

CHEM 3331
Fundamentals of Biochemistry

Chapter
12 Nutrition and Energy for Life

Organic and Biochemistry for Today
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Nutritional Requirements

- The science of **nutrition** focuses on the study of food, water, and other nutrients and the ways in which they are used by living organisms.
- Nutrients** are necessary for the body to function and remain healthy.
 - Macronutrients** are needed in large amounts (gram quantities) because they provide energy and materials required to build and repair tissues.
 - carbohydrates, proteins, and lipids
 - Micronutrients** are required in small amounts (milligram or microgram quantities). Many of these are used in enzymes.
 - vitamins and minerals

Nutritional Requirements

- In addition to nutrients, the body also requires water and fiber.
 - Water** — 45-75% of human body mass is water.
 - Fiber** is an indigestible plant material made mostly of cellulose. It helps to maintain digestive health by providing roughage to stimulate contraction of the intestines and help pass food through the digestive system.
- The **Daily Values (DV)** are a set of nutritional guidelines established by the FDA for use on food labels:
 - Reference Daily Intakes (RDI)** — proteins and 19 vitamins and minerals
 - Daily Reference Values (DRV)** — other nutrients and food components

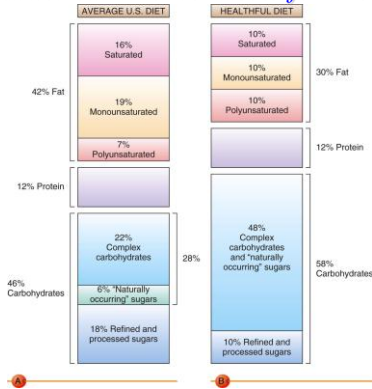
Daily Values (DV)

Carbohydrates

- Carbohydrates provide energy for body functions and useful materials for the synthesis of cell and tissue components.
- Simple carbohydrates** are the monosaccharides and disaccharides such as glucose, fructose, sucrose, etc.
- Complex carbohydrates** are the polysaccharides amylose and amylopectin (starch).
 - Cellulose is also a complex carbohydrate, but it serves a nonnutritive role as fiber.
- Current recommendations are that about 58% of our daily calories should come from carbohydrates; currently, about 46% of the typical American diet comes from carbohydrates, and much of that comes from simple sugars rather than from complex carbohydrates.

Macronutrients:
Carbohydrates, Lipids,
and Proteins

American Diet vs. Healthful Diet



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Lipids

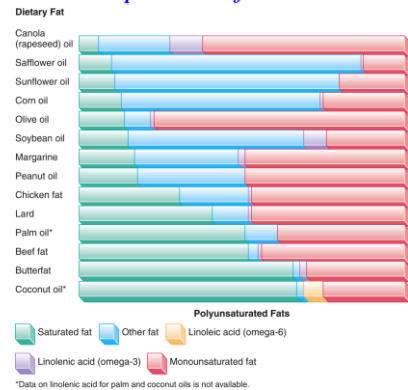
- About 95% of the lipids in foods and in our bodies is in the form of triglycerides. The fatty acids in the triglycerides can be either *saturated* or *unsaturated*.
 - Triglycerides containing a high concentration of unsaturated fatty acids are liquids at room temperature (oils).
 - Triglycerides containing a high concentration of saturated fatty acids are solids at room temperature (fats).
- Lipids provide a concentrated source of energy.
 - lipids: 9 Cal/g
 - proteins and carbohydrates: 4 Cal/g
- Lipids contain some fat-soluble vitamins and help to carry them through the body.

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Lipids

- Lipids improve the texture of foods, absorb and retain flavors, and are digested more slowly than other foods, prolong the feeling of *satiety* (satisfaction and fullness after a meal).
- Linoleic and linolenic acids are *essential fatty acids* because they cannot be synthesized in the body, and must be obtained from the diet.
 - Corn, cottonseed, soybean oils, and wheat germ are good sources for these acids.
- The average American receives about 42% of the calories in their diets from fat, while the recommendation is about 30%.

Fatty Acid Composition of Common Food Fats



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Proteins

- The RDI for proteins varies for different groups of people.
- Protein is necessary for:
 - production of new tissue
 - maintenance and repair of cells
 - production of enzymes, hormones, and other important nitrogen-containing compounds
- Proteins provide 4 Cal/g of energy.

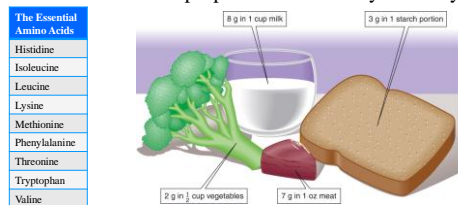
Table 22.1 The RDI for Protein

Group	RDI (g)
Pregnant women	60
Nursing mothers	65
Infants under age 1	14
Children age 1 to 4	16
Adults	50

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Proteins

- On digestion, proteins are broken down into amino acids, which are then absorbed into the body's amino acid pool.
 - Several amino acids are *essential*, and must be obtained from the diet.
- Complete proteins** contain all of the essential amino acids in the proportions needed by the body.



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Micronutrients I: Vitamins

Vitamins

- **Vitamins** are organic micronutrients that the body cannot produce in amounts needed for good health.
- Some vitamins are highly polar, and are **water-soluble**.
 - With the exception of Vitamin C, water-soluble vitamins function as *coenzymes*.
 - Excess amounts of water-soluble vitamins are usually removed by the kidneys.
- Vitamins with nonpolar molecule structure dissolve only in nonpolar solvents, and are *fat-soluble*.
 - Care must be taken to avoid overdoses of the fat-soluble vitamins, since they are not eliminated as readily. (They are stored in the liver and fatty tissues.)

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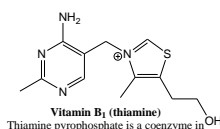
Vitamin	Solubility	Functions	Dietary Sources	RDI	Deficiency Conditions	Upper Intake Level	Overdose Disease
A (retinol)	Fat	Synthesis of visual pigments	Eggs, butter, cheese, dark green and deep orange vegetables	900 µg	Inflamed eye membranes, night blindness, scalliness of skin	3000 µg	Birth defects, liver problems, reduced bone density, skin discoloration, dry skin
B ₁ (thiamin)	Water	Coenzyme in decarboxylation reactions	Bread, beans, nuts, milk, peas, pork, rice bran	1.2 mg	Beriberi: nausea, severe exhaustion, paralysis	N/D	Drowsiness, muscle relaxation
B ₂ (riboflavin)	Water	Forms the coenzymes FMN and FAD, which are hydrogen transporters	Milk, meat, eggs, dark green vegetables, bread, beans, peas	1.3 mg	Dermatitis (skin problems)	N/D	
B ₃ (niacin)	Water	Forms the coenzyme NAD ⁺ , which is a hydride transporter	Meat, whole grains, poultry, fish	16.0 mg	Pellagra: weak muscles, no appetite, diarrhea, dermatitis	35.0 mg	Liver damage
B ₅ (pantothenic acid)	Water	Part of coenzyme A, acyl group carrier	All plants and animals, nuts; whole-grain cereals	5.0 mg	Anemia	N/D	Diarrhea; possibly nausea and heartburn
B ₆ (pyridoxine)	Water	Coenzyme form carries amino and carboxyl groups	Meats, whole grains, poultry, fish	1.3-1.7 mg	Dermatitis, nervous disorders	100 mg	Impaired sense of balance and location, nerve damage (> 100 mg/day)
B ₇ (biotin)	Water	Coenzyme form used in fatty acid synthesis	Found widely; egg yolk, liver, yeast, nuts	30.0 µg	Dermatitis, muscle weakness	N/D	

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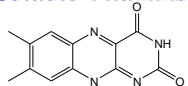
Vitamin	Solubility	Functions	Dietary Sources	RDI	Deficiency Conditions	Upper Intake Level	Overdose Disease
B ₉ (folic acid)	Water	Coenzyme in methyl group transfers	Leafy green vegetables, peas, beans	400 µg	Anemia	1000 µg	May mask symptoms of vitamin B ₁₂ deficiency
B ₁₂ (cobalamin)	Water	Coenzyme in amino acid metabolism	Meat, fish, eggs, milk	2.4 µg	Rare except in vegetarians; pernicious anemia	N/D	Acne-like rash is possible
C (ascorbic acid)	Water	Synthesis of collagen for connective tissue	Citrus fruits, tomatoes, green pepper, strawberries, leafy green vegetables	90.0 mg	Scurvy: tender tissues, weak and bleeding gums, swollen joints	3000 mg	
D (calciferol)	Fat	Regulation of calcium and phosphorus metabolism	Fish-liver oils, fortified milk	5-10 µg	Rickets (malformation of the bones)	50 µg	Dehydration, vomiting, decreased appetite, irritability, constipation, fatigue, muscle weakness
E (tocopherol)	Fat	Prevention of oxidation of vitamin A and fatty acids	Whole-grain cereals, margarine, vegetable oil	15.0 mg	Breakage of red blood cells	1000 mg	Increased congestive heart failure seen in one study
K	Fat	Synthesis of blood-clotting substances	Cabbage, potatoes, peas, leafy green vegetables	120 µg	Blood-clotting disorders	N/D	Increases coagulation in patients taking warfarin

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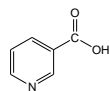
Water-Soluble Vitamins



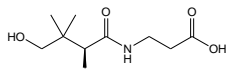
Vitamin B₁ (thiamine)
Thiamine pyrophosphate is a coenzyme in the catabolism of sugars and amino acids. All living organisms use thiamine, but it is only synthesized in bacteria, fungi, and plants; deficiency results in beriberi



Vitamin B₂ (riboflavin)
Central component of the cofactors FAD and FMN, and is used in all flavoproteins; repairs damage due to oxidative stress, and is involved in photosynthesis, DNA repair, and apoptosis



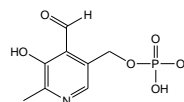
Vitamin B₃ (niacin, nicotinic acid)
Forms part of the coenzyme NAD⁺ (nicotinamide adenine dinucleotide); involved in DNA repair and the production of steroid hormones in the adrenal gland



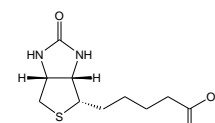
Vitamin B₅ (pantothenic acid)
Required for the synthesis of coenzyme-A; needed in the synthesis and metabolism of proteins, carbohydrates, and fats

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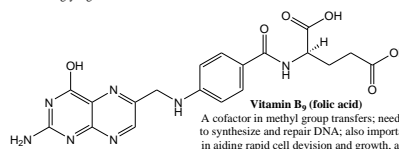
Water-Soluble Vitamins



Vitamin B₆ (pyridoxine, pyridoxal pyrophosphate)
A cofactor in many reactions in amino acid metabolism; necessary for the enzymatic reaction governing the release of glucose from glycogen



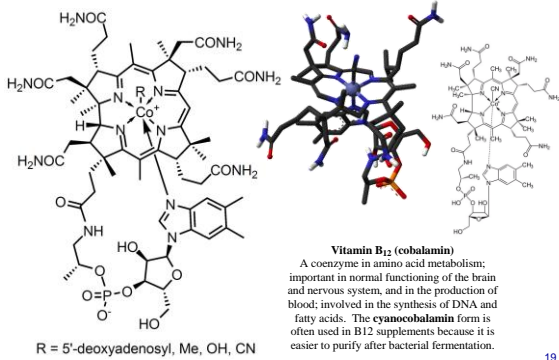
Vitamin B₇ (biotin)
A coenzyme in the metabolism of fatty acids and some amino acids, and plays a role in gluconeogenesis



Vitamin B₉ (folic acid)
A cofactor in methyl group transfers; needed to synthesize and repair DNA; also important in aiding rapid cell division and growth, and producing healthy red blood cells (and preventing anemia)

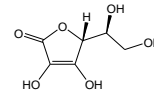
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Water-Soluble Vitamins



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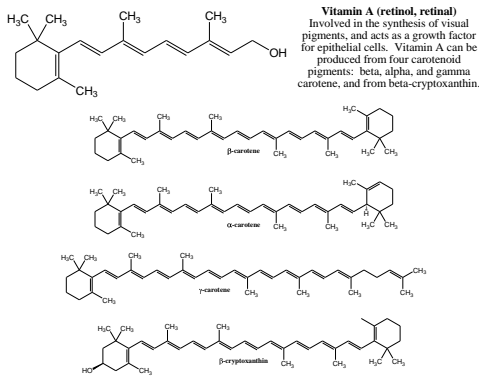
Water-Soluble Vitamins



Vitamin C (ascorbic acid)
Acts as an antioxidant; cofactor in at least eight enzymatic reactions; involved in the synthesis of collagen (prevention of scurvy)

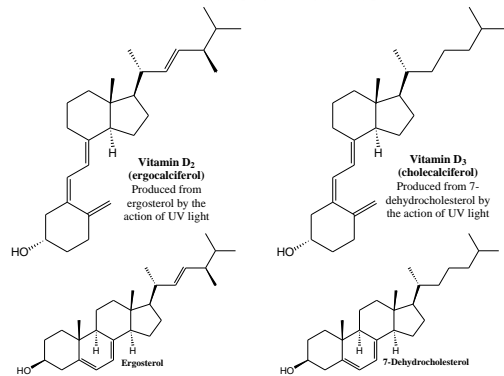
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Fat-Soluble Vitamins



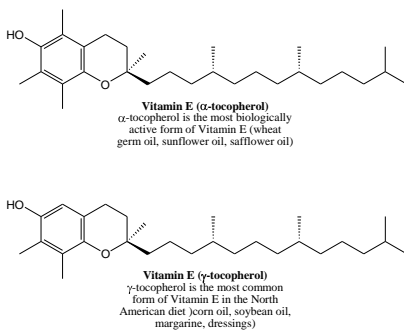
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Fat-Soluble Vitamins



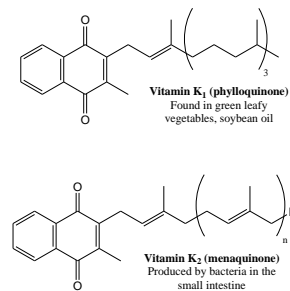
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Fat-Soluble Vitamins



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Fat-Soluble Vitamins



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Micronutrients II: Minerals

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Major and Trace Mineral Sources and Functions

Mineral	Dietary Sources	RDI	Functions	Deficiency Conditions
Major Minerals				
Calcium	Dairy foods, dark green vegetables	1300 mg	Bone and tooth formation, blood clotting, nerve impulse transmission	Stunted growth, rickets, weak and brittle bones
Chlorine	Table salt, seafood, meat	2300 mg	HCl in gastric juice, acid-base balance	Muscle cramps, apathy, reduced appetite
Magnesium	Whole-grain cereals, meat, nuts, milk, legumes	420 mg	Activation of enzymes, protein synthesis	Inhibited growth, weakness, spasms
Phosphorus	Milk, cheese, meat, fish, grains, legumes, nuts	700 mg	Enzyme component, acid-base balance, bone and tooth formation	Weakness, calcium loss, weak bones
Potassium	Meat, milk, many fruits, cereals, legumes	4700 mg	Acid-base and water balance, nerve function	Muscle weakness, paralysis
Sodium	Most foods except fruit	1500 mg	Acid-base and water balance, nerve function	Muscle cramps, apathy, reduced appetite
Sulfur	Protein foods		Component of proteins	Deficiencies are very rare
Trace Minerals				
Arsenic*	Many foods		Growth and reproduction	Poor growth and reproduction
Cobalt	Meat, liver, dairy foods		Component of vitamin B ₁₂	Pernicious anemia (vitamin-deficiency symptom)
Copper	Drinking water, liver, grains, legumes, nuts	900 µg	Component of numerous enzymes, hemoglobin formation	Anemia, fragility of arteries
Chromium	Fats, vegetable oils, grains, meat		Enhances insulin action	Reduced ability to metabolize glucose

* Need and deficiency symptoms determined for animals, probable in humans, but not yet certain.

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Minerals

- **Minerals** are metals or nonmetals used in the body in the form of ions or compounds. Although we talk about them as if they are in their pure elemental form, all of these substances are ingested in the form of either ionic or molecular compounds.
 - **Major minerals** are found in the body in quantities greater than 5 grams.
 - They are inorganic structural components of bones and teeth (Ca, P), or are needed in large amounts for the regulation of fluids and the transmission of nerve impulses (Na, K).
 - **Trace minerals** are found in the body in smaller amounts.
 - They are components of vitamins, enzymes, hormones, or specialized proteins.

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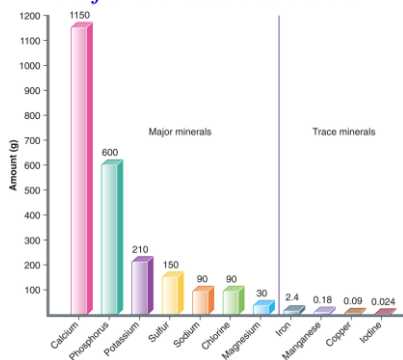
Major and Trace Mineral Sources and Functions

Mineral	Dietary Sources	RDI	Functions	Deficiency Conditions
Fluorine	Drinking water, seafood, onions, spinach		Maintenance of bones and teeth	Higher frequency of tooth decay
Iodine	Iodized salt, fish, dairy products	150 µg	Component of thyroid hormones	Hypothyroidism, goiter
Iron	Liver, lean meat, whole grains, dark green vegetables	18 µg	Component of enzymes and hemoglobin	Anemia
Manganese	Grains, beet greens, legumes, fruit	2.3 µg	Component of enzymes	Deficiencies are rare
Molybdenum	Legumes, cereals, organ meats, dark green vegetables	45 µg	Component of enzymes	Deficiencies are rare
Nickel	Many foods		Needed for health of numerous tissues	Organ damage; deficiencies are rare
Selenium	Grains, meats, poultry, milk	55 µg	Component of enzymes	Deficiencies are rare
Silicon*	Many foods		Bone calcification	Poor bone development; deficiencies are rare
Tin*	Many foods		Needed for growth	Poor growth
Vanadium*	Many foods		Growth, bone development, reproduction	Poor growth, bone development, reproduction
Zinc	Milk, liver, shellfish, wheat bran	11 mg	Component of numerous enzymes	Poor growth, lack of sexual maturation, loss of appetite, abnormal glucose tolerance

* Need and deficiency symptoms determined for animals, probable in humans, but not yet certain.

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Major and Trace Minerals



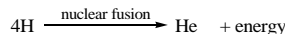
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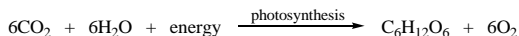
Metabolism and an Overview of Energy Production

The Sun and Photosynthesis

- The sun is the ultimate source of energy for all biological processes. This energy results from the fusion of hydrogen atoms to form helium atoms:



- A portion of this energy reaches the Earth's surface as sunlight, and is captured by the chlorophyll in plants. This energy drives the conversion of carbon dioxide and water to form glucose, and then into starch, triglycerides, and other forms of stored energy:



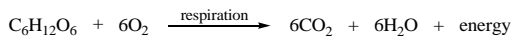
- All animals obtain energy either directly or indirectly from these energy stores in plants.

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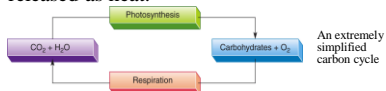
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Cellular Respiration

- During cellular respiration, plants and animals combine energy-rich compounds with oxygen from the air, producing CO₂ and releasing energy.
- Cellular respiration can be represented as:

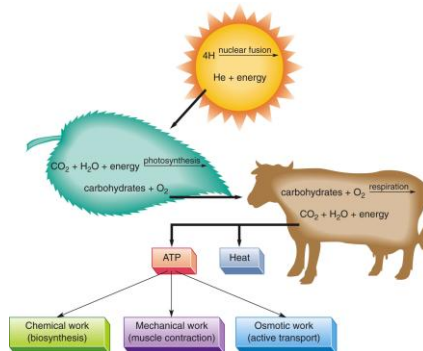


- A portion of the energy released during respiration is captured in the form of adenosine triphosphate (ATP), which stores energy for use in other processes.
- The remainder of the energy from respiration is released as heat.



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Energy Flow in the Biosphere



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Metabolism

- Metabolism** is the sum of all reactions occurring in an organism:
 - catabolism** — the reactions involved in the *breakdown* of biomolecules.
 - anabolism** — the reactions involved in the *synthesis* of biomolecules.
 - In general, energy is released during catabolism and required during anabolism.

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Metabolic Pathways

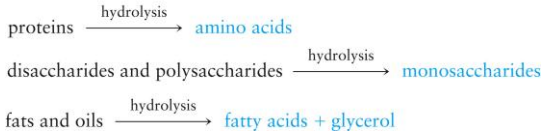
- A **metabolic pathway** is a sequence of reactions used to produce one product or accomplish one process.
 - Each pathway consists of a series of chemical reactions that convert a starting material into an end product (e.g., the citric acid cycle and the electron transport chain).
 - Fortunately, there are a great many similarities among the major metabolic pathways in all life forms.

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The Catabolism of Food

The catabolism of food is a three stage process.

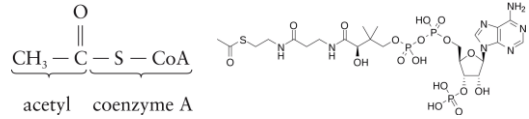
- **Stage I:** The **digestion** of large, complex molecules into simpler ones.
 - The most common reaction in digestion is **hydrolysis**:



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The Catabolism of Food

- **Stage II:** The small molecules from digestion are broken down into even simpler units, usually the two-carbon acetyl portion of acetyl coenzyme A (acetyl CoA):



- Some energy is produced at this stage, but much more is produced during the oxidation of the acetyl units in Stage III.

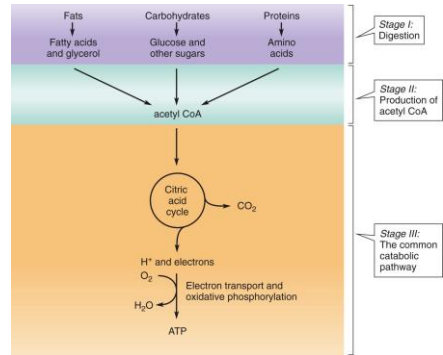
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The Catabolism of Food

- **Stage III:** This is referred to as the **common catabolic pathway** because the reactions are the same regardless of the type of food being degraded.
 - citric acid cycle
 - electron transport
 - oxidative phosphorylation
- Energy released in Stage III appears in the form of energy-rich molecules of **ATP**.
 - The whole purpose of the catabolic pathway is to convert the chemical energy in foods into molecules of ATP, which carries energy to parts of the cell where energy is needed.
 - The common catabolic pathway and the ways in which carbohydrates, lipids, and proteins provide molecules that are degraded by this pathway will be discussed in Chapters 13-15.

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The Catabolism of Food

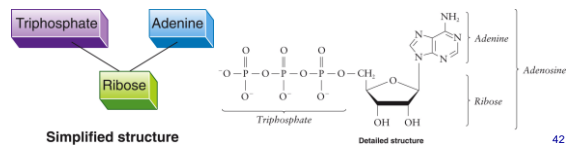


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ATP: The Primary Energy Carrier

The Structure of ATP

- **Adenosine triphosphate, ATP**, consists of:
 - the heterocyclic base **adenine**
 - the sugar **ribose**
 - a **triphosphate group**
 adenine + ribose is called **adenosine**
- At physiological pH, the protons on the triphosphate group are removed, giving ATP a charge of -4.
 - In the cell, it is complexed with Mg^{2+} in a 1:1 ratio, giving it a net charge of -2.

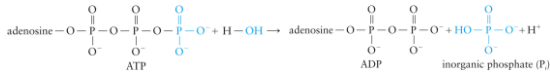


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The Hydrolysis of ATP

- The triphosphate group is the part of the molecule that is important in the transfer of biochemical energy. The key reaction is the transfer of a **phosphoryl group**, $-\text{PO}_3^{2-}$, from ATP to another molecule.
 - During the hydrolysis of ATP in water, a phosphoryl group is transferred from ATP to a water molecule:



- The products are **adenosine diphosphate (ADP)** and a **phosphate ion**, often referred to as an inorganic phosphate, P_i, or just *phosphate*.

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The Hydrolysis of ATP

- The transfer of a phosphoryl group from ATP to water is accompanied by a release of energy.
- Free energy**, ΔG, is used as a measure of the energy change.
 - When energy is released, ΔG is negative.
 - When energy is absorbed, ΔG is positive.
 - When ΔG is measured under standard conditions, it is represented by ΔG°.
 - When ΔG° is measured under body conditions, it is represented by ΔG°'.

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The Hydrolysis of ATP

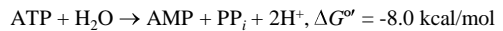
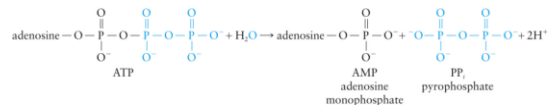
- The liberated free energy is available for use by the cell to carry out processes requiring an input of energy:
 - ATP + H₂O → ADP + P_i + H⁺, ΔG°' = -7.3 kcal/mol
- Other phosphate-containing compounds also liberate energy on hydrolysis:

Reaction	ΔG°' (kcal/mol)
Phosphoenolpyruvate + H ₂ O → pyruvate + phosphate	-14.8
Carbamoyl phosphate + H ₂ O → ammonia + CO ₂ + phosphate	-12.3
1,3-bisphosphoglycerate + H ₂ O → 3-phosphoglycerate + phosphate	-11.8
Phosphocreatine + H ₂ O → creatine + phosphate	-10.3
ATP + H ₂ O → ADP + phosphate	-7.3
ADP + H ₂ O → AMP + phosphate	-7.3
Glucose-1-phosphate + H ₂ O → glucose + phosphate	-5.0
AMP + H ₂ O → adenosine + phosphate	-3.4
Glucose-6-phosphate + H ₂ O → glucose + phosphate	-3.3
Glycerol-3-phosphate + H ₂ O → glycerol + phosphate	-2.2

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The Hydrolysis of ATP

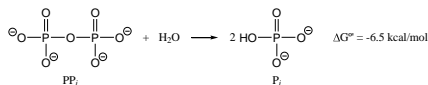
- Compounds that liberate a large amount of free energy on hydrolysis are called **high-energy compounds**.
- The hydrolysis of ATP to ADP is the principal energy-releasing reaction for ATP. Some other hydrolysis reaction occur under some conditions, such as the hydrolysis of ATP to adenosine monophosphate, AMP, and pyrophosphate, PP_i:



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The Hydrolysis of ATP

- This is usually followed by immediate hydrolysis of the pyrophosphate, which releases even more energy:



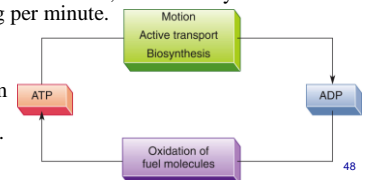
- The hydrolyses of ATP and related compounds are summarized below:

Reaction	ΔG°' (kcal/mol)
ATP + H ₂ O → ADP + P _i + H ⁺	-7.3
ATP + H ₂ O → AMP + PP _i + 2H ⁺	-8.0
PP _i + H ₂ O → 2P _i	-6.5
ADP + H ₂ O → AMP + P _i + H ⁺	-7.3

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The ATP-ADP Cycle

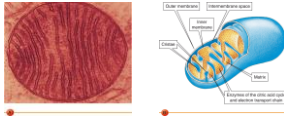
- ATP functions as an immediate donor of free energy rather than as an energy storage medium.
 - The turnover rate of ATP is very high: typically, an ATP molecule is hydrolyzed within 1 minute after its formation.
 - At rest, a human body hydrolyzes ATP at the rate of about 40 kg every 24 hours.
 - During strenuous exertion, this rate may be as high as 0.5 kg per minute.
- ATP must be continuously regenerated from ADP if cellular work is to occur.



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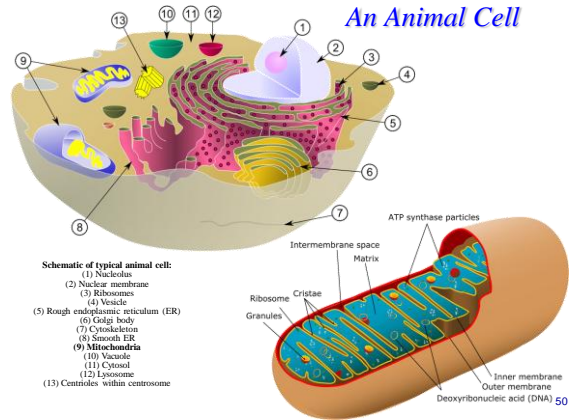
Mitochondria

- The **mitochondrion** is the powerhouse of the cell. It is the organelle where many of the reactions of the common catabolic pathway occur. It consists of an outer membrane, which surrounds a inner membrane.
 - The folds of the inner membrane are called *cristae*.
 - The space that surrounds them is the *matrix*.
- The enzymes for ATP synthesis (electron transport and oxidative phosphorylation) are located on the cristae. The enzymes for the citric acid cycle are found within the matrix, near the surface of the inner membrane.



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An Animal Cell

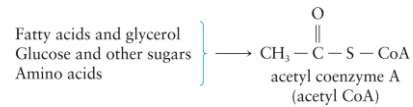


- Schematic of typical animal cell:
- Nucleolus
 - Nuclear membrane
 - Ribosomes
 - Vesicle
 - Rough endoplasmic reticulum (ER)
 - Gold body
 - Cytoskeleton
 - Smooth ER
 - Mitochondria
 - Vacuole
 - Cytosol
 - Lysosome
 - Centrioles within centrosome

Coenzyme A

- Coenzymes** are weakly-bound organic groups that participate in enzyme-catalyzed reactions, often by acting as shuttle systems for the transfer of chemical groups (e.g., hydrogen transport). Many important coenzymes are formed from vitamins.
- Coenzyme A** is a central compound in metabolism. It is part of **acetyl coenzyme A (acetyl CoA)**, the substance formed from all foods as they pass through Stage II of catabolism.

Important Coenzymes in the Common Catabolic Pathway

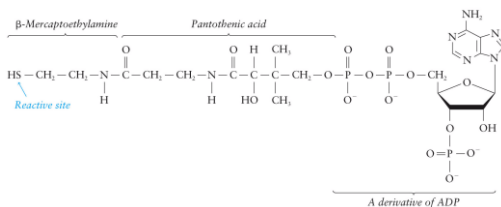


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Coenzyme A

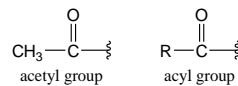
- Components of coenzyme A:
 - vitamin B₅, pantothenic acid, in the center.
 - a phosphate derivative of ADP
 - β -mercaptoethylamine, which puts a reactive sulfhydryl group ($-\text{SH}$) at the end of the molecule ($\text{CoA}-\text{SH}$).



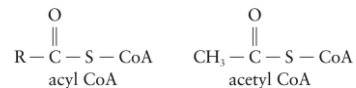
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Coenzyme A

- The letter A is included in the name Coenzyme A to signify its participation in the transfer of acetyl groups, but Coenzyme A transfers all acyl groups. This is important in fatty acid oxidation and synthesis.



- Acyl groups are linked to coenzyme A through the sulfur atom in a **thioester bond**:



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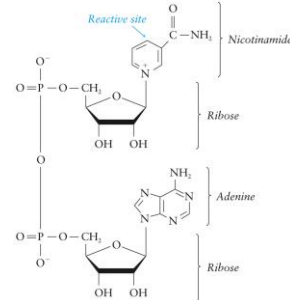
Electron Transporters

- Most of energy for ATP synthesis is released when the oxygen we breathe is reduced.
 - Oxygen accepts electrons and H⁺, producing water.
 - The electrons come from the oxidation of fuel molecules, but are not transferred directly to the oxygen.
 - These substrates first transfer the electrons to special coenzyme carriers.
 - The reduced forms of these coenzymes transfer the electrons to oxygen through the reactions of the electron transport chain.
 - ATP is formed from ADP and P_i as a result of this flow of electrons.

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Nicotinamide Adenine Dinucleotide (NAD⁺)

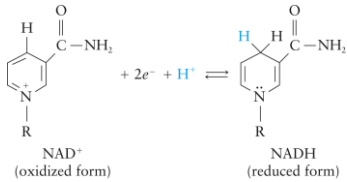
- **Nicotinamide adenine dinucleotide (NAD⁺)**, is an electron transporter which is a derivative of ADP and the vitamin nicotinamide (B₃).



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Nicotinamide Adenine Dinucleotide (NAD⁺)

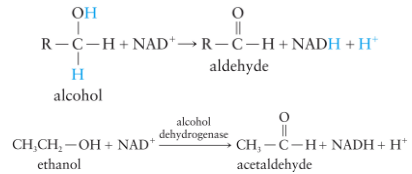
- The reactive site of NAD⁺ is in the nicotinamide portion.
 - When oxidizing a substrate, the nicotinamide ring accepts two electrons and one proton, forming the reduced coenzyme NADH:



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Nicotinamide Adenine Dinucleotide (NAD⁺)

- A typical cellular reaction in which NAD⁺ serves as an electron acceptor is the oxidation of an alcohol:



- In this reaction, one hydrogen atom of the alcohol substrate is directly transferred to NAD⁺, whereas the other appears in solution as H⁺. Both electrons lost by the alcohol have been transferred to the nicotinamide ring in NADH.

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Nicotinamide Adenine Dinucleotide (NAD⁺)

- Biochemical reactions involving coenzymes are often written more concisely:

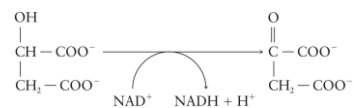


- This notation emphasizes the oxidation reaction and the involvement of the coenzyme.

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Example: Biochemical Reactions

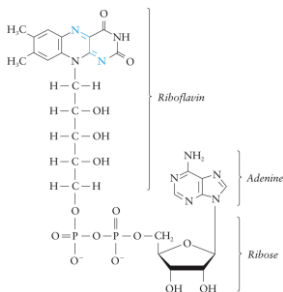
- Write the following reaction in the normal form of a chemical equation:



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Flavin Adenine Dinucleotide (FAD)

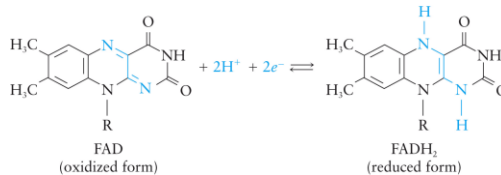
- Flavin adenine dinucleotide (FAD) is another major electron carrier. It is a derivative of ADP and the vitamin riboflavin.



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Flavin Adenine Dinucleotide (FAD)

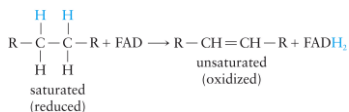
- The active site is located within the riboflavin ring system. Unlike NAD^+ , FAD accepts both of the hydrogen atoms lost by the substrate, forming the reduced species FADH_2 :



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Flavin Adenine Dinucleotide (FAD)

- The substrates for reactions involving FAD are often those in which a $-\text{CH}_2-\text{CH}_2-$ portion of the substrate is oxidized to a double bond:



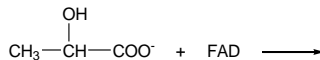
Specific example:



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Example: Biochemical Reactions

- Complete the following reactions:



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The End

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