Energy Flow in the Life of A Cell
Energy

• Energy is the capacity to do work
  ▪ Potential energy is stored energy
    • Includes chemical energy stored in biological molecules and other molecules such as fossil fuels, gravitational energy stored in water behind a dam, and energy stored in a wound clock spring
  ▪ Kinetic energy is the energy of movement
    • Includes radiant energy from waves of light and x-rays, heat (thermal energy, the motion of molecules or atoms), and electricity
The Laws of Thermodynamics

• The laws of thermodynamics describe the basic properties of energy

  1) The first law of thermodynamics states that energy can neither be created nor destroyed

     • The total energy in a closed system remains constant
     • Energy can change form
     • The first law is often called the law of conservation of energy
The Laws of Thermodynamics

• The laws of thermodynamics describe the basic properties of energy

2) The second law of thermodynamics states that when energy is converted from one form to another, the amount of useful energy decreases

• Entropy: the tendency toward an increase in randomness, disorder, and low-level energy
Energy

• Living things use the energy of sunlight to create the low-entropy conditions of life
  • Living things use a continuous input of solar energy to synthesize complex molecules and maintain orderly structures
Energy Transfer

• Chemical reaction: a process that breaks or forms chemical bonds
  1) These reactions convert reactants to products
  2) A reaction is exergonic (exothermic) if it releases energy
  3) A reaction is endergonic (endothermic) if it requires a net input of energy
Energy Transfer

• Exergonic reactions release energy
  ▪ In an exergonic reaction, the reactants have more energy than the products and energy is released
  ▪ The reaction happens spontaneously

• Endergonic reactions require a net input of energy
  ▪ In this reaction, the products of a chemical reaction contain more energy than the reactants
  ▪ An input of energy is required for the reaction to proceed
  ▪ The reaction does not happen spontaneously
Energy Transfer

• Activation energy
  ▪ All chemical reactions require activation energy (an input of energy) to begin
    • The energy of activation provides the “push” to get chemical reactions started
      ▪ A rock at the top of a hill will not roll down unless someone or something gives it a push to start it rolling. Similarly, chemical reactions need a “push” to force the reaction to happen.
    ▪ Activation energy overcomes the repulsive electrical forces between electron shells so that they can move close enough together to react
Energy Transport within Cells

• Energy-carrier molecules are high-energy molecules that move energy within cells

• Electron carriers transport energy in the form of electrons
  ▪ Common electron carriers are nicotinamide adenine dinucleotide (NAD\textsuperscript{+}) and flavin adenine dinucleotide (FAD)
Energy Transport within Cells

• ATP and electron carriers transport energy within cells

  ▪ Adenosine triphosphate (ATP) is the “energy currency” of living cells because it provides energy for a wide variety of endergonic reactions
  ▪ ATP is composed of a nitrogen-containing base, adenine, the sugar ribose, and three phosphate groups
  ▪ ATP can be synthesized from adenosine diphosphate (ADP) and phosphate, using the energy released by exergonic reactions such as glucose breakdown
  ▪ ATP can be broken down to ADP and phosphate to provide energy for endergonic reactions
  ▪ ATP is not a long-term energy-storage molecule
Energy Transport within Cells

• Coupled reactions link exergonic with endergonic reactions
  ▪ Living organisms use the energy from exergonic reactions to drive endergonic reactions
  ▪ Exergonic and endergonic reactions may occur in different locations
  ▪ Energy is transferred from place to place by energy-carrier molecules such as ATP
  ▪ Example: During photosynthesis, plants use the sunlight (exothermic reactions in the sun’s core) to drive endothermic synthesis of high-energy glucose molecules from lower-energy reactants (carbon dioxide and water)
Enzymes Promote Biochemical Reactions

• Catalysts reduce the energy required to start a reaction
  ▪ Catalysts work by reducing the amount of activation energy required by a reaction
  ▪ Three principles apply to all catalysts
    1) Catalysts speed up chemical reactions by lowering the activation energy
    2) Catalysts can speed up only exergonic reactions that would occur spontaneously if the activation energy is overcome
    3) Catalysts are not consumed or permanently changed by the reactions they promote
  ▪ Catalysts cannot make endergonic reactions happen spontaneously
Enzymes Promote Biochemical Reactions

• Enzymes are biological catalysts
  ▪ In living organisms, enzymes are usually proteins
    • Enzymes are usually very specific for a particular chemical reaction
  ▪ Enzymes, like all catalysts, lower activation energy
Enzymes Promote Biochemical Reactions

• The structure of enzymes allows them to catalyze specific reactions
  ▪ Because of its three-dimensional shape, an enzyme has a “pocket,” or active site into which a specific reactant molecule, or substrate, can enter
    • Only certain molecules called substrates can enter the active site
  ▪ There are three steps in the cycle of enzyme–substrate interactions
    1) Substrate(s) enter the active site in a specific orientation
    2) Substrate(s) and active site change shape, promoting the reaction
    3) Product is released; enzyme is ready for new substrate(s)
Enzyme Regulation

• The metabolism of a cell is the sum of its chemical reactions
  ▪ These reactions are linked in sequences called metabolic pathways

• Cells regulate metabolic pathways by controlling enzyme synthesis and activity
  ▪ The rate of enzyme-catalyzed reactions depends on the concentration of enzymes and substrates
  ▪ Genes that code for enzymes may be turned on or off
    • Cells can regulate enzymes by regulating the genes that dictate the production of the enzyme
  ▪ Some enzymes are synthesized in inactive forms
    • Cells activate them only when needed
Enzyme Regulation

• Cells regulate metabolic pathways by controlling enzyme synthesis and activity
  ▪ Enzyme activity may be controlled by competitive or noncompetitive inhibition
    • Cells must regulate enzyme function
      ▪ Remember that substrates must bind to the active site
    • In competitive inhibition, a substance competes with the substrate for the active site of the enzyme
    • In noncompetitive inhibition, a molecule binds to a site on the enzyme distinct from the active site
      ▪ When this binding occurs, the active site is distorted and the substrate can no longer bind
Enzyme Regulation

• Cells regulate metabolic pathways by controlling enzyme synthesis and activity
  ▪ Some enzymes are controlled by allosteric regulation
    • In allosteric regulation, certain enzymes have their activity enhanced or inhibited by regulator molecules
      ▪ Feedback inhibition is a type of allosteric regulation where the enzyme is inhibited by a regulator molecule that is the end product of a metabolic pathway
Enzyme Regulation

- Poisons, drugs, and environmental conditions influence enzyme activity
  - Some poisons and drugs are competitive or noncompetitive inhibitors of enzymes
    - Some inhibitors bind permanently to the enzyme
Enzyme Regulation

• Competitive inhibition
  - A substance that is not the enzyme’s normal substrate can also bind to the active site of the enzyme
    - The other substance competes with the normal substrate for the active site
  - To increase the rate of reaction, even in the presence of the inhibitor, more substrate needs to be added

• Noncompetitive inhibition
  - A molecule binds to a site on the enzyme that is distinct from the active site
    - This distorts the enzyme’s active site, slowing down reactions
Enzyme Regulation

• The activity of enzymes is influenced by their environment
  ▪ When conditions fall outside a particular range, the enzyme is denatured
  ▪ Environmental factors that can influence enzyme activity include:
    • pH
    • Temperature
    • Salt concentration
Enzyme Regulation

• Example: Cellular enzymes work optimally at a pH level of 7.3. Most human enzymes work optimally at 37°C (98.6°F).
  ▪ The reaction might go slightly faster if the temperature is increased to 38°C, remaining at the same pH.
Enzyme Regulation

• When an enzyme’s conditions fall outside the normal range, it becomes denatured – it loses its exact three-dimensional shape required for it to function properly
  ▪ Example: Normally, a certain enzyme has maximum activity at 57°C, but once it has been heated to 150°C and then cooled back down to 57°C, the enzyme is no longer active. (The enzyme was heated up too much, out of its normal range)
  • When the enzyme was heated, its three-dimensional shape was distorted and changed. The active site of the enzyme is no longer able to bind to the substrates because the substrates are specific for the original shape. The reaction will no longer happen with this enzyme.