

# Energy and Enzymes

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Energy flow is a universal feature of living systems. It is also at the core of atomic and molecular motions and reactions that characterize nonliving systems as well. Water molecules would not move through the soil, into the plant, up the xylem, into the leaf, and out into the atmosphere without the appropriate energy gradients to drive them. Sunlight, the visible portion of the electromagnetic spectrum, must be captured and converted to chemical energy to allow the synthesis of the complex organic molecules required for life. Indeed, there is not a single physical or chemical process in plants that does not involve energy transformations of some kind. Thus the study of energy in living systems—or bioenergetics—is central to an understanding of plant physiology.

This chapter reviews the basic concepts and principles of energy transformations, called *thermodynamics*, as they apply to plants and other organisms. The concept of free energy provides a framework for understanding the direction of spontaneous processes. The presence of semi-permeable membranes in living cells allows the formation of energy gradients that drive a host of reactions necessary for life. This chapter provides an introduction to basic concepts of membrane transport, which are treated more extensively in later chapters on water relations (Chapters 3 and 4) and solute transport (Chapter 6).

Finally, life would be impossible without the presence of protein catalysts, called *enzymes*, which speed up reactions that would ordinarily occur much too slowly for living processes to be carried out. This chapter therefore ends with a brief overview of protein structure, the mechanisms of enzyme-catalyzed reactions, and the fundamental ways in which enzymes are regulated in living cells.

## ENERGY FLOW THROUGH LIVING SYSTEMS

### ENERGY AND WORK

The First Law: the Total Energy is Always Conserved

The Change in the Internal Energy of a System Represents the Maximum Work It Can Do

Each Type of Energy Is Characterized by a Capacity Factor and a Potential Factor

### THE DIRECTION OF SPONTANEOUS PROCESSES

The Second Law: The Total Entropy Always Increases

A Process Is Spontaneous if  $\Delta S$  for the System and Its Surroundings Is Positive

### FREE ENERGY AND CHEMICAL POTENTIAL

$\Delta G$  Is Negative for a Spontaneous Process at Constant Temperature and Pressure

The Standard Free-Energy Change,  $\Delta G^0$ , Is the Change in Free Energy When the Concentration of Reactants and Products is 1 M

The Value of  $\Delta G$  Is a Function of the Displacement of the Reaction from Equilibrium

The Enthalpy Change Measures the Energy Transferred as Heat

### REDOX REACTIONS

The Free-Energy Change of an Oxidation–Reduction

Reaction Is Expressed as the Standard Redox Potential in Electrochemical Units

(Continued)

## THE ELECTROCHEMICAL POTENTIAL

Transport of and Uncharged Solute against Its  
Concentration Gradient Decreases the Entropy of the  
System

The Membrane Potential Is the Work That Must Be Done to  
Move an Ion from One Side of the Membrane to the  
Other

The Electrochemical-Potential Difference,  $\Delta\tilde{\mu}$ , Includes Both  
Concentration and Electric Potentials

## ENZYMES: THE CATALYSTS OF LIFE

Proteins Are Chains of Amino Acids Joined by Peptide  
Bonds

Protein Structure Is Hierarchical

Enzymes Are Highly Specific Protein Catalysts

Enzymes Lower the Free-Energy Barrier between Substrates  
and Products

A Simple Kinetic Equation Describes an Enzyme-Catalyzed  
Reaction

Enzymes Are Subject to Various Kinds of Inhibition

pH and Temperature Affect the Rate of Enzyme-Catalyzed  
Reactions

Cooperative Systems Increase the Sensitivity to Substrates  
and Are Usually Allosteric

The Kinetics of Some Membrane Transport Processes Can Be  
Described by the Michaelis–Menten Equation

Enzyme Activity Is Often Regulated

## SUMMARY