An Introduction to Photosynthesis

7.1 Photosynthesis Powers Most Life on Earth

- Plants, algae, and some photosynthetic protists and bacteria are **photoautotrophs**, the producers of food consumed by heterotrophic organisms.
- **Heterotrophs** are consumers that feed on plants or animals or decompose organic material.

Checkpoint question What do "self-feeding" photoautotrophs require from the environment to make their own food?

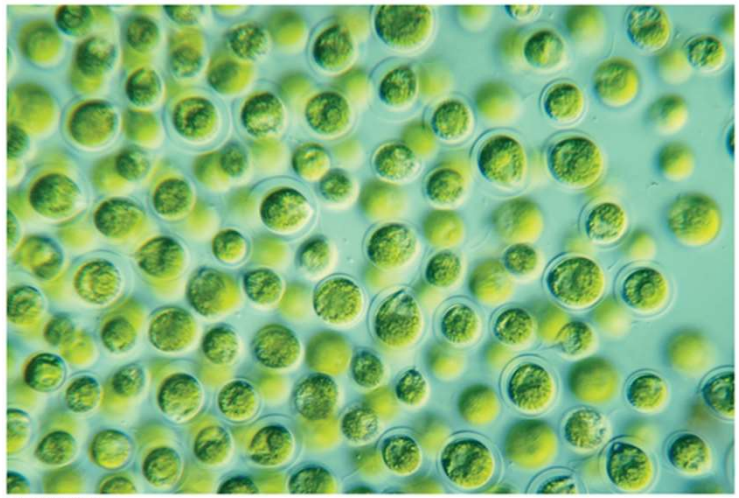
Light, CO_2, and H_2O. (Minerals are also required; you'll learn about the needs of plants in Chapter 32).

7.1 Autotrophs are the producers of the biosphere

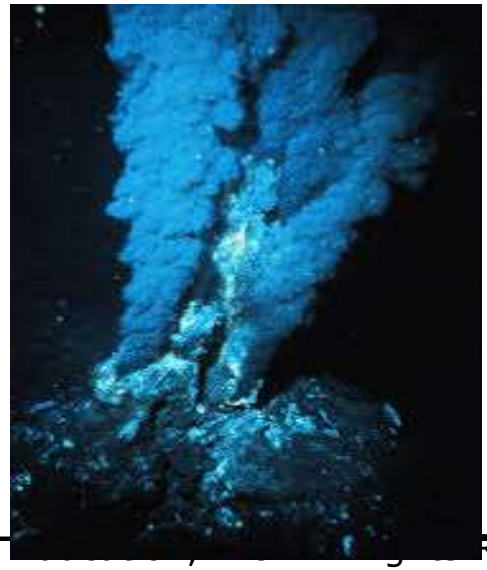
- **Autotrophs**
  - make their own food through the process of **photosynthesis**,
  - convert inorganic matter to organic matter
  - do not usually consume organic molecules derived from other organisms.

7.1 Autotrophs are the producers of the biosphere

- Photoautotrophs use the energy of light to produce organic molecules.



- Chemoautotrophs are prokaryotes that use inorganic chemicals as their energy source.



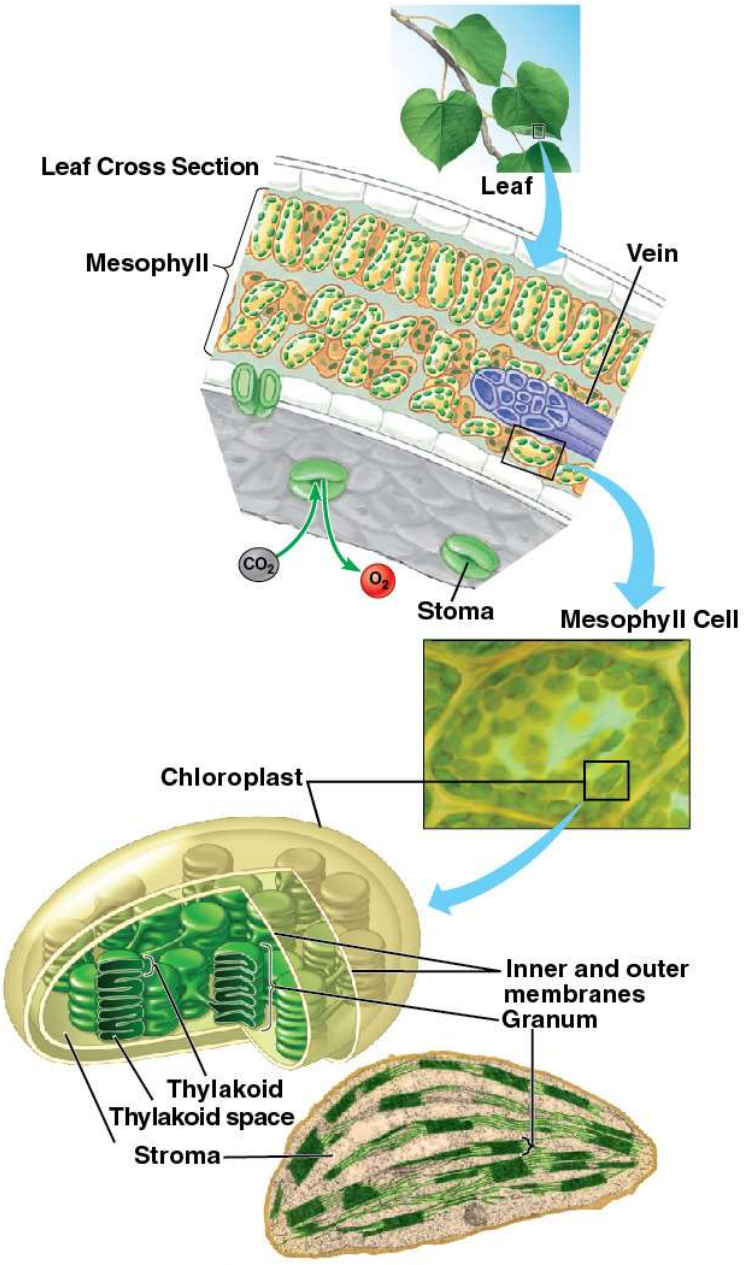
7.2 Photosynthesis Occurs in Chloroplasts in Plant Cells

- Chloroplasts are surrounded by a double membrane and contain stacks of **thylakoids** and a thick fluid called **stroma**.
- **Chlorophyll** is a light-absorbing pigment in the chloroplasts that plays a central role in converting solar energy to chemical energy.

Checkpoint question How do the reactant molecules of photosynthesis reach the chloroplasts in leaves?

CO_2 enters leaves through stomata, and H_2O enters the roots and is carried to leaves through veins.

Figure 7.2



7.3 Scientists Traced the Process of Photosynthesis Using Isotopes (1 of 2)

- Experiments using both heavy and radioactive isotopes helped determine the details of the process of photosynthesis.
- Using a heavy isotope of oxygen, O-18, scientists were able to follow the fate of oxygen atoms during photosynthesis.
- The results were that plants produced O_2 containing O-18 only when supplied with labeled H_2O, never when provided with labeled CO_2.

7.3 Scientists Traced the Process of Photosynthesis Using Isotopes (2 of 2)

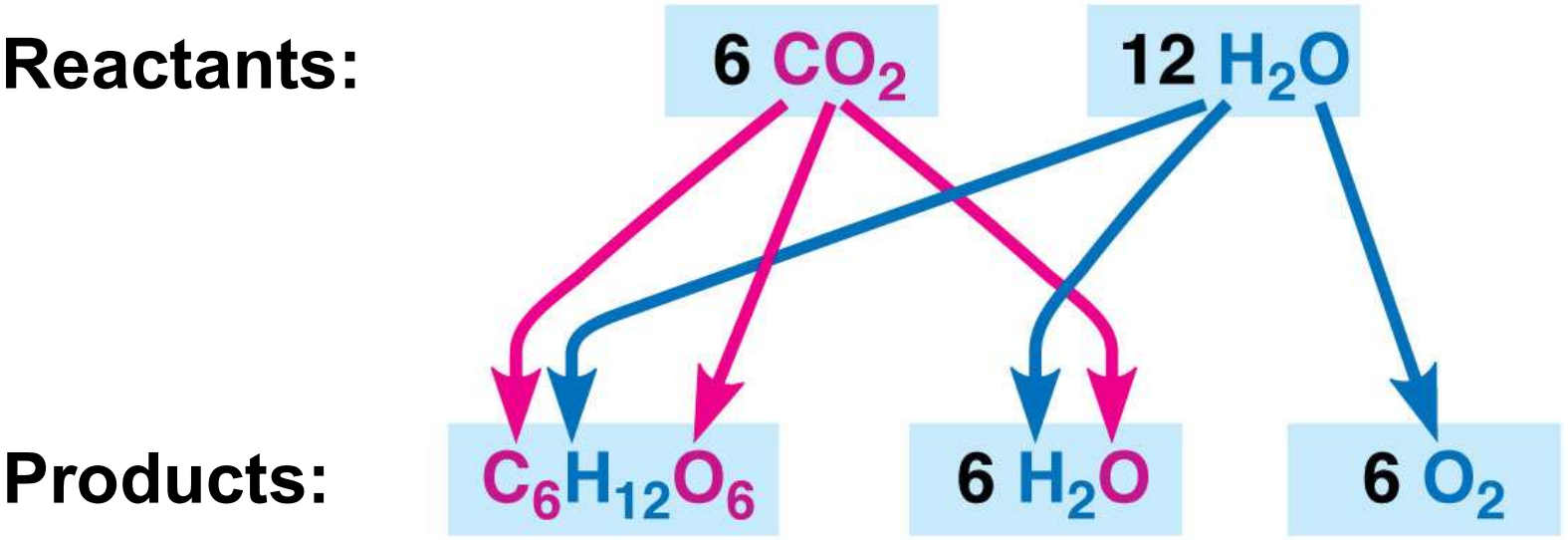
- Experiment 1: $6C\mathbf{O}_2 + 12H_2O \rightarrow C_6H_{12}\mathbf{O}_6 + 6H_2O + 6O_2$
- Experiment 2: $6CO_2 + 12H_2\mathbf{O} \rightarrow C_6H_{12}O_6 + 6H_2O + 6\mathbf{O}_2$

Checkpoint question Photosynthesis produces billions of tons of carbohydrate a year. Where does most of the mass of this huge amount of organic matter come from?

- Mostly from CO_2 in the air, which provides both the carbon and oxygen in carbohydrate. Water supplies only the hydrogen.

7.3 SCIENTIFIC DISCOVERY: Scientists traced the process of photosynthesis using isotopes

- Experiment 1: $6\ CO_2 + 12\ H_2O \rightarrow C_6H_{12}O_6 + 6\ H_2O + 6\ O_2$
- Experiment 2: $6\ CO_2 + 12\ H_2O \rightarrow C_6H_{12}O_6 + 6\ H_2O + 6\ O_2$



7.4 Photosynthesis Is a Redox Process

- Photosynthesis, like respiration, is a redox (oxidation-reduction) process.
  - In photosynthesis, H_2O is oxidized and CO_2 is reduced.
  - Cellular respiration uses redox reactions to harvest the chemical energy stored in a glucose molecule.

Checkpoint question Which redox process, photosynthesis or cellular respiration, is exergonic?

Cellular respiration; photosynthesis

7.5 Photosynthesis Occurs in Two Stages, Which Are Linked by ATP and NADPH

- The **light reactions** occur on and inside the thylakoids, producing ATP and **NADPH** for the **Calvin cycle**, which takes place in the stroma.
- During the Calvin cycle, CO_2 is incorporated into organic compounds in a process called **carbon fixation**.

Checkpoint question For chloroplasts to produce sugar from carbon dioxide in the dark, they would need to be supplied with _____ and _____. ATP; NADPH

Figure 7.5a

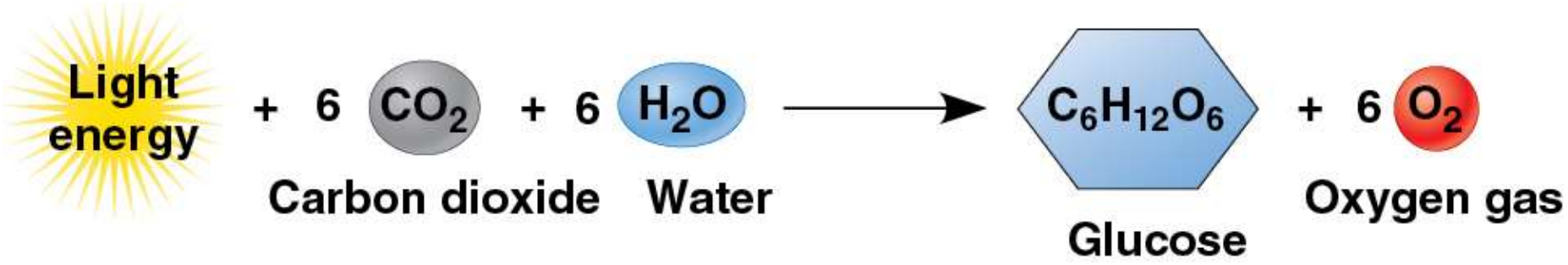
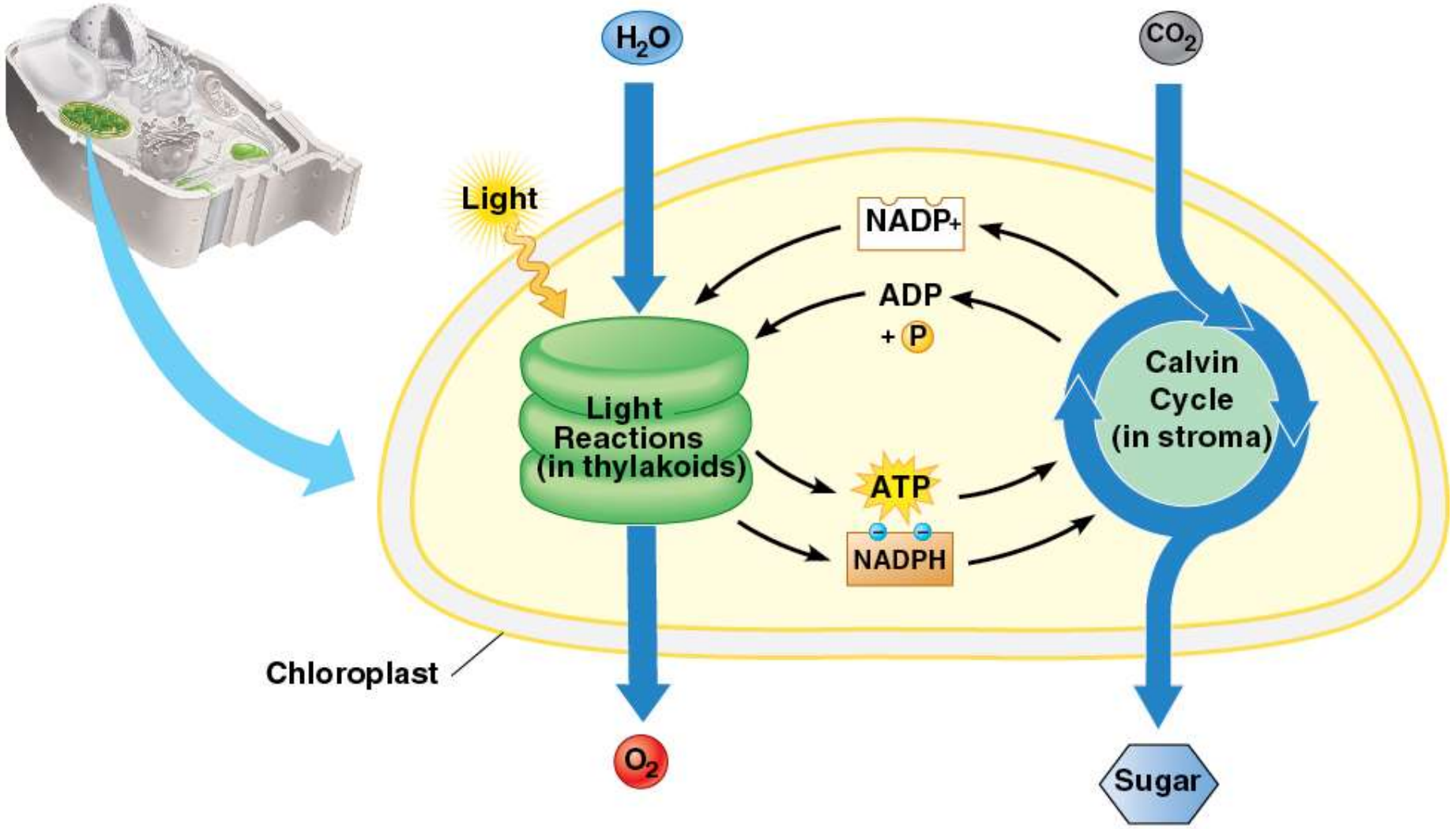


Figure 7.5b_3



The Light Reactions: Converting Solar Energy to Chemical Energy

7.6 Visible Radiation Absorbed by Pigments Drives the Light Reactions

- Sunlight is a type of energy called electromagnetic energy or radiation.
  - Certain **wavelengths** of visible light are absorbed by chlorophyll and other pigments.
  - Carotenoids also function in photoprotection from excessive light.

Checkpoint question What color of light is least effective at driving photosynthesis? Explain.

Green, because it is mostly transmitted and reflected—not absorbed—by photosynthetic pigments.

Figure 7.6a

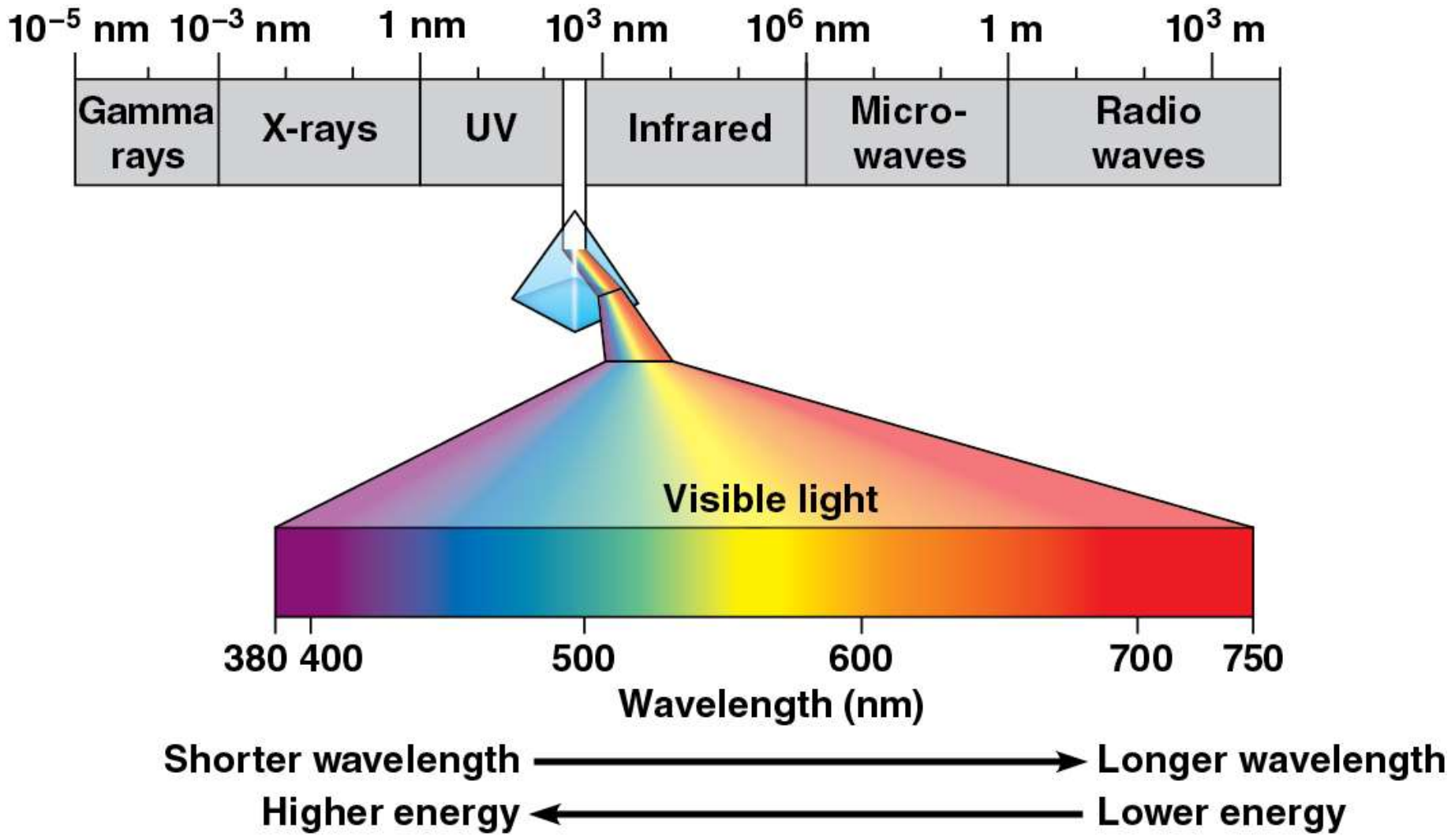
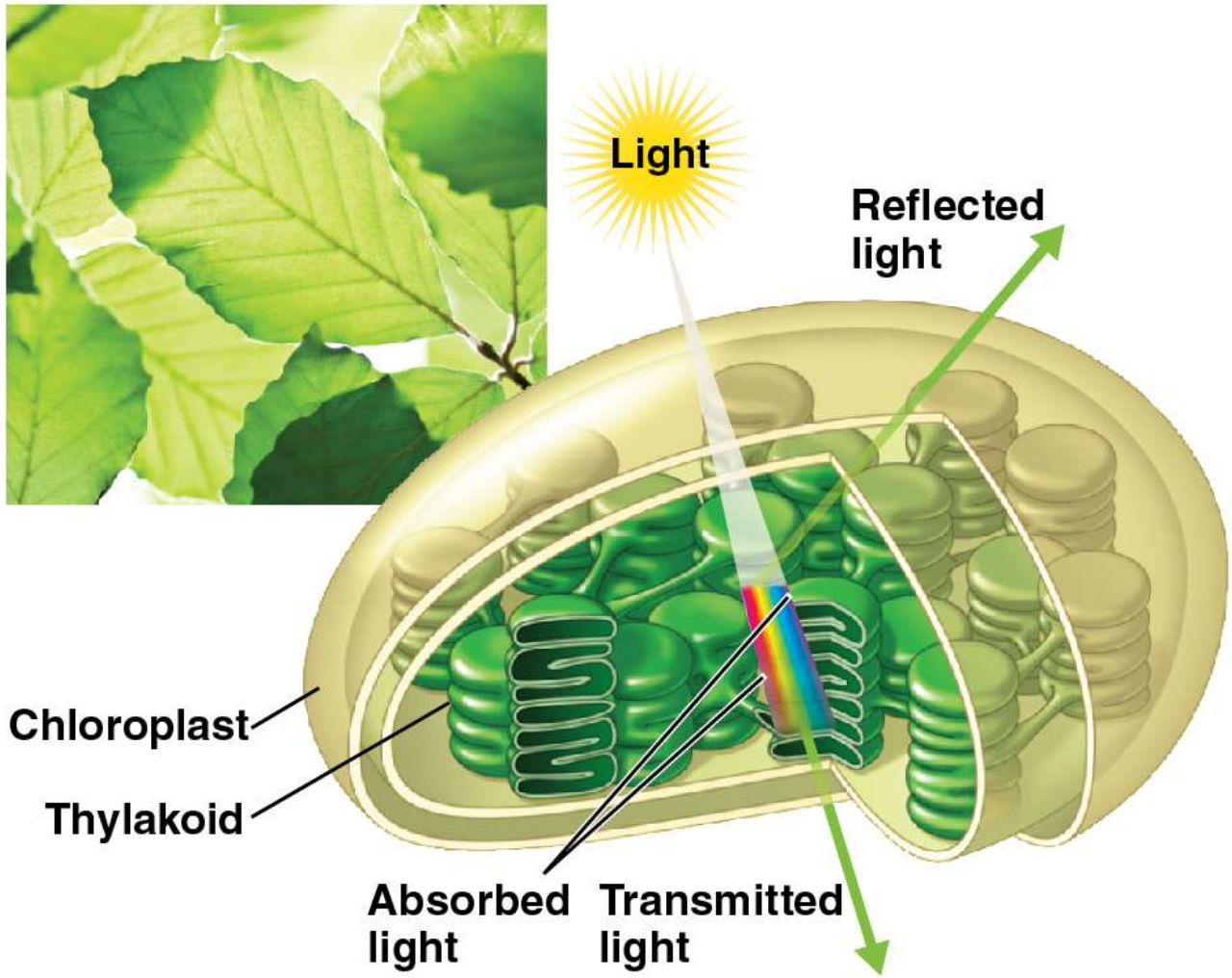


Figure 7.6b



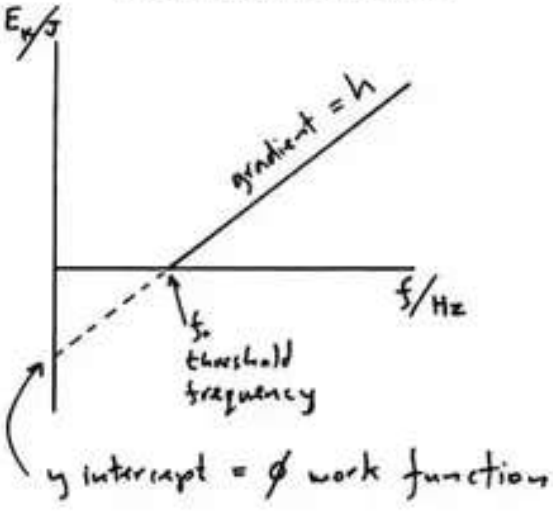
7.7 Photosystems Capture Solar Energy

- Thylakoid membranes contain **photosystems**, each consisting of light-harvesting complexes and a reaction-center complex.
- A primary electron acceptor receives photoexcited electrons from reaction-center chlorophyll *a*.

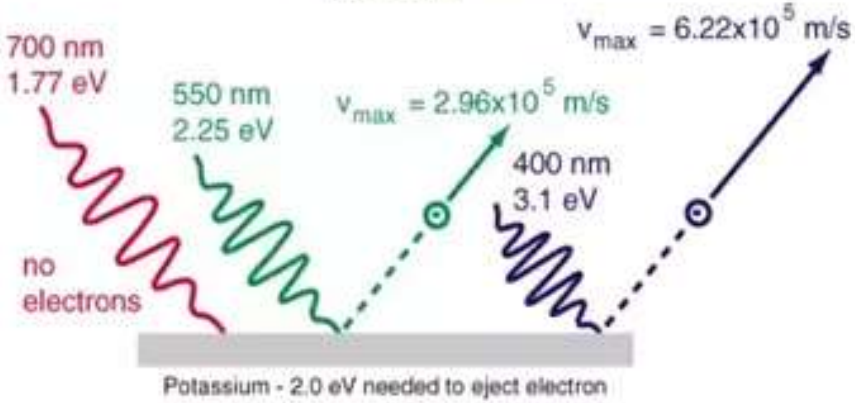
Checkpoint question Compared with a solution of isolated chlorophyll, why do intact chloroplasts not release heat and light when illuminated?

In the chloroplasts, a light-excited electron from the reaction-center chlorophyll molecules is passed to a primary electron acceptor before it can fall back to the ground state.

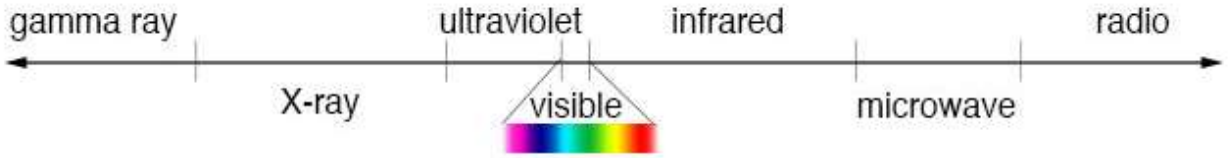
Albert Einstein 1879-1955

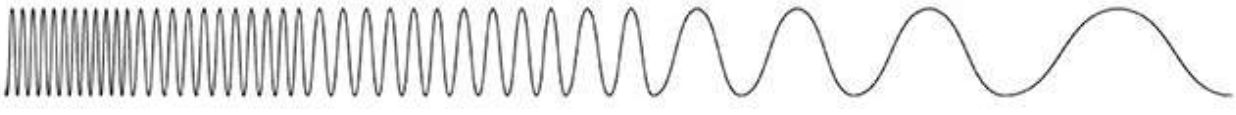


$E_{photon} = h\nu$



Photoelectric effect

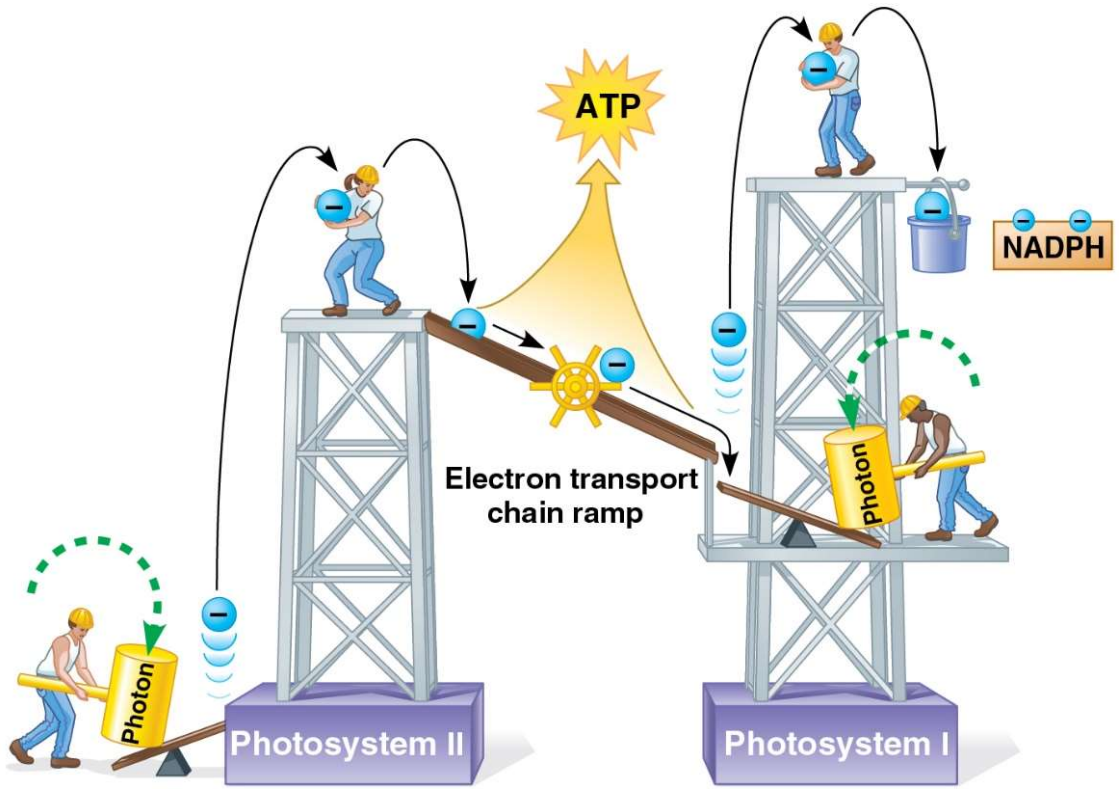




7.8 Two Photosystems Connected by an Electron Transport Chain Convert Light Energy to the Chemical Energy of ATP and NADPH (1 of 2)

- Electrons shuttle from photosystem II to photosystem I, providing energy to make ATP, and then reduce $NADP^+$ to NADPH.
- Photosystem II regains electrons as water is split and O_2 released.

7.8 Two Photosystems Connected by an Electron Transport Chain Convert Light Energy to the Chemical Energy of ATP and NADPH (2 of 2)



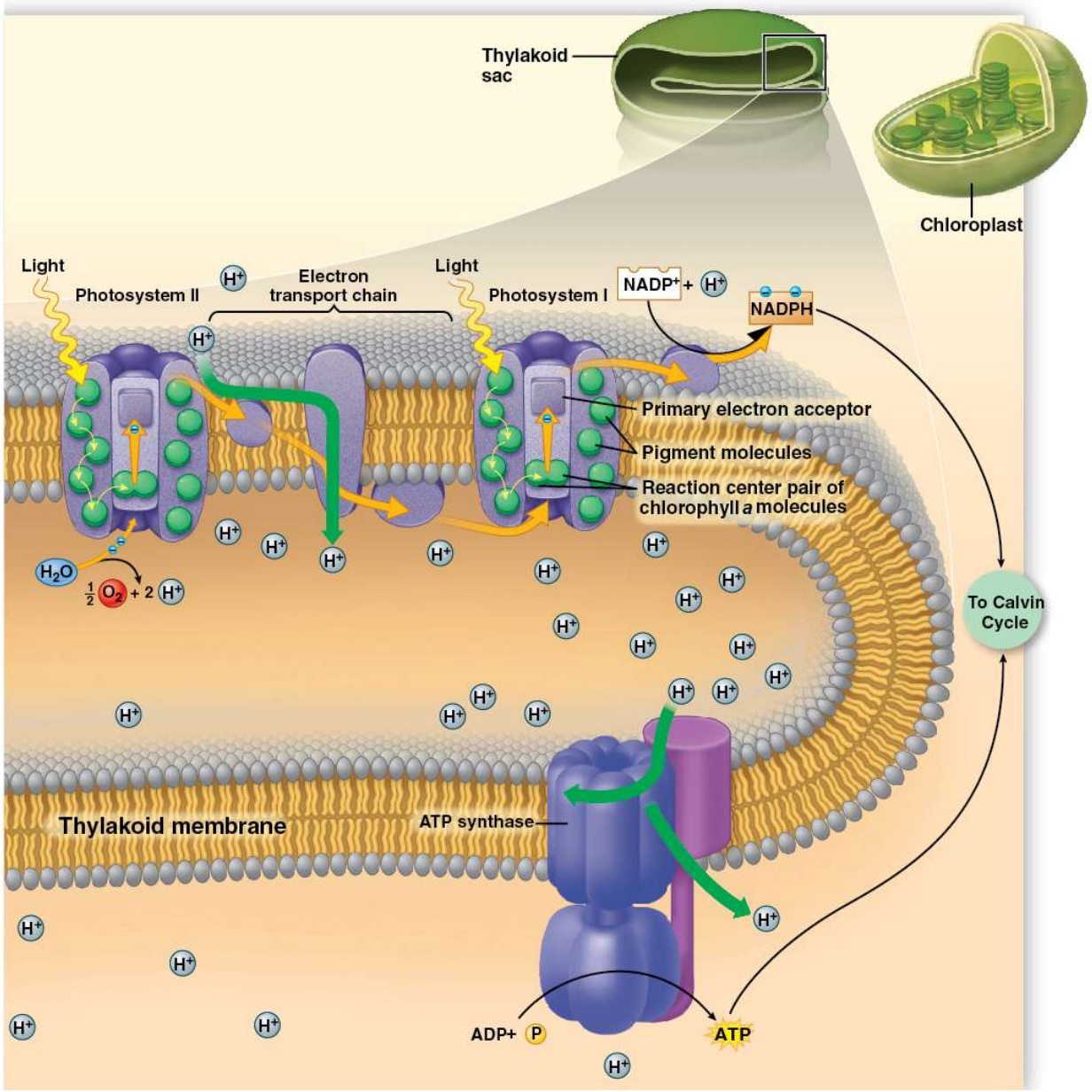
One photon excites an electron from photosystem II, which is passed down an electron transfer chain to photosystem I. A second photon excites an electron from photosystem I, which is then used in the reduction of $NADP^+$ to NADPH.

Checkpoint question Looking at the model of the light reactions in Figure 7.8, explain why two photons of light are required in the movement of electrons from water to NADPH.

7.9 Visualizing the Concept: The Light Reactions Take Place Within the Thylakoid Membranes

- In **photophosphorylation**, the electron transport chain pumps H^+ into the thylakoid space.
- The concentration gradient drives H^+ back through ATP synthase, powering the synthesis of ATP.

Figure 7.9

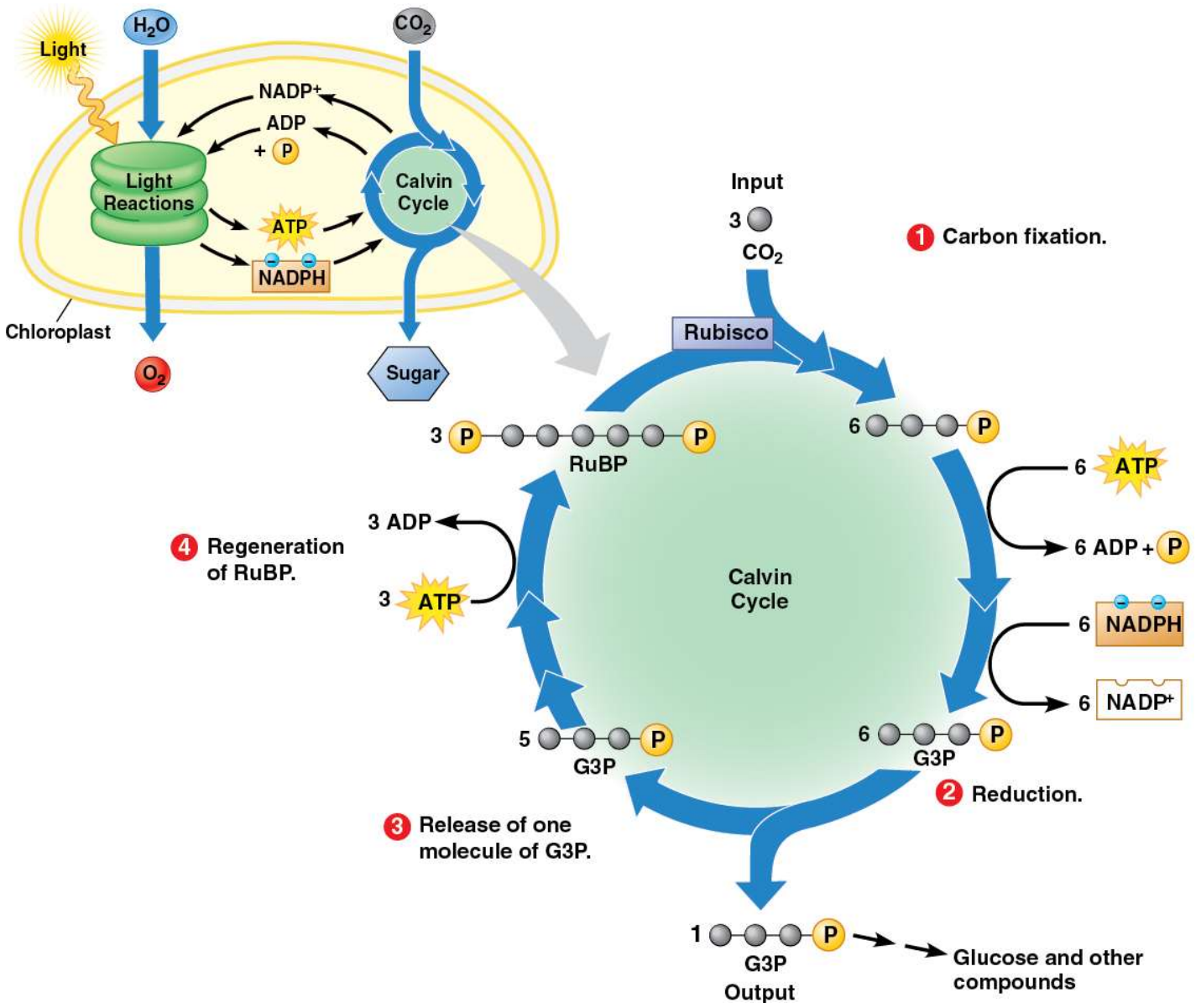


The Calvin Cycle: Reducing CO_2 to Sugar

7.10 ATP and NADPH Power Sugar Synthesis in the Calvin Cycle

- The steps of the Calvin cycle include
  - carbon fixation,
  - reduction,
  - release of G3P, and
  - regeneration of RuBP.
- Using carbon from CO_2, electrons from NADPH, and energy from ATP, the cycle constructs G3P, which is used to build glucose and other organic molecules.

Figure 7.10



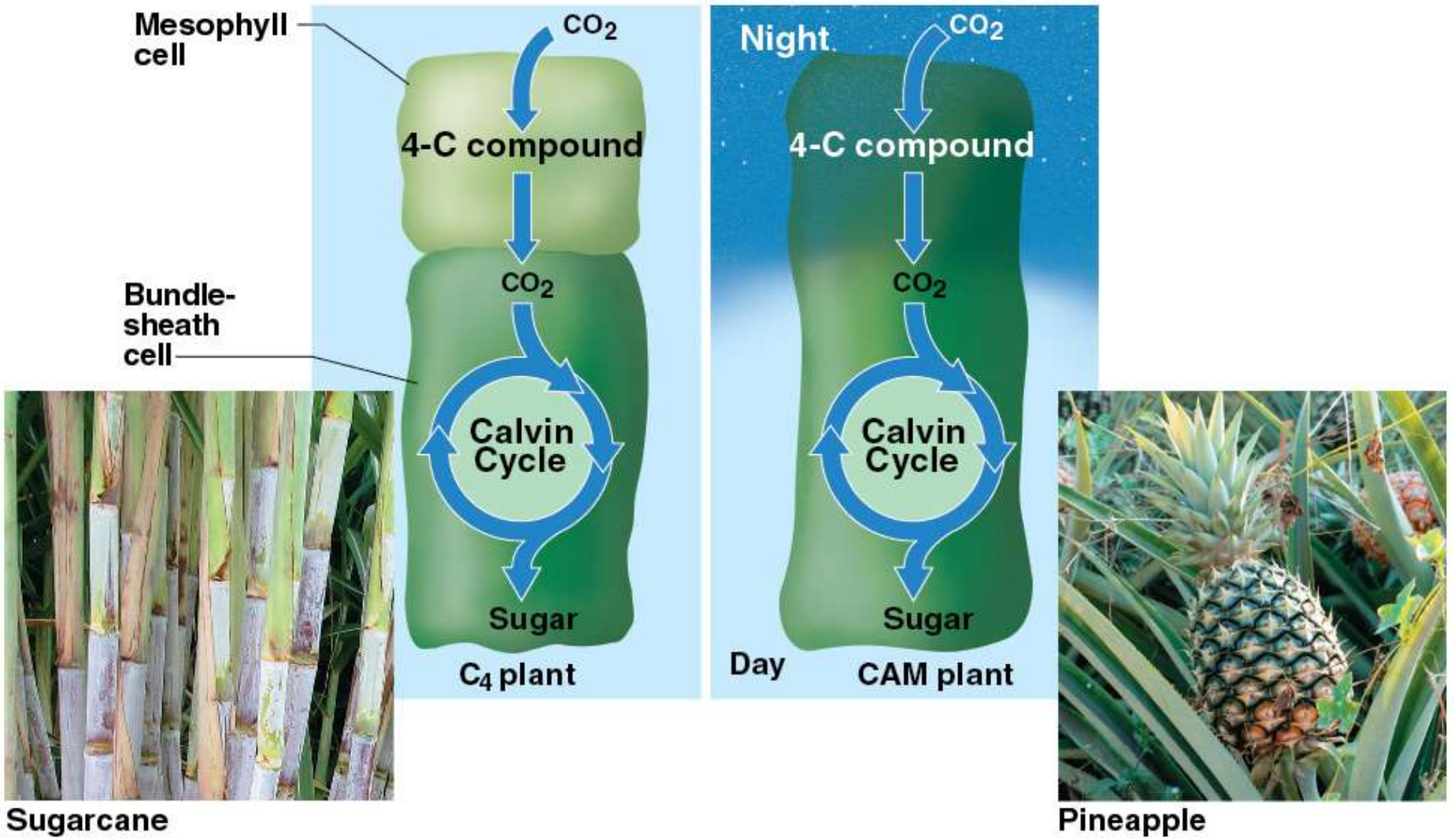
7.11 Evolution Connection: Other Methods of Carbon Fixation Have Evolved in Hot, Dry Climates

- In **C_3 plants**, a drop in CO_2 and rise in O_2 when stomata close divert the Calvin cycle to **photorespiration**.
- **C_4 plants** and **CAM plants** first fix CO_2 into four-carbon compounds that provide CO_2 to the Calvin cycle even when stomata close on hot, dry days.

Checkpoint question Why would you expect photorespiration on a hot, dry day to occur less in C_4 and CAM plants than in C_3 plants?

Because of their initial fixing of carbon, both C_4 and CAM plants can supply rubisco with CO_2. When a C_3 plant closes its stomata, CO_2 levels drop and O_2 rises, making it more likely that rubisco will add O_2 to RuBP.

Figure 7.11



The Global Significance of Photosynthesis

7.12 Photosynthesis Provides Food and O_2 For Almost All Living Organisms (1 of 2)

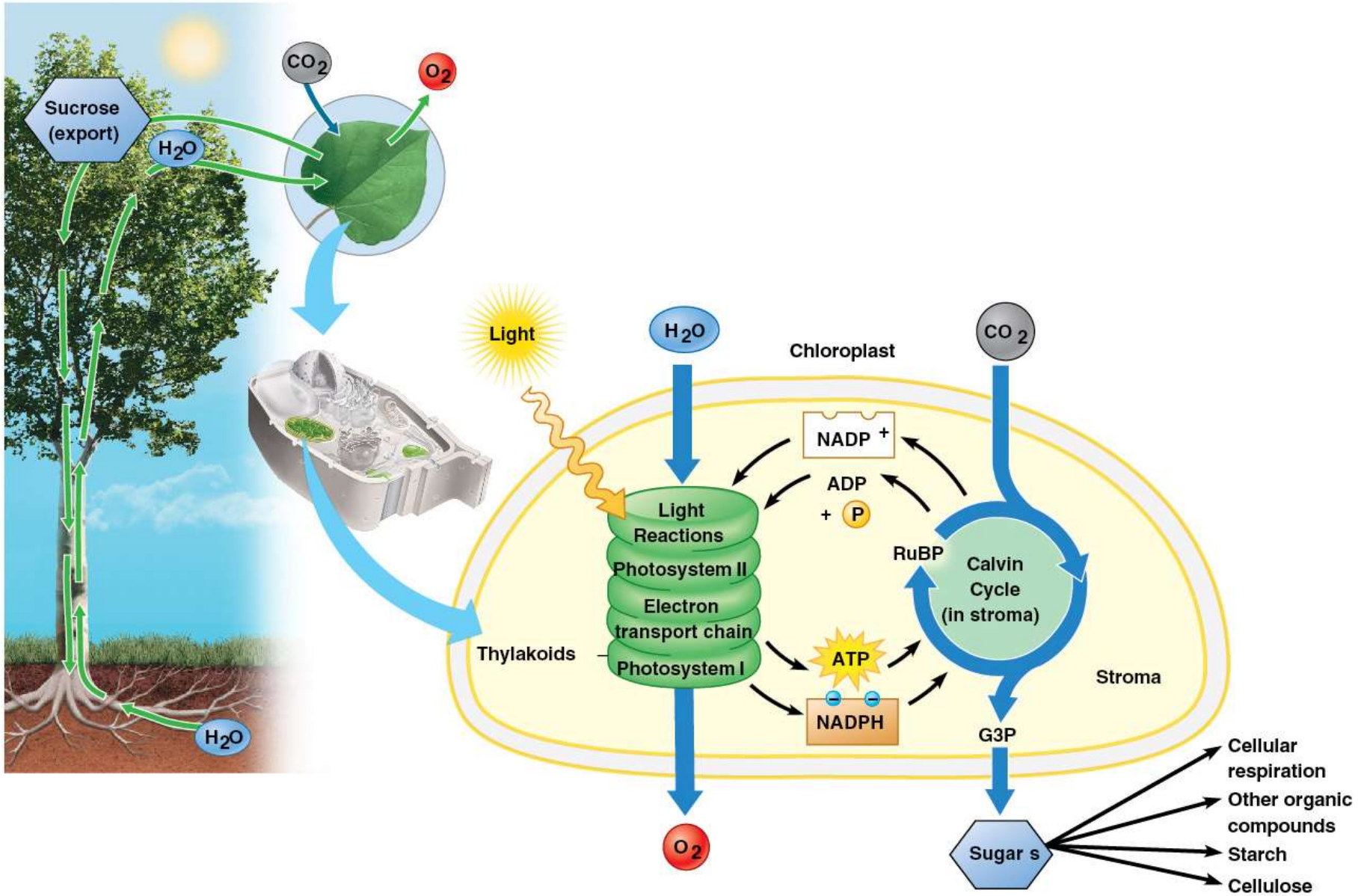
- Cellular respiration in the mitochondria of plant cells uses about 50% of the carbohydrates made by photosynthesis.
- Sugars also serve as starting material for making other organic molecules, such as proteins and lipids.
- Glucose molecules are linked together to make cellulose, the main component of cell walls.

7.12 Photosynthesis Provides Food and O_2 For Almost All Living Organisms (2 of 2)

Checkpoint question Explain this statement: No process is more important to the welfare of life on Earth than photosynthesis.

Photosynthesis is the ultimate source of the food for almost all organisms and the O_2 they need for cellular respiration

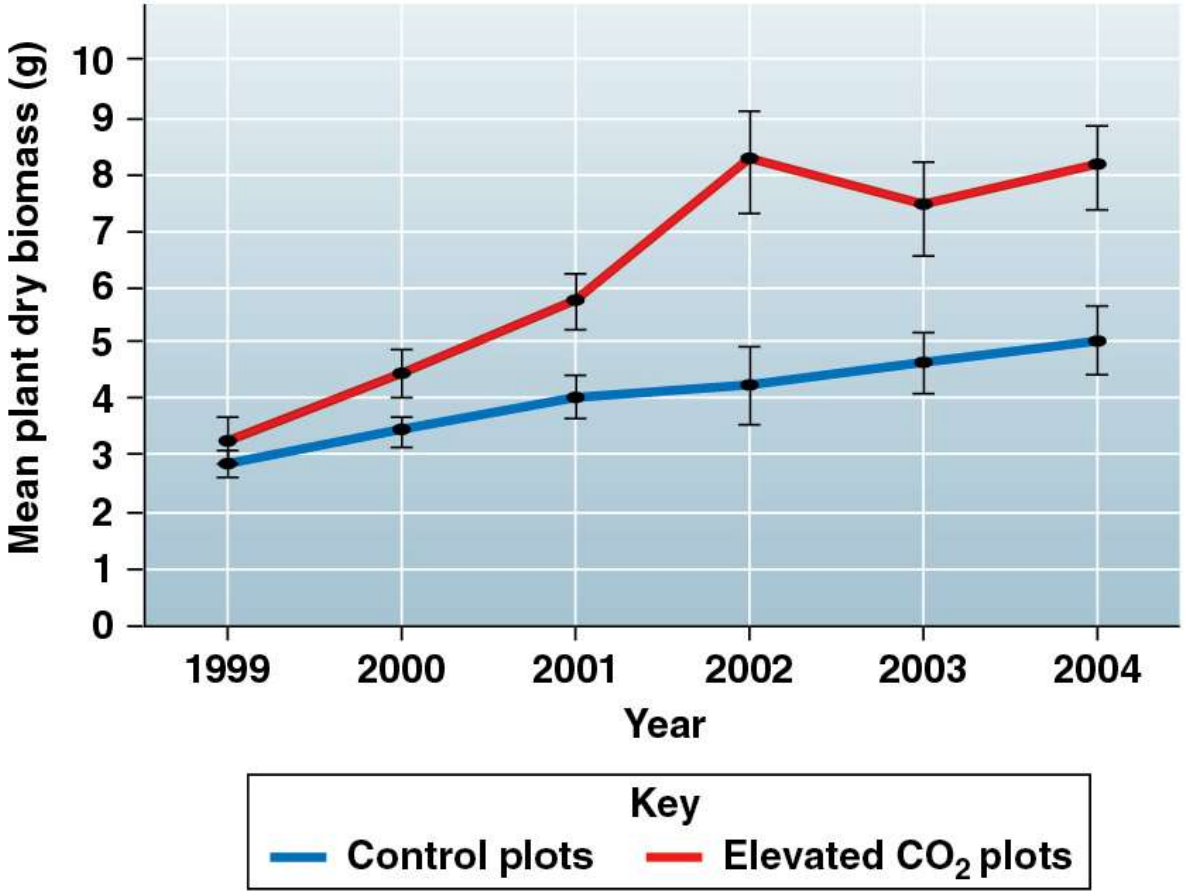
Figure 7.12



7.13 Scientific Thinking: Rising Atmospheric Levels of Carbon Dioxide May Affect Plants in Various Ways

- Scientists study the effects of rising CO_2 levels using laboratory growth chambers and field studies.
- Long-term field projects enable scientists to assess the effects of CO_2 levels on natural ecosystems.

Figure 7.13b

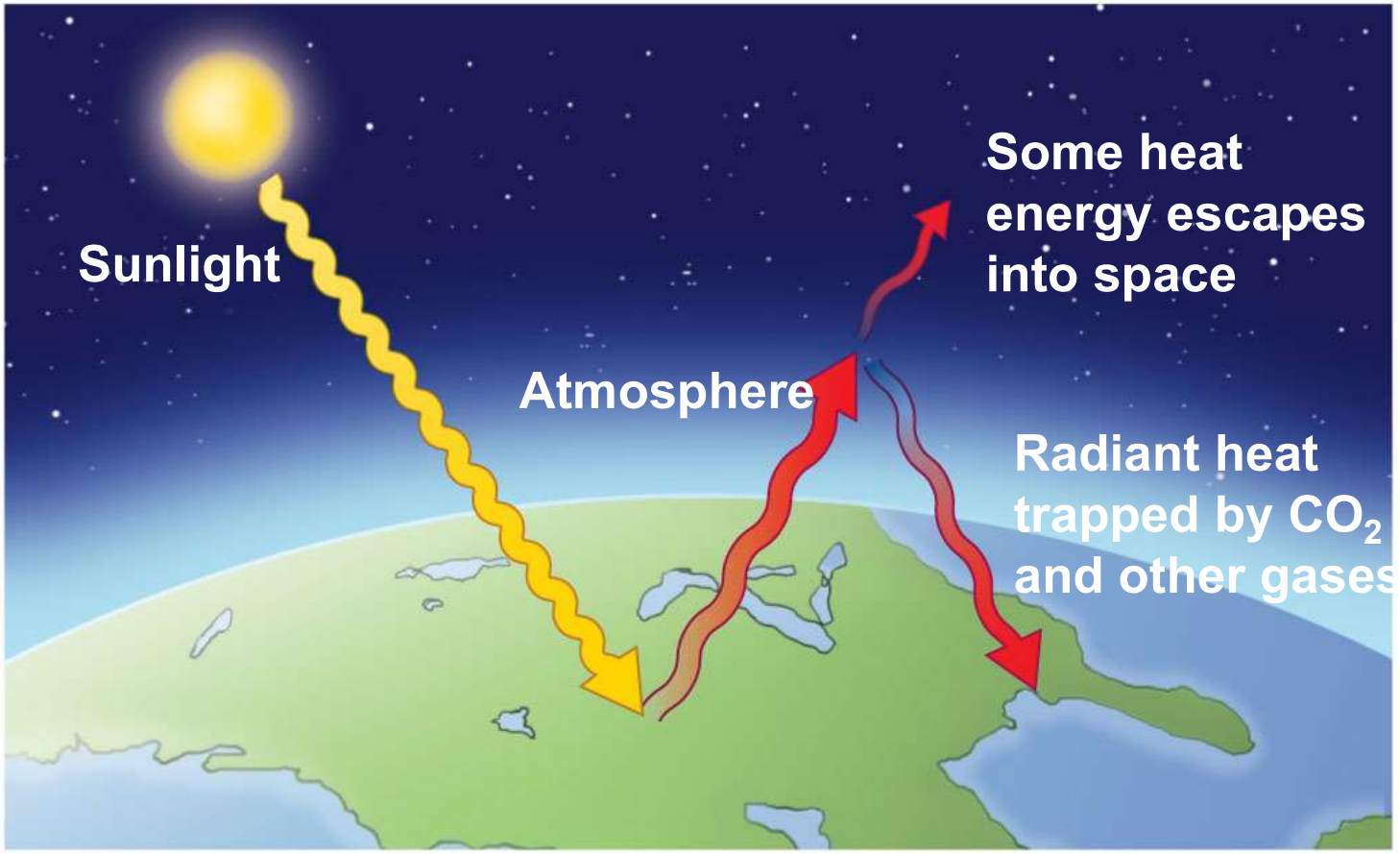


Source: Adaptation of Figure 1A from "Biomass and toxicity responses of poison ivy (*Toxicodendron radicans*) to elevated atmospheric CO_2" by Jacqueline E. Mohan, et al., from PNAS, June 2006, Volume 103(24). National Academy of Sciences.

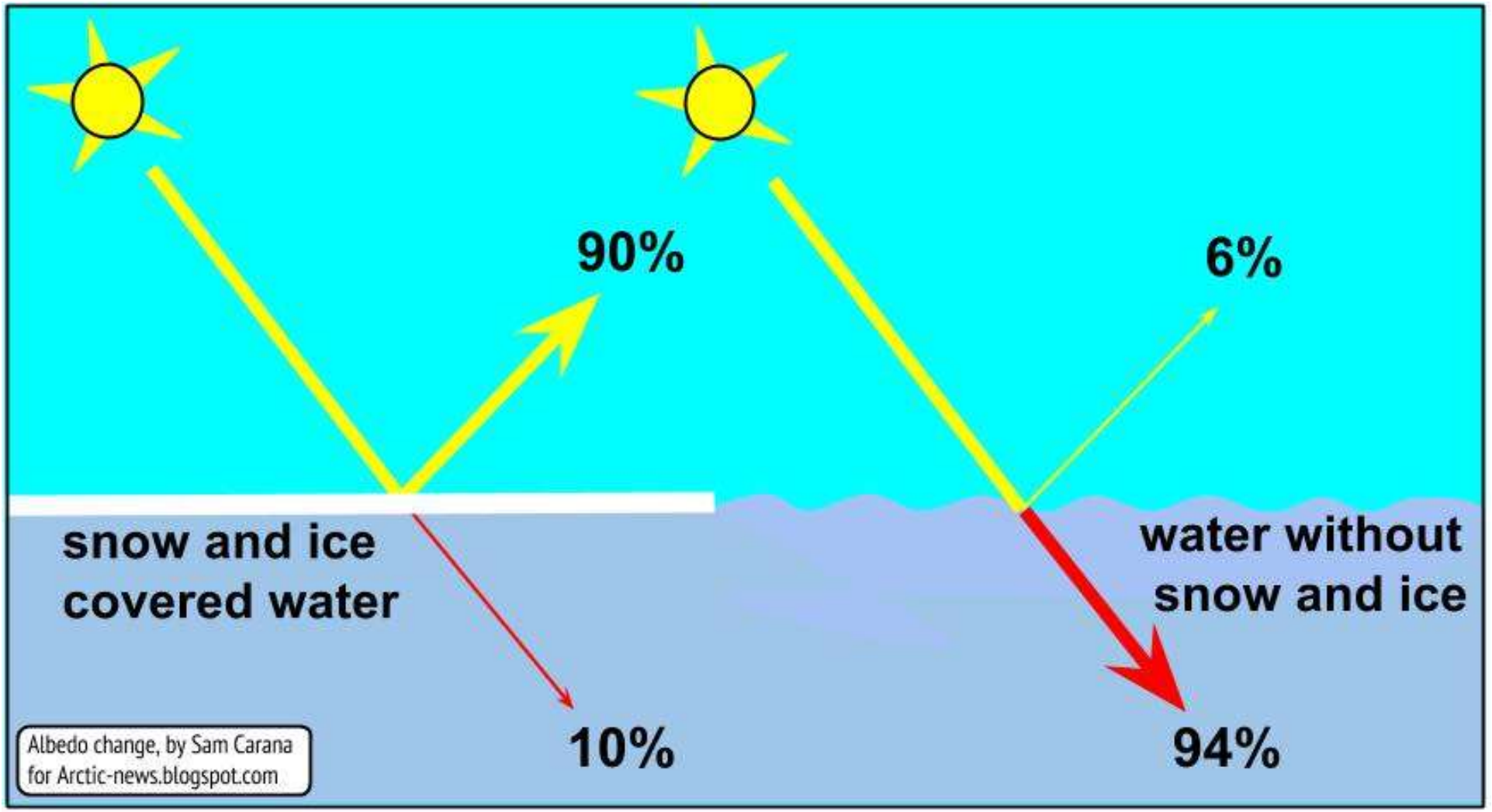
7.14 Connection: Reducing Both Fossil Fuel Use and Deforestation May Moderate Climate Change (1 of 2)

- CO_2 and other gases in the atmosphere create the **greenhouse effect**.
- Global warming is a major aspect of **climate change**, a long-term directional change to the global climate that lasts for three decades or more.
- An international agreement reached at the Paris climate conference of 2015 seeks to reduce greenhouse gas emissions and limit global warming.

Figure 7.13B



ALBEDO EFFECT



CONNECTION: Photosynthesis may moderate global climate change

- The gases in the atmosphere that absorb heat radiation are called greenhouse gases. These include
  - water vapor,
  - carbon dioxide, and
  - methane.

CONNECTION: Photosynthesis may moderate global climate change

- Increasing concentrations of greenhouse gases have been linked to **global climate change** (also called global warming), a slow but steady rise in Earth's surface temperature.
- Since 1850, the atmospheric concentration of CO_2 has increased by about 40%, mostly due to the combustion of fossil fuels including
  - coal,
  - oil, and
  - gasoline.

CONNECTION: Photosynthesis may moderate global climate change

- The predicted consequences of continued warming include
  - melting of polar ice,
  - rising sea levels,
  - extreme weather patterns,
  - droughts,
  - increased extinction rates, and
  - the spread of tropical diseases.

CONNECTION: Photosynthesis may moderate global climate change

- Widespread deforestation has aggravated the global warming problem by reducing an effective CO_2 sink.
- Global warming caused by increasing CO_2 levels may be reduced by
  - limiting deforestation,
  - reducing fossil fuel consumption, and
  - growing biofuel crops that remove CO_2 from the atmosphere.

SCIENTIFIC DISCOVERY: Scientific study of Earth's ozone layer has global significance

- Solar radiation converts O_2 high in the atmosphere to ozone (O_3), which shields organisms from damaging UV radiation.
- Industrial chemicals called CFCs have caused dangerous thinning of the ozone layer, but international restrictions on CFC use are allowing a slow recovery.