present in females as well as males, testosterone is produced mainly in the testes. It regulates some male sexual characteristics (facial hair, voice), strengthens bones, and helps build and maintain muscle mass.

- *Insulin:* Produced in the pancreas by beta cells, it regulates the blood level and use of glucose. The body cannot use glucose, a main source of energy, without insulin. When the pancreas cannot create insulin, or when the body struggles to process the insulin it makes, this leads to diabetes.

- *Growth hormone:* Produced in the pituitary, growth hormone stimulates and regulates growth during the early stages of life. After maturity, it helps regulate bone repair.

Catabolic hormones include:

* *Adrenaline:* Also called "epinephrine," adrenaline is produced by the adrenal glands. It is the key component of the "fight or flight" response that accelerates heart rate, opens up bronchioles in the lungs for better oxygen absorption and floods the body with glucose for fast energy.

* *Cortisol:* Also produced in the adrenal glands, cortisol is known as the "stress hormone." It is released during times of anxiety, nervousness or when the organism feels prolonged discomfort. It increases blood pressure, blood sugar levels and suppresses the body's immune processes.

•*Glucagon:* Produced by the alpha cells in the pancreas, glucagon stimulates the breakdown of glycogen into glucose. Glycogen is stored in the liver and when the body needs more energy (exercise, fighting, high level of stress), glucagon stimulates the liver to catabolize glycogen, which enters the blood as glucose.

Cytokines: This hormone is a small protein that regulates communication and interactions between cells. Cytokines are constantly being produced and broken down in the body, where their amino acids are either reused or recycled for other processes. Two examples of cytokines are interleukin and lymphokines, most often released during the body's immune response to invasion (bacteria, virus, fungus, tumor) or injury.

Anabolism Examples

*Anabolic reactions are those that build complex molecules from simple ones. Cells use these processes to make polymers, grow tissue, and repair damage.
For example:

.* Glycerol reacts with fatty acids to make lipids:

$CH_2OHCH(OH)CH_2OH + C_{17}H_{35}COOH \rightarrow CH_2OHCH(OH)CH_2OOCC_{17}H_{35}$

* Simple sugars combine to form disaccharides and water:

$C_6H_{12}O_6 + C_6H_{12}O_6 \rightarrow C_{12}H_{22}O_{11} + H_2O$

* Amino acids join together to form dipeptides:

$NH_2CHRCOOH + NH_2CHRCOOH \rightarrow NH_2CHRCONHCHRCOOH + H_2O$

* Carbon dioxide and water react to form glucose and oxygen in photosynthesis:

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

Anabolic hormones stimulate anabolic processes. Examples of anabolic hormones include insulin, which promotes glucose absorption, and anabolic steroids, which stimulate muscle growth. Anabolic exercise is anaerobic exercise, such as weightlifting, which also builds muscle strength and mass.

Catabolism

Cells can store useful raw materials in complex molecules, use catabolism to break them down, and recover the smaller molecules to build new products. For example, catabolism of proteins, lipids, nucleic acids, and polysaccharides generates amino acids, fatty acids, nucleotides, and monosaccharides, respectively. Sometimes waste products are generated, including carbon dioxide, urea, ammonia, acetic acid, and lactic acid.

Examples

Catabolic processes are the reverse of anabolic processes. They are used to generate energy for anabolism, release small molecules for other purposes, detoxify chemicals, and regulate metabolic pathways. For example:

* During cellular respiration, glucose and oxygen react to yield carbon dioxide and water

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

* In cells, hydroxide peroxide decomposes into water and oxygen:

$2H_2O_2 \rightarrow 2H_2O + O_2$

Many hormones act as signals to control catabolism. The catabolic hormones include adrenaline, glucagon, cortisol, melatonin, hypocretin, and cytokines. Catabolic exercise is aerobic exercise such as a cardio workout, which burns calories as fat (or muscle) is broken down.

Summary of Metabolism

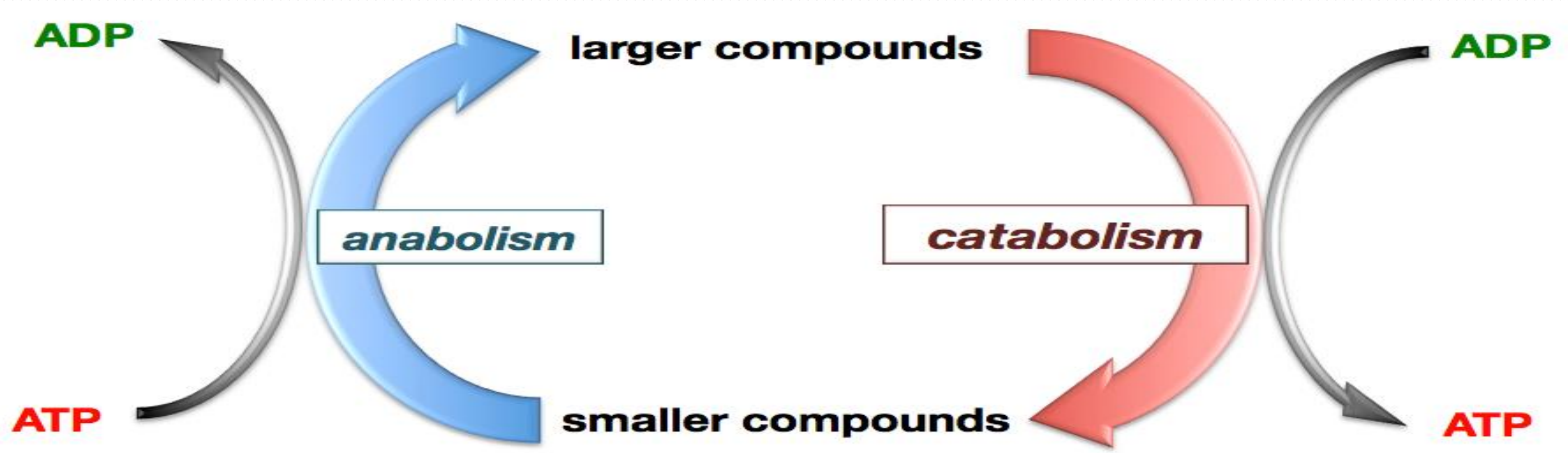
The body is able to build proteins, carbohydrates, and triglycerides from
smaller organic compounds in anabolic processes.

- Anabolic processes generally require the input of external energy.
- This energy often comes from chemical potential energy in **ATP.**

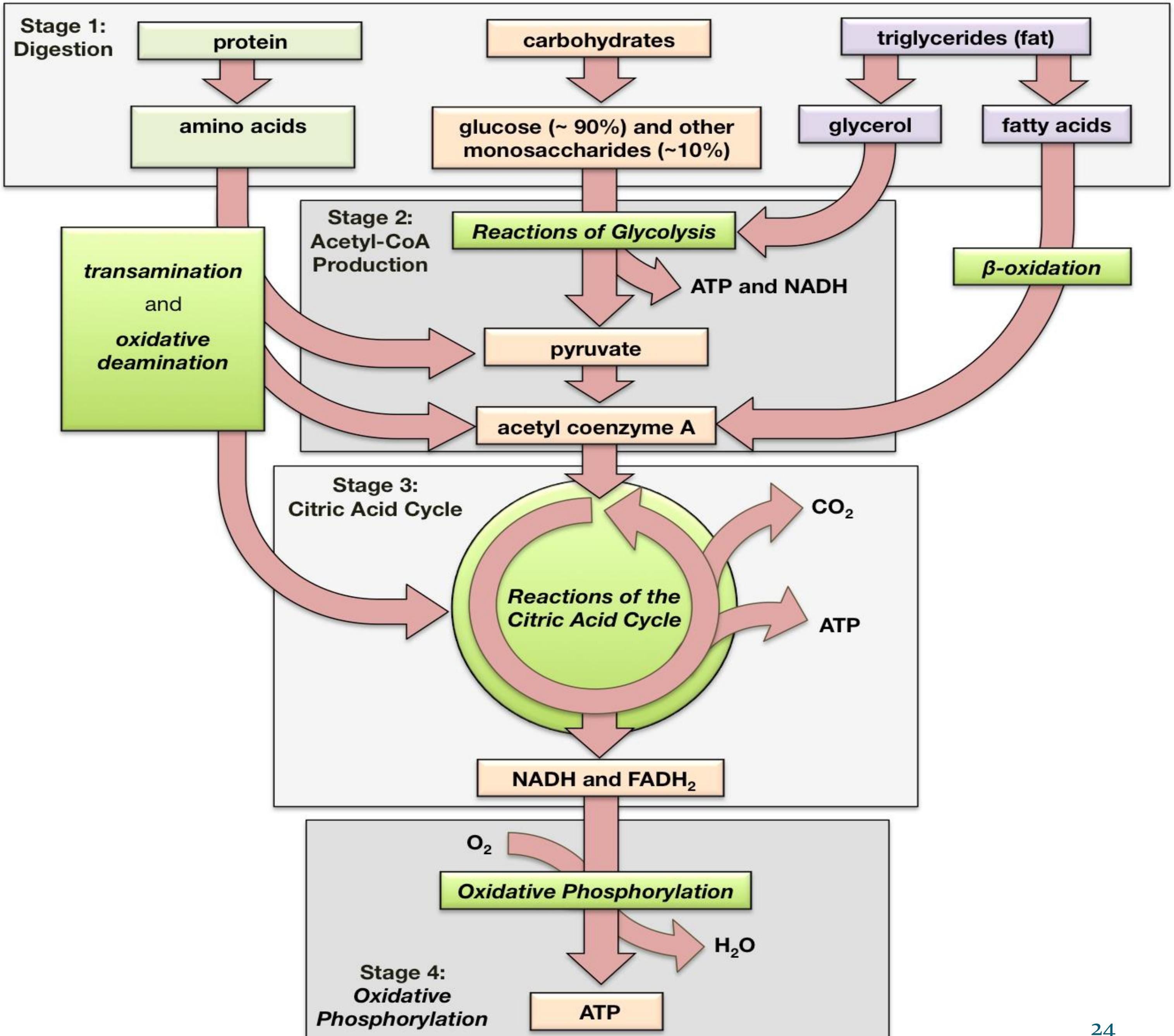
The body is able to break down proteins, carbohydrates, and triglycerides
into smaller organic compounds in catabolic processes.

- Catabolic processes typically release energy.
- This energy is often used by the body to produce **ATP.**

The metabolic strategy behind the production of **ATP is that ATP is an energy source** that can be instantaneously used by organisms to do cellular work and to provide the energy required for life-sustaining reactions that would otherwise not occur spontaneously. The metabolic strategies of catabolism and anabolism are summarized in the illustration below.



Over-view of the Cata-bolism of Food



Catabolism

* In the four stages of food catabolism, chemical potential energy in food is converted to chemical potential energy in ATP, NADH, and $FADH_2$.

* The NADH and $FADH_2$ can then be converted to electrochemical energy in the form of a hydrogen ion gradient.

* The electrochemical potential in this gradient is used to drive the production of ATP.

Catabolism

The ***catabolic processes*** discussed in this chapter are digestion, glycolysis, pyruvate oxidation/decarboxylation, the citric acid cycle, glycogenolysis, lipolysis, *β-oxidation, and* oxidative deamination. These *catabolic processes are* listed and briefly described in this table. See the textbook for a higher resolution image.

Name	Description	Notes
digestion	***Carbohydrates*** are *hydrolyzed* to ***monosaccharides***. ***Triglycerides*** are "***partially***" *hydrolyzed* to ***fatty acid salts*** and ***monoglyceride***. ***Proteins*** are *hydrolyzed* to ***amino acids***.	
glycolysis	A ***linear metabolic pathway*** in which *glucose* is converted into **two** *pyruvate ions.*	**High** concentrations of **ATP**, *pyruvate*, or *other pathway products* suppress this process.
pyruvate oxidation/ decarboxylation	*Pyruvate* is oxidized and decarboxylated to produce *acetyl*-**CoA**.	
citric acid cycle	A ***circular metabolic pathway*** in which *acetyl*-**CoA** is metabolized to produce **ATP**, **NADH**, and **$FADH_2$**	
glycogenolysis	*Glycogen* is converted to *glucose*. Glycogenolysis occurs primarily in ***liver*** and ***muscle*** cells. Liver cells will release the glucose into the bloodstream so that it can be taken in by other types of cells.	***Low blood glucose*** and ***glucagon*** accelerate this process. ***High blood glucose*** and ***insulin*** suppress this process.
β-oxidation	A ***linear metabolic pathway*** in which *fatty acids are converted to acetyl*-**CoA**, **NADH** and **$FADH_2$**.	
lipolysis	*Triglycerides* that are stored primarily in adipose (fat) cells and muscle cells are broken down into *fatty acids* and *glycerol*. Liver cells can release the fatty acids and glycerol into the bloodstream so that they can be taken in by other types of cells.	
oxidative deamination	A *quaternary ammonium group* ($-NH_3^+$) is removed from *glutamic acid*, thereby producing ammonium (NH_4^+) and ***α***-ketoglutarate.	

Anabolism

The ***anabolic processes discussed*** in this chapter are gluconeogenesis, glycogenesis, fatty acid synthesis, and protein synthesis. These *anabolic processes are listed* and briefly described in this table.

Name	Description	Notes
gluconeogenesis	The conversion of ***non-carbohydrate species into glucose***. This process is *similar* to the reverse of glycolysis. Gluconeogenesis occurs primarily in the liver. It increases blood glucose levels because liver cells can release the glucose that is produced into the bloodstream.	***Low blood glucose*** and ***glucagon*** accelerate this process.
glycogenesis	*Glucose* is converted to *glycogen*. Glycogenesis occurs primarily in ***liver*** and ***muscle*** cells. Glycogenesis lowers blood glucose levels because glucose is taken up by liver and muscle cells and then converted to glycogen.	***High blood glucose*** and ***insulin*** accelerate this process. ***Low blood glucose*** and ***glucagon*** suppress this process.
fatty acid synthesis	Fatty acids are produced by a spiral pathway that works in the opposite direction of **β**-oxidation; it builds up fatty acyl-CoA by a repeating series of reactions that add acetyl-CoA to a growing fatty acyl-CoA structure. Fatty acid synthesis occurs primarily in adipose and liver cells.	
protein synthesis	*Amino acids* are converted to *proteins*.	This process was mentioned briefly in this chapter, however it was ***thoroughly discussed chapter 14***

Amphibolic Pathways

A metabolic pathway that can be either catabolic or anabolic depending on energy availability is called an amphibolic pathway. The glyoxylate cycle and the citric acid cycle are examples of amphibolic pathways. These cycles can either produce energy or use it, depending on cellular needs.

Thank You