What Is Energy?

• Capacity to do work

• Forms of energy
  – Potential energy
  – Kinetic energy
  – Chemical energy
What Can Cells Do with Energy?

• Energy inputs become coupled to energy-requiring processes

• Cells use energy for:
  – Chemical work
  – Mechanical work
  – Electrochemical work
First Law of Thermodynamics

- The total amount of energy in the universe remains constant

- Energy can undergo conversions from one form to another, but it cannot be created or destroyed
Entropy

• Measure of degree of disorder in a system

• The world of life can resist the flow toward maximum entropy only because it is resupplied with energy from the sun
Second Law of Thermodynamics

- No energy conversion is ever 100 percent efficient
- The total amount of energy is flowing from high-energy forms to forms lower in energy
One-Way Flow of Energy

• The sun is life’s primary energy source

• Producers trap energy from the sun and convert it into chemical bond energy

• All organisms use the energy stored in the bonds of organic compounds to do work
Endergonic Reactions

- Energy input required
- Product has more energy than starting substances

Glucose, a high energy product

ENERGY IN

Glucose, a high energy product

Low energy starting substances

6 + 6O₂

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Exergonic Reactions

- Energy is released
- Products have less energy than starting substance

Glucose, a high energy starting substance + 6O₂ → low energy products

ENERGY OUT

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The Role of ATP

• Cells “earn” ATP in exergonic reactions
• Cells “spend” ATP in endergonic reactions
ATP/ADP Cycle

• When adenosine triphosphate (ATP) gives up a phosphate group, adenosine diphosphate (ADP) forms

• ATP can re-form when ADP binds to inorganic phosphate or to a phosphate group that was split from a different molecule

• Regenerating ATP by this ATP/ADP cycle helps drive most metabolic reactions
Participants in Metabolic Reactions

- Reactants
- Intermediates
- Products
- Energy carriers
- Enzymes
- Cofactors
- Transport proteins
Chemical Equilibrium

- At equilibrium, the energy in the reactants equals that in the products
- Product and reactant molecules usually differ in energy content
- Therefore, at equilibrium, the amount of reactant almost never equals the amount of product
Chemical Equilibrium
Redox Reactions

- Cells release energy efficiently by electron transfers, or oxidation-reduction reactions ("redox" reactions)
- One molecule gives up electrons (is oxidized) and another gains them (is reduced)
- Hydrogen atoms are commonly released at the same time, thus becoming H⁺
Electron Transfer Chains

• Arrangement of enzymes, coenzymes, at cell membrane
• As one molecule is oxidized, next is reduced
• Function in aerobic respiration and photosynthesis
Uncontrolled vs. Controlled Energy Release

**Uncontrolled Energy Release**

- Explosive release of energy as heat that cannot be harnessed for cellular work

**Controlled Energy Release**

- Energy input splits hydrogen into protons ($H^+$) and electrons
- Some released energy is harnessed for cellular work (e.g., making ATP)
- Spent electrons and free oxygen form water.

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\begin{align*}
\text{H}_2 & \quad 1/2 \text{O}_2 \\
\rightarrow & \\
\text{H}_2\text{O} & \\
\end{align*}
```
Metabolic Pathways

• Defined as enzyme-mediated sequences of reactions in cells
  – Biosynthetic (anabolic) – ex: photosynthesis
  – Degradative (catabolic) – ex: aerobic respiration
Enzyme Structure and Function

• Enzymes are catalytic molecules

• They speed the rate at which reactions approach equilibrium
Four Features of Enzymes

1) Enzymes do not make anything happen that could not happen on its own. They just make it happen much faster.

2) Reactions do not alter or use up enzyme molecules.
Four Features of Enzymes

3) The same enzyme usually works for both the forward and reverse reactions.

4) Each type of enzyme recognizes and binds to only certain substrates.
Activation Energy

- For a reaction to occur, an energy barrier must be surmounted.
- Enzymes make the energy barrier smaller.
How Catalase Works

a. Hydrogen peroxide (H$_2$O$_2$) enters a cavity in catalase. It is the substrate for a reaction aided by an iron molecule in a heme group (red).

b. A hydrogen of the peroxide is attracted to histidine, an amino acid projecting into the cavity. One oxygen binds the iron.

c. This binding destabilizes the peroxide bond, which breaks. Water (H$_2$O) forms. In a later reaction, another H$_2$O$_2$ will pull the oxygen from iron, which will then be free to act again.
Induced-Fit Model

• Substrate molecules are brought together
• Substrates are oriented in ways that favor reaction
• Active sites may promote acid-base reactions
• Active sites may shut out water
Factors Influencing Enzyme Activity

- Temperature
- pH
- Salt concentration
- Allosteric regulators
- Coenzymes and cofactors
Enzyme Helpers

- Cofactors
  - Coenzymes
    - $\text{NAD}^+$, $\text{NADP}^+$, FAD
    - Accept electrons and hydrogen ions; transfer them within cell
    - Derived from vitamins
  - Metal ions
    - Ferrous iron in cytochromes
Allosteric Activation

Allosteric activator

Vacant allosteric binding site

Enzyme active site

Active site cannot bind substrate

Active site altered, can bind substrate
Allosteric Inhibition

allosteric inhibitor

allosteric binding site vacant; active site can bind substrate

active site altered, can’t bind substrate
Feedback Inhibition

A cellular change, caused by a specific activity, shuts down the activity that brought it about.

SUBSTRATE

END PRODUCT (tryptophan)
Effect of Temperature

- Small increase in temperature increases molecular collisions, reaction rates
- High temperatures disrupt bonds and destroy the shape of active site
Effect of pH

![Graph showing the effect of pH on enzyme activity.](chart.png)
Cell Membranes Show Selective Permeability

- Oxygen, carbon dioxide, and other small, nonpolar molecules; some water molecules
- Glucose and other large, polar, water-soluble molecules; ions (e.g., H+, Na+, K+, Ca++, Cl–); water molecules
Concentration Gradient

• Means the number of molecules or ions in one region is different than the number in another region

• In the absence of other forces, a substance moves from a region where it is more concentrated to one where it’s less concentrated - “down” gradient
Fluid Mosaic Model

• Membrane is a mosaic of
  – Phospholipids
  – Glycolipids
  – Sterols
  – Proteins

• Most phospholipids and some proteins can drift through membrane
Diffusion

- The net movement of like molecules or ions down a concentration gradient

- Although molecules collide randomly, the net movement is away from the place with the most collisions (down gradient)
Factors Affecting Diffusion Rate

• Steepness of concentration gradient
  – Steeper gradient, faster diffusion
• Molecular size
  – Smaller molecules, faster diffusion
• Temperature
  – Higher temperature, faster diffusion
• Electrical or pressure gradients
Membrane Crossing Mechanisms

- Diffusion across lipid bilayer
- Passive transport
- Active transport
- Endocytosis
- Exocytosis
Membrane Crossing: Overview I

- High Concentration gradient across cell membrane
- Low Diffusion of lipid-soluble Substances across bilayer

Passive transport of water-soluble substances through channel protein; no energy input needed

Active transport through ATPase; requires energy input from ATP

Diagram:

- ATP
- Diffusion of lipid-soluble Substances across bilayer
- Passive transport of water-soluble substances through channel protein; no energy input needed
- Active transport through ATPase; requires energy input from ATP

High Concentration gradient across cell membrane

Low
Membrane Crossing: Overview II

Endocytosis (vesicles in)

Exocytosis (vesicles out)
Transport Proteins

- Span the lipid bilayer
- Interior is able to open to both sides
- Change shape when they interact with solute
- Play roles in active and passive transport
Passive Transport

• Flow of solutes through the interior of passive transport proteins down their concentration gradients

• Passive transport proteins allow solutes to move both ways

• Does not require any energy input
Passive Transport

Glucose binds to a vacant site inside the channel through the transport protein.

When the glucose binding site is again vacant, the protein resumes its original shape.

Bound glucose makes the protein change shape. Part of the channel closes behind the solute. Another part opens in front of it.

Glucose becomes exposed to fluid on other side of the membrane. It detaches from the binding site and diffuses out of the channel.

Glucose, more concentrated outside cell than inside.
Active Transport

- Net diffusion of solute is against concentration gradient
- Transport protein must be activated
- ATP gives up phosphate to activate protein
- Binding of ATP changes protein shape and affinity for solute
Active Transport

• ATP gives up phosphate to activate protein

• Binding of ATP changes protein shape and affinity for solute
Active Transport

An ATP molecule binds to a calcium pump.
Calcium enters a tunnel through the pump, binds to functional groups inside.
The ATP transfers a phosphate group to pump. The energy input will cause pump’s shape to change.
The shape of the pump returns to its resting position.
The shape change permits calcium to be released at opposite membrane surface. A phosphate group and ADP are released.

Glucose, more concentrated outside cell than inside.
Osmosis

• Diffusion of water molecules across a selectively permeable membrane

• Direction of net flow is determined by water concentration gradient

• Side with the most solute molecules has the lowest water concentration
Tonicity

Refers to *relative* solute concentration of two fluids

Hypertonic - having more solutes

Isotonic - having same amount

Hypotonic - having fewer solutes
Tonicity and Osmosis
Increase in Fluid Volume

- **Hypotonic Solution (compartment 1):** Membrane permeable to water but not to solutes.
- **Hypertonic Solution (compartment 2):** Fluid volume increases in compartment 2.
Pressure and Osmosis

• Hydrostatic pressure
  – Pressure exerted by fluid on the walls that contain it
  – The greater the solute concentration of the fluid, the greater the hydrostatic pressure

• Osmotic pressure
  – Amount of pressure necessary to prevent further increase of a solution’s volume
Endocytosis and Exocytosis

- Exocytosis: A cytoplasmic vesicle fuses with the plasma membrane and contents are released outside the cell.
- Endocytosis: A small patch of plasma membrane sinks inward and seals back on itself, forming a vesicle inside the cytoplasm – membrane receptors often mediate this process.
Endocytosis and Exocytosis

a Molecules get concentrated inside coated pits of plasma membrane.

b Endocytic vesicles form from the pits.

c Enclosed molecules are sorted and often released from receptors.

d Many sorted molecules are cycled back to the plasma membrane.

e,f Many other sorted molecules are delivered to lysosomes and stay there or are degraded. Still others are routed to spaces in the nuclear envelope and inside ER membranes, and others to Golgi bodies.