The Living World

Fourth Edition

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6 How Cells Acquire Energy

PowerPoint® Lectures prepared by Johnny El-Rady

6.1 An Overview of Photosynthesis

- Photosynthesis is the process that captures light energy and transforms into the chemical energy of carbohydrates

- It occurs in the
  - Plasma membranes of some bacteria
  - Cells of algae
  - Leaves of plants

Fig. 6.1 Journey into a leaf

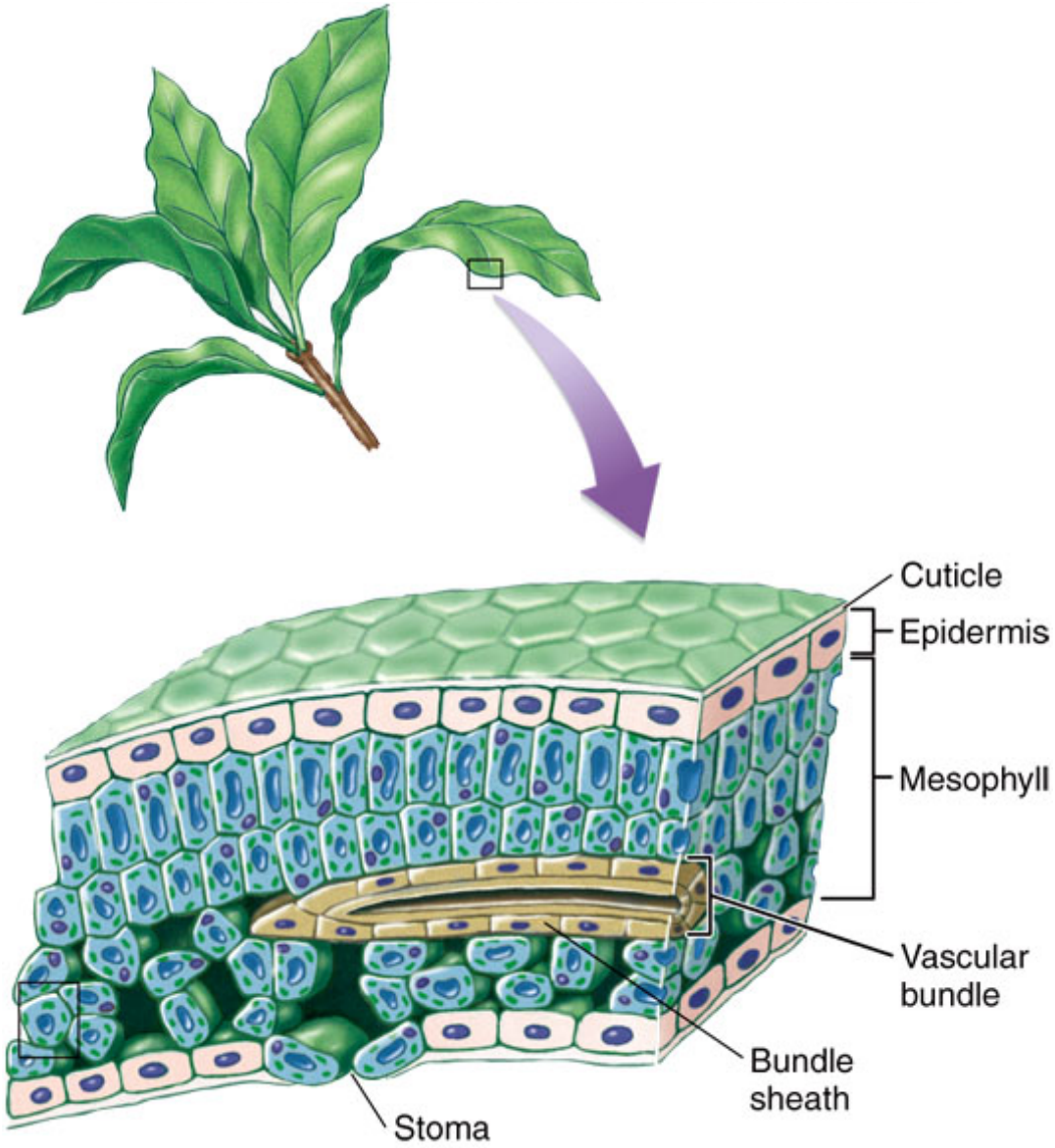
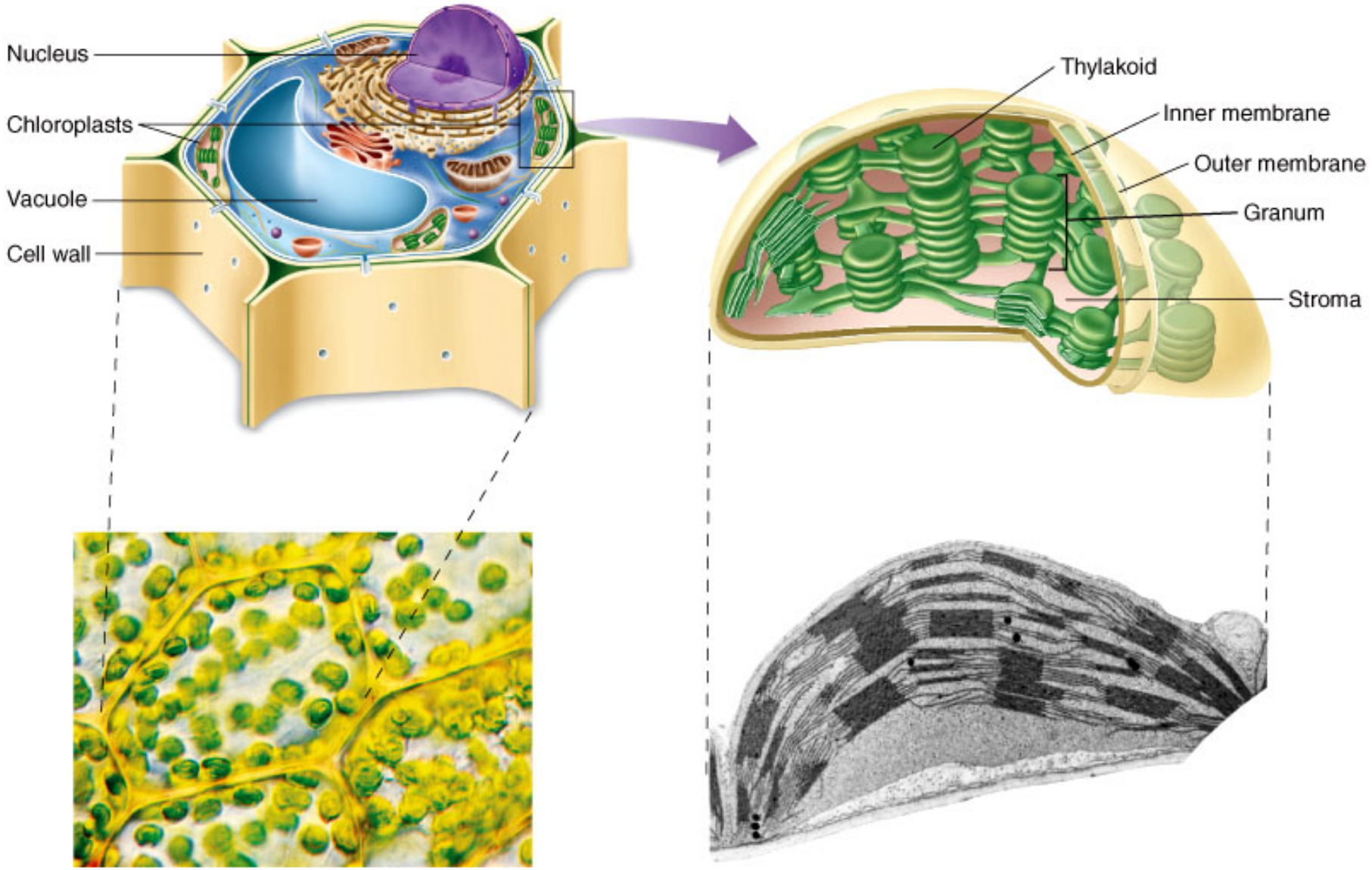


Fig. 6.1 Journey into a leaf



- Photosynthesis takes place in three stages:

Light-dependent reactions

1. Capturing energy from sunlight
2. Using energy to make ATP and NADPH

Light-independent reactions

The Calvin cycle

3. Using ATP and NADPH to power the synthesis of carbohydrates from CO_2

$$6\ CO_2 + 12\ H_2O + \text{Light energy} \longrightarrow C_6H_{12}O_6 + 6\ H_2O + 6\ O_2$$

carbon dioxide — water — glucose — water — oxygen

- All three stages occur in the chloroplast

Contain the pigment chlorophyll, which captures light

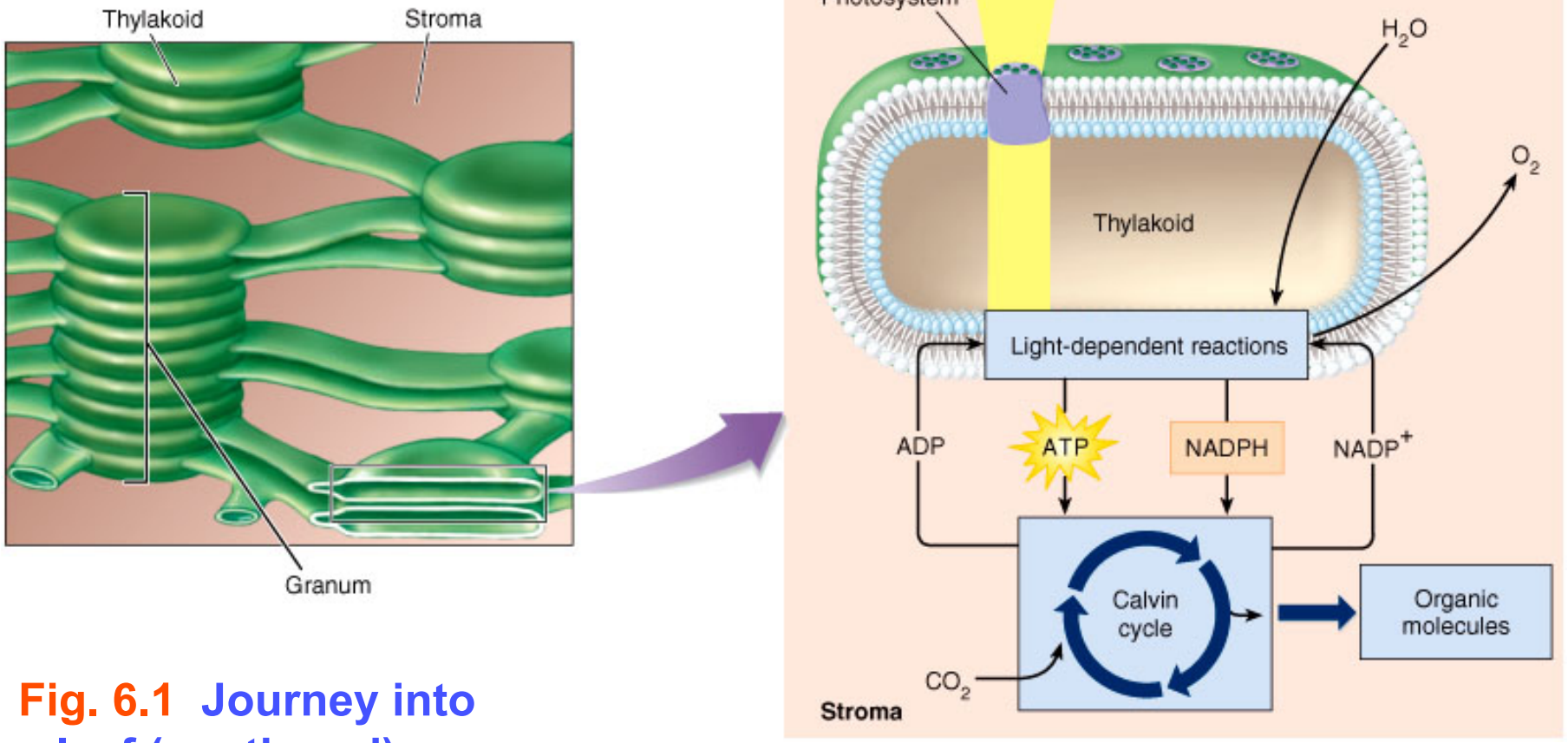
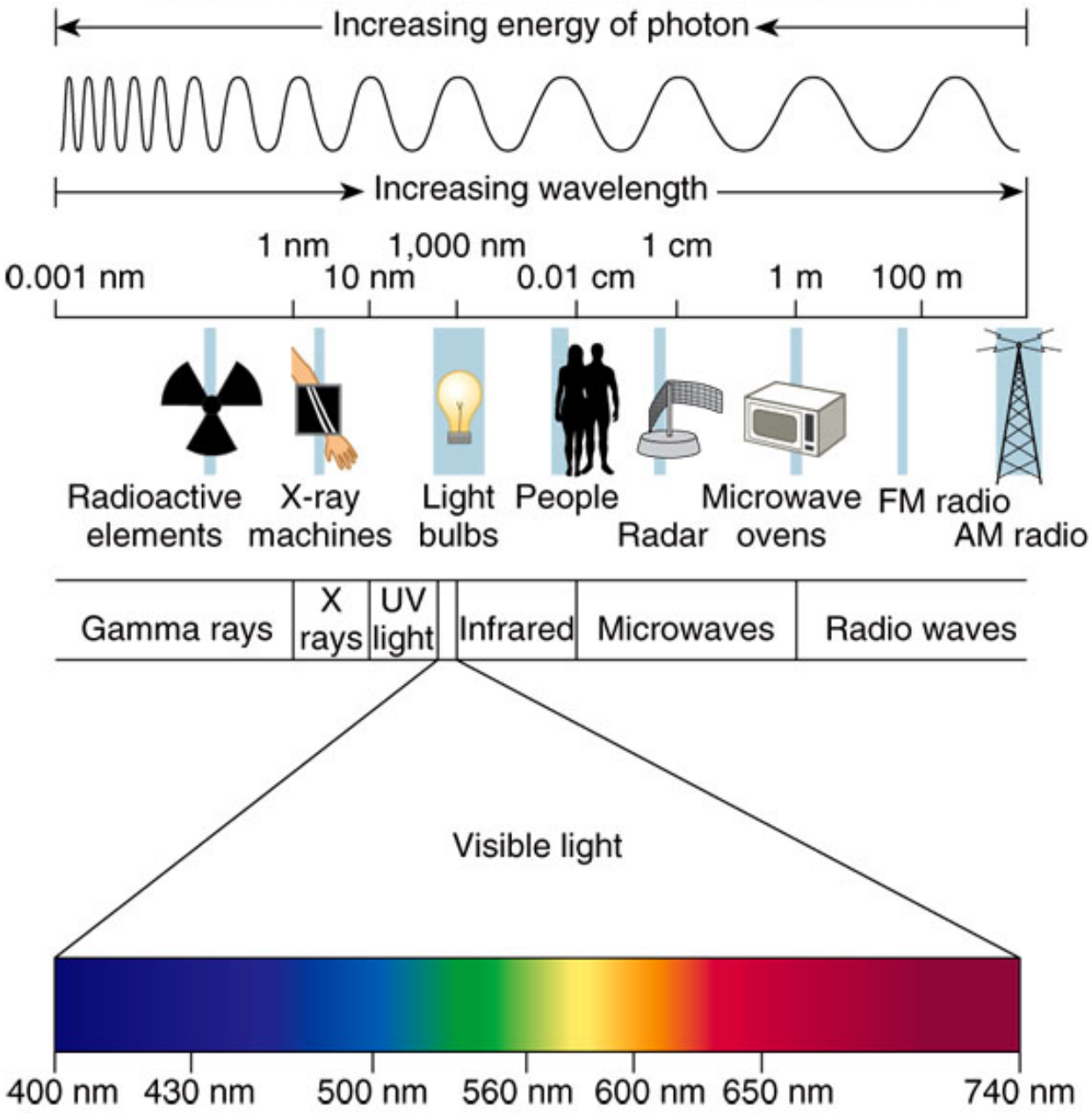


Fig. 6.1 Journey into a leaf (continued)

6.2 How Plants Capture Energy from Sunlight

- Light consists of tiny packets of energy called photons
- Sunlight contains photons of many energy levels
  - High energy photons have lower wavelength than low energy photons
- The full range of these photons is called the electromagnetic spectrum

Fig. 6.2 Photons of different energy: the electromagnetic spectrum



Pigments

- Are molecules that absorb light energy
- The pigment in human eyes is retinal
  - Absorption: ~ 380 (violet) – 750 (red) nm
- The main pigment in plants is chlorophyll
  - Chlorophyll *a* and chlorophyll *b*
    - Have slight differences in absorption spectra
- Carotenoids are accessory pigments
  - They capture wavelengths not efficiently absorbed by chlorophyll

Fig. 6.4
Absorption spectra of chlorophylls and carotenoids

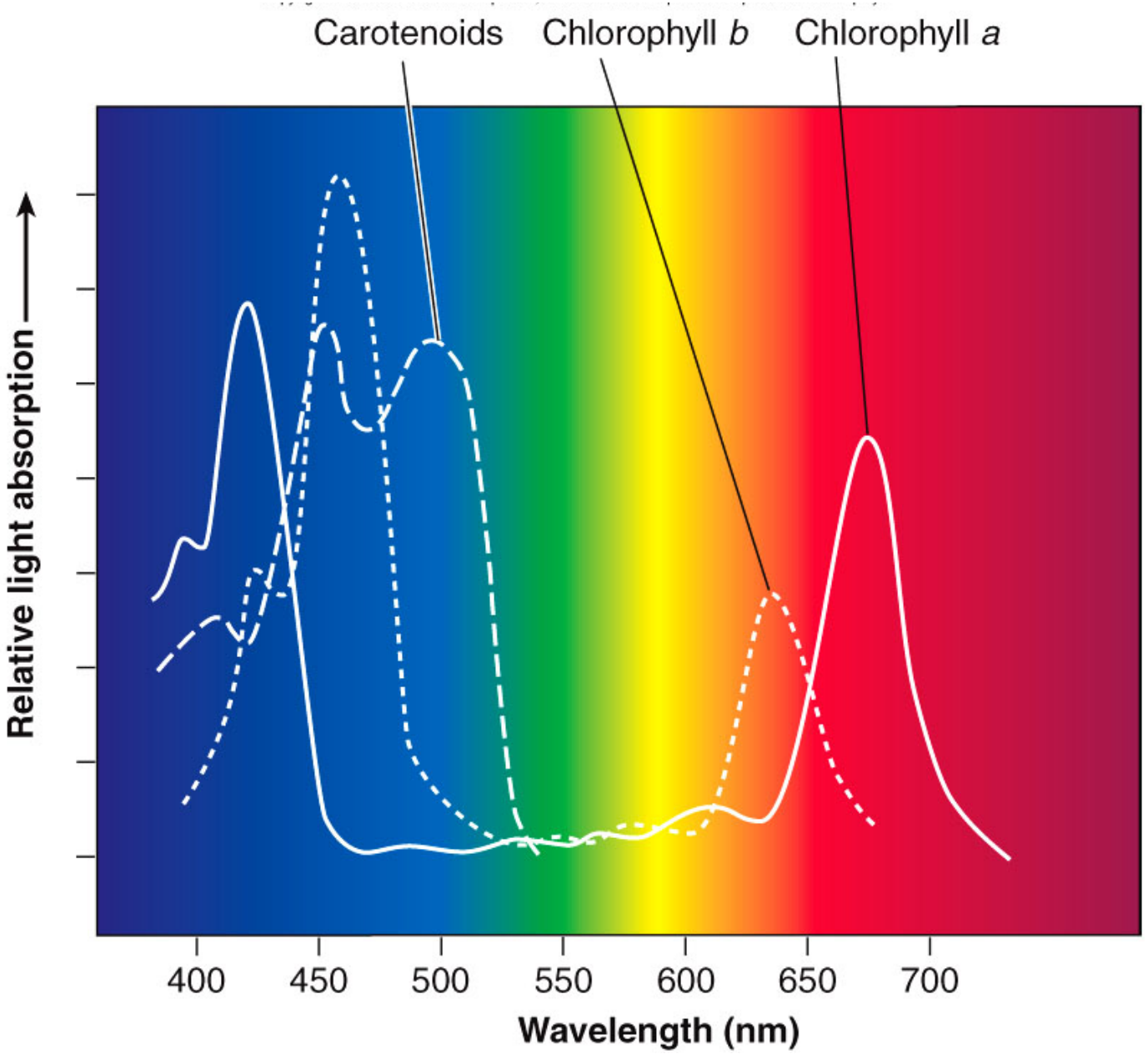
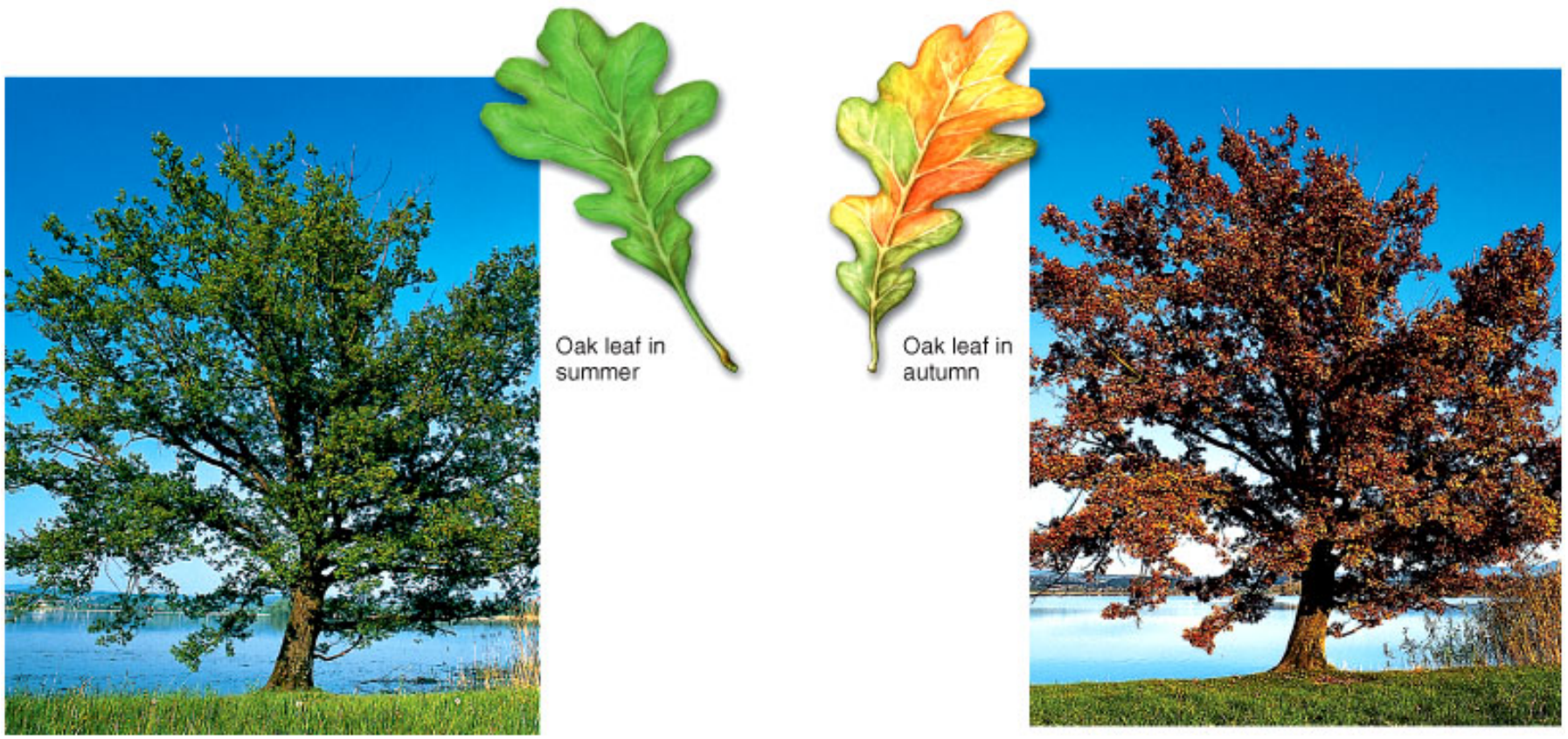


Fig. 6.5 Fall colors are produced by pigments such as carotenoids



6.3 Organizing Pigments into Photosystems

- Chlorophyll is embedded in a protein complex in the thylakoid membrane

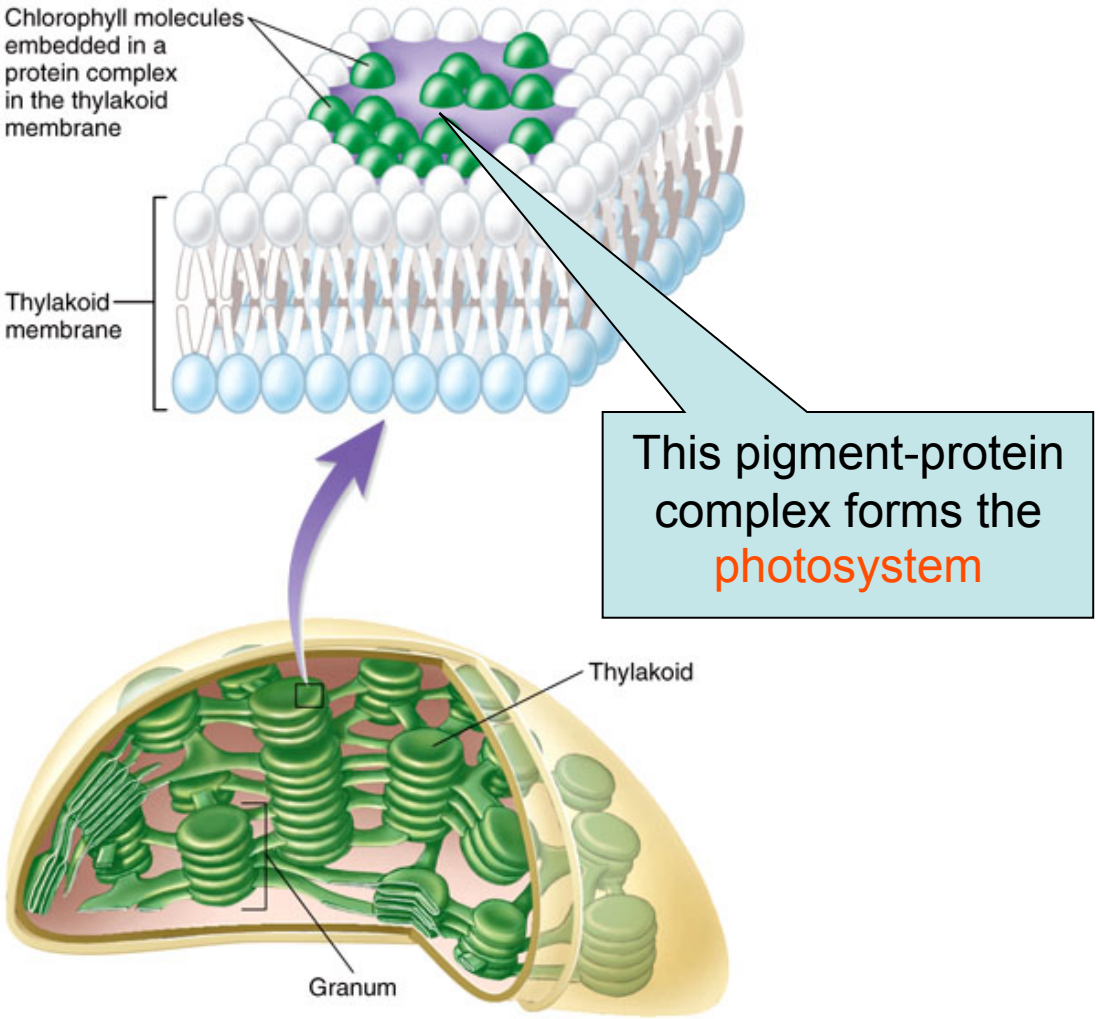
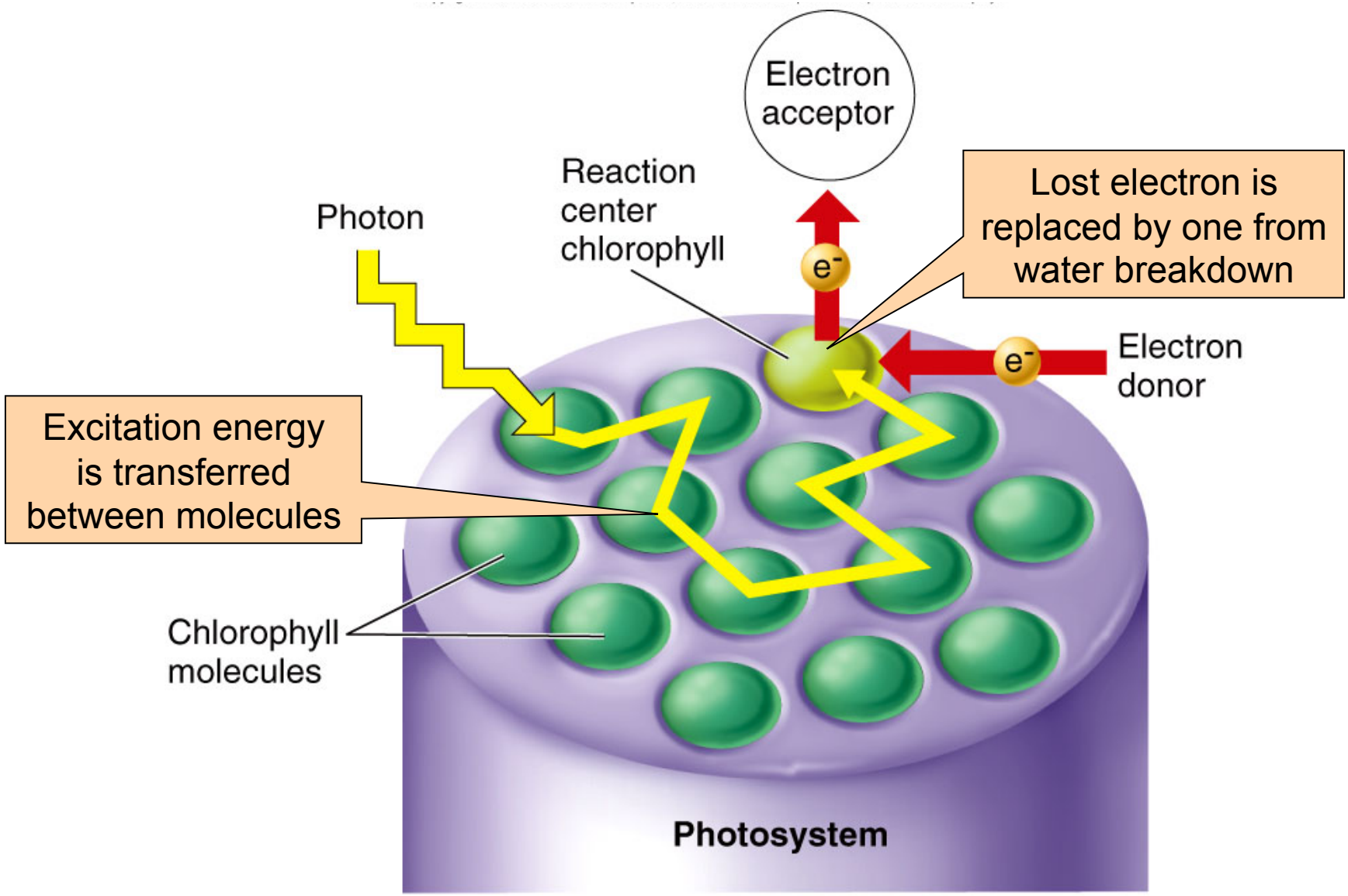


Fig. 6.6

6.3 Organizing Pigments into Photosystems

- The light-dependent reactions take place in five stages
  1. Capturing light
  2. Exciting an electron
  3. Electron transport
  4. Making ATP
  5. Making NADPH

Fig. 6.7 How a photosystem works



- Plants use two photosystems that occur in series
  - Process is called noncyclic photophosphorylation

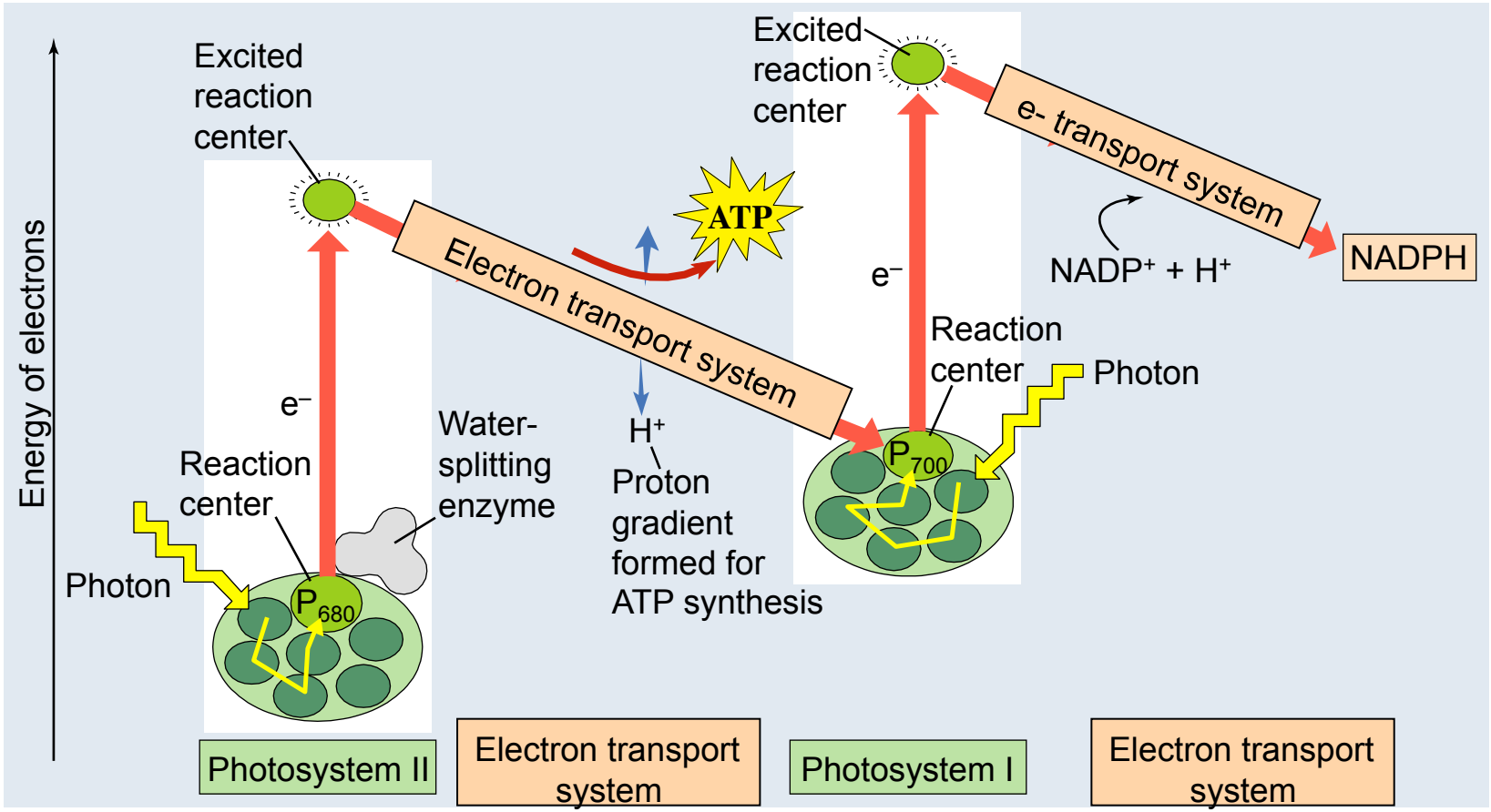


Fig. 6.8

6.4 How Photosystems Convert Light to Chemical Energy

- The antenna complex of photosystem II first captures the photons
  - It generates a high-energy electron that is passed through an electron transport system
  - This drives the synthesis of ATP

- The electron is then transferred to photosystem I
  - It gets an energy boost from another photon of light
  - It is passed through another electron transport system
  - This drives the synthesis of NADPH

Fig. 6.9 The photosynthetic electron transport system

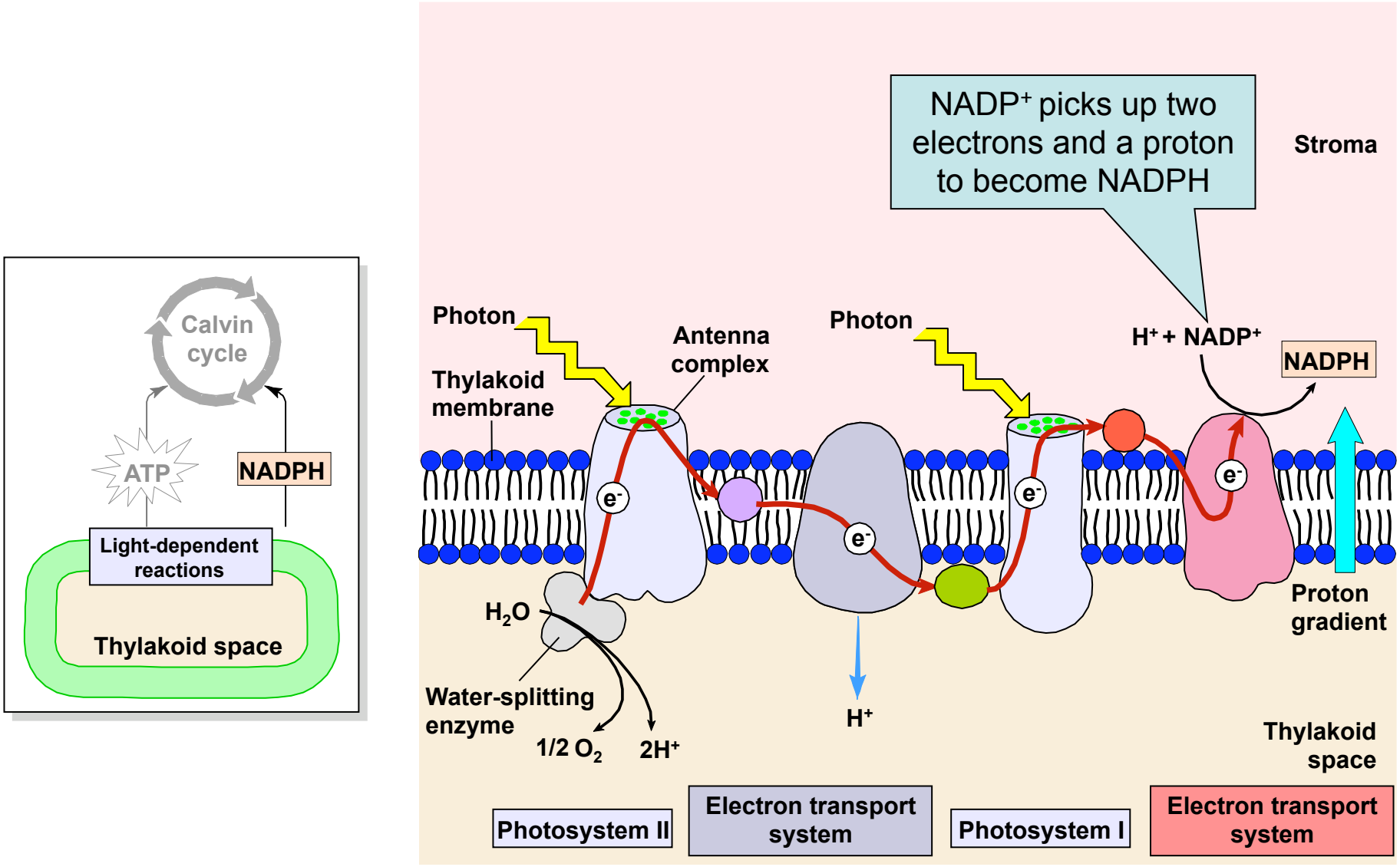
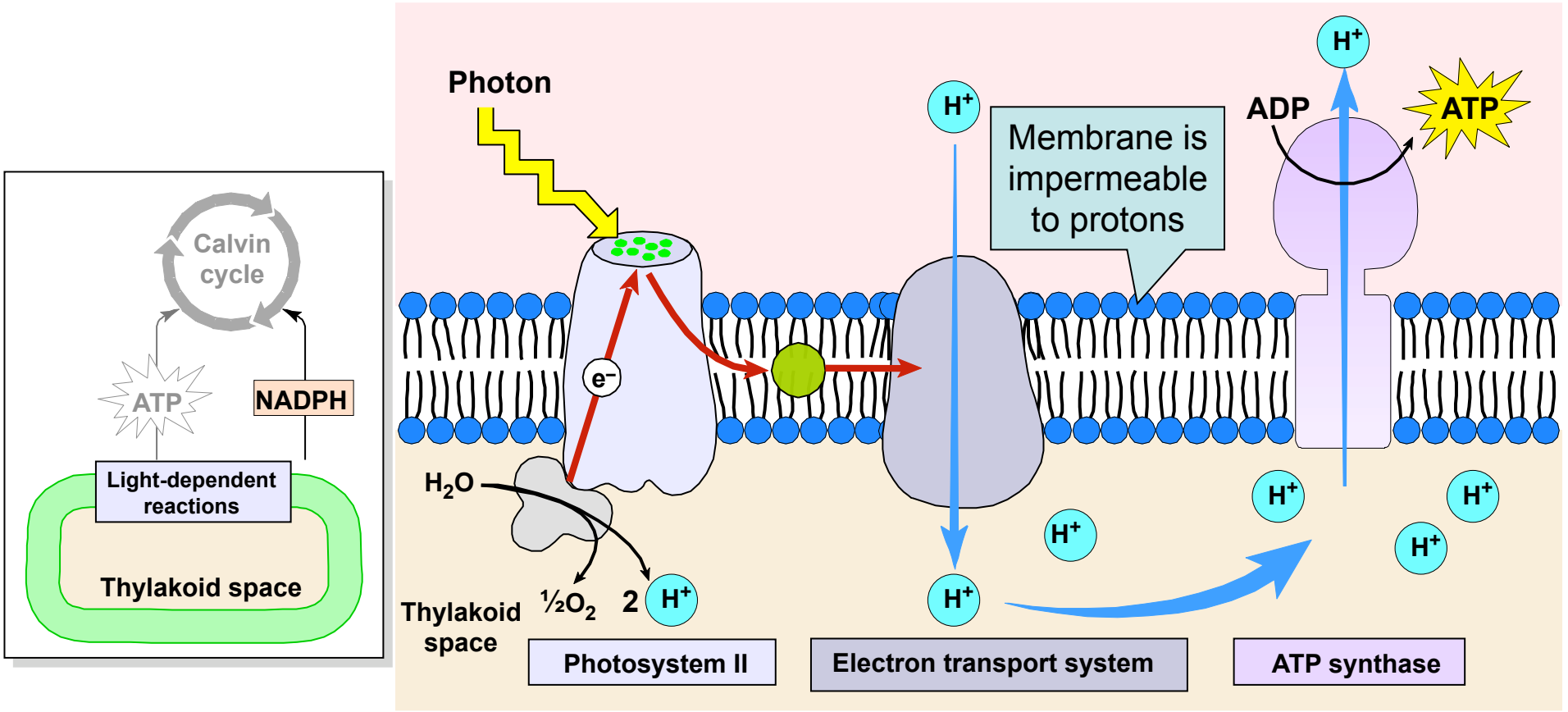


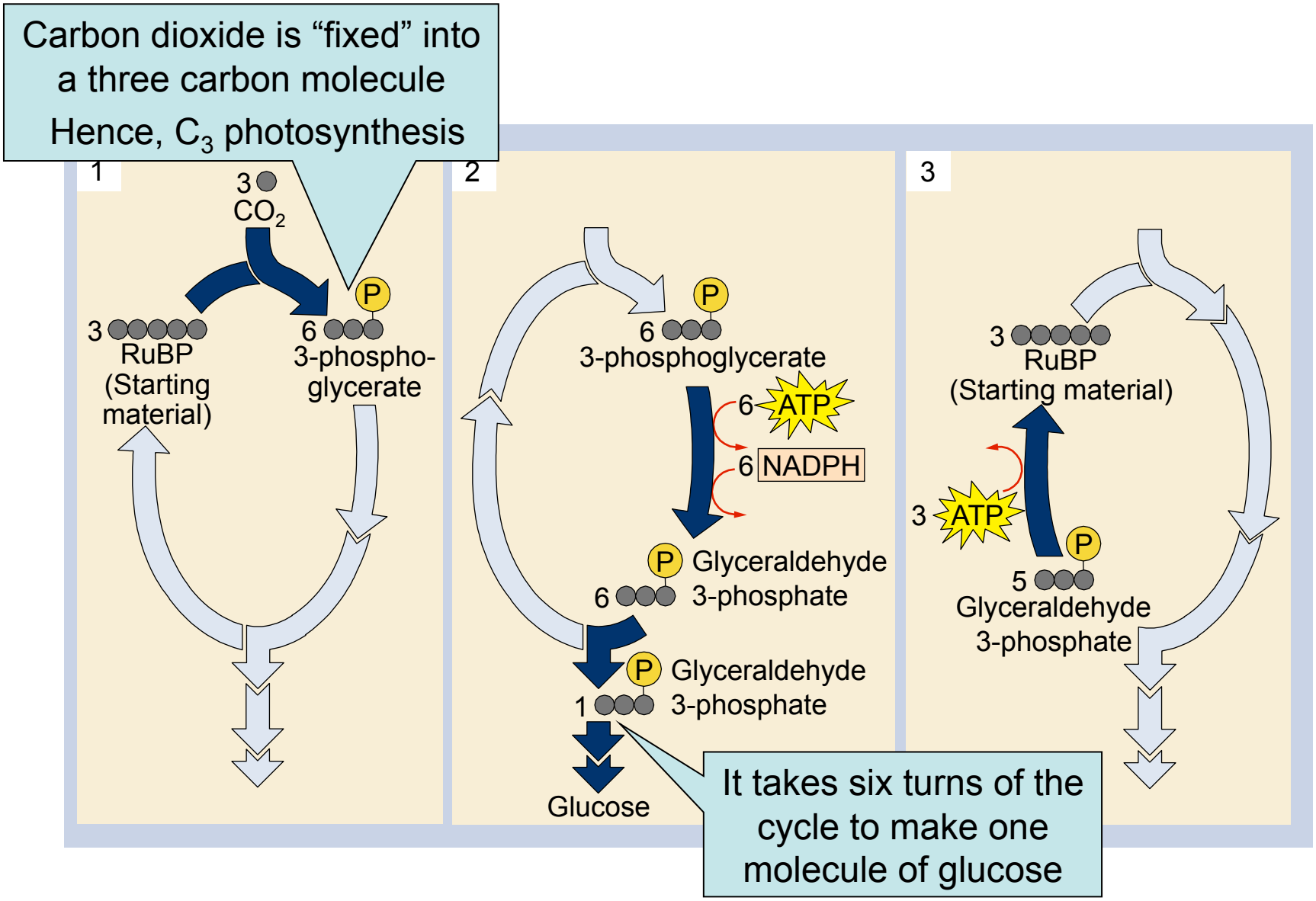
Fig. 6.10 Chemiosmosis in a chloroplast



6.5 Building New Molecules

- Light-dependent reactions provide the raw material
  - 1. ATP serves as the source of energy
    - Provided by photosystem II
  - 2. NADPH provides the reducing power
    - Provided by photosystem I
- The Calvin Cycle (C_3 photosynthesis) is the pathway that assembles the new molecules
  - It takes place in the stroma of the chloroplast

Fig. 6.11 How the Calvin cycle works



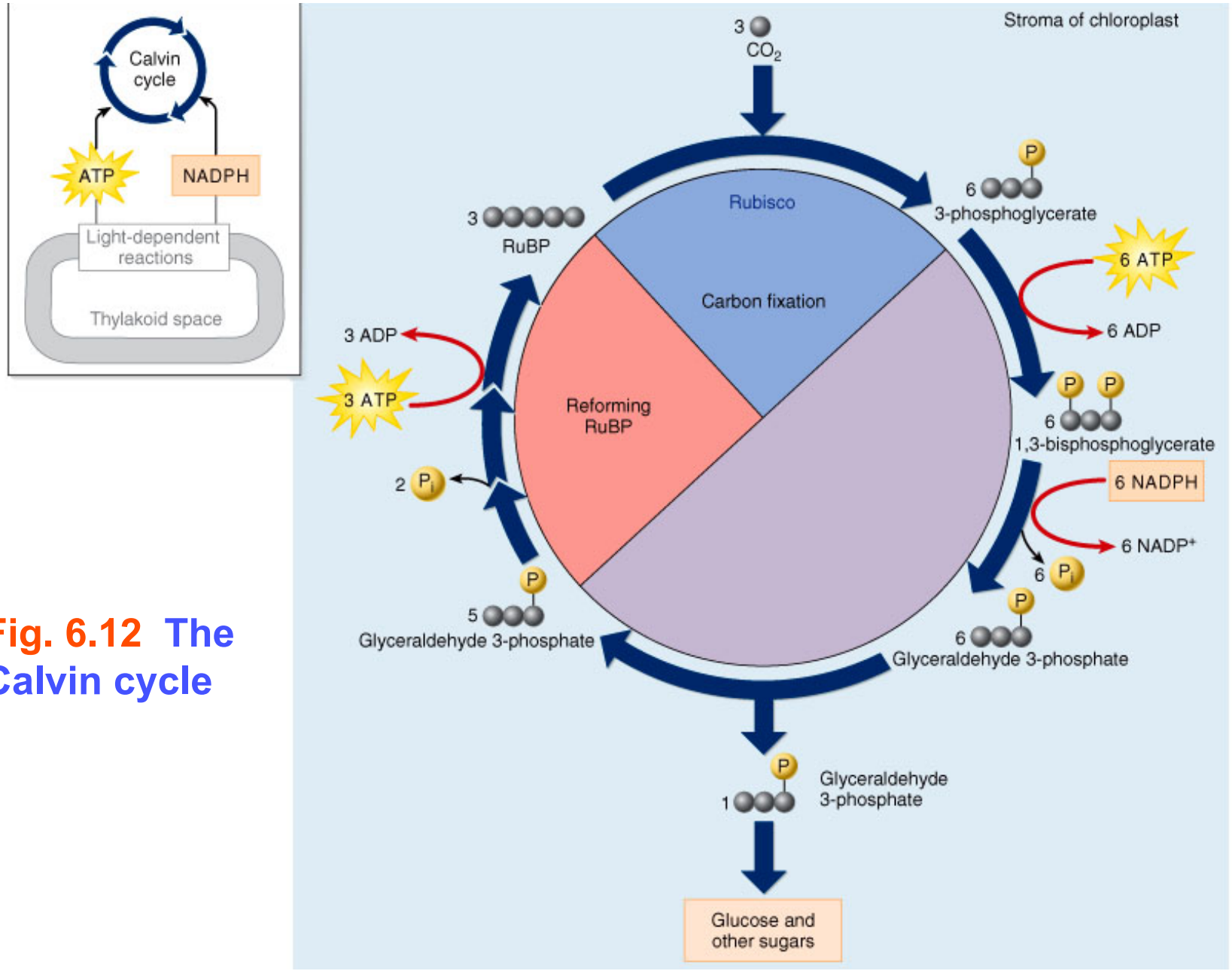
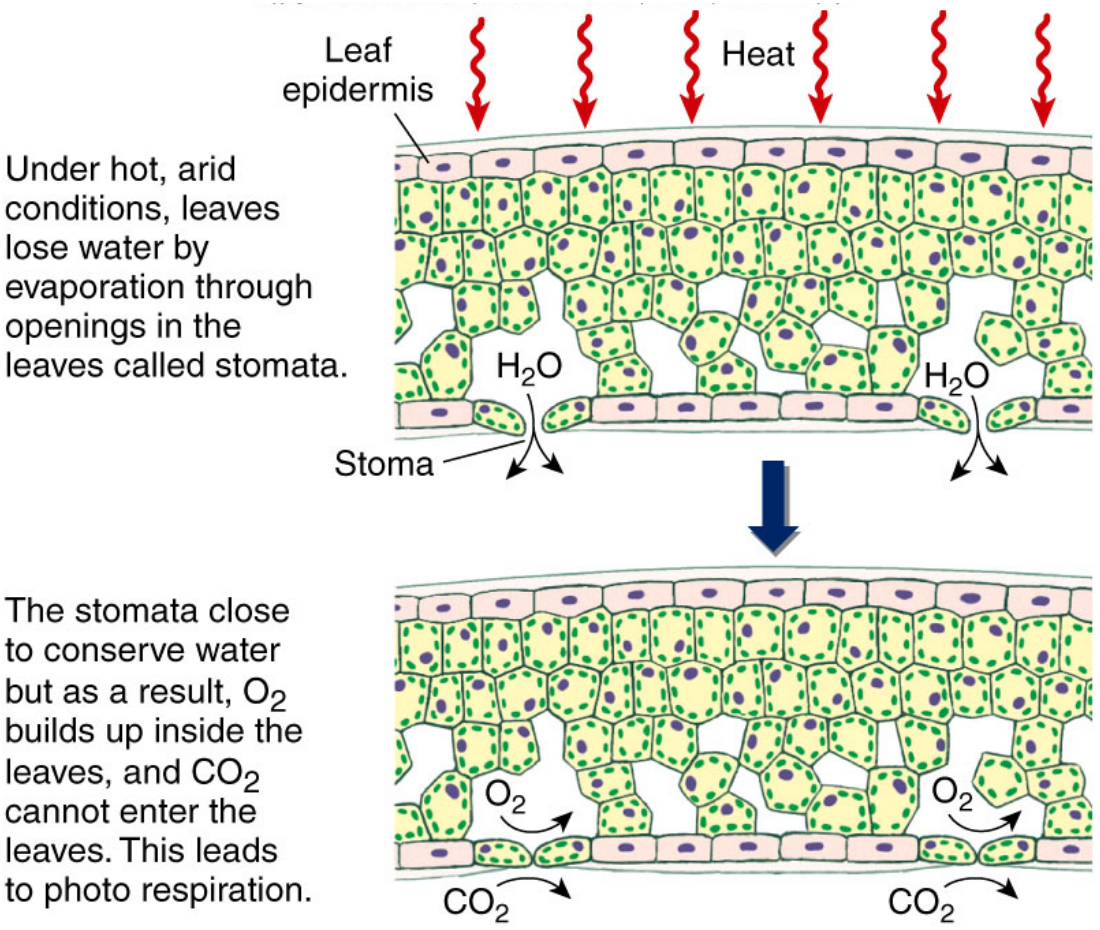


Fig. 6.12 The Calvin cycle

6.5 Building New Molecules

- In hot weather, plants have trouble with C_3 photosynthesis
- This leads to photorespiration
  - O_2 is now consumed and CO_2 is produced as a by-product
  - This decreases the photosynthetic yields

Fig. 6.13



6.5 Building New Molecules

- Some plants decrease photorespiration by performing C_4 photosynthesis
  - CO_2 is fixed initially into a four-carbon molecule
  - It is later broken down to regenerate CO_2

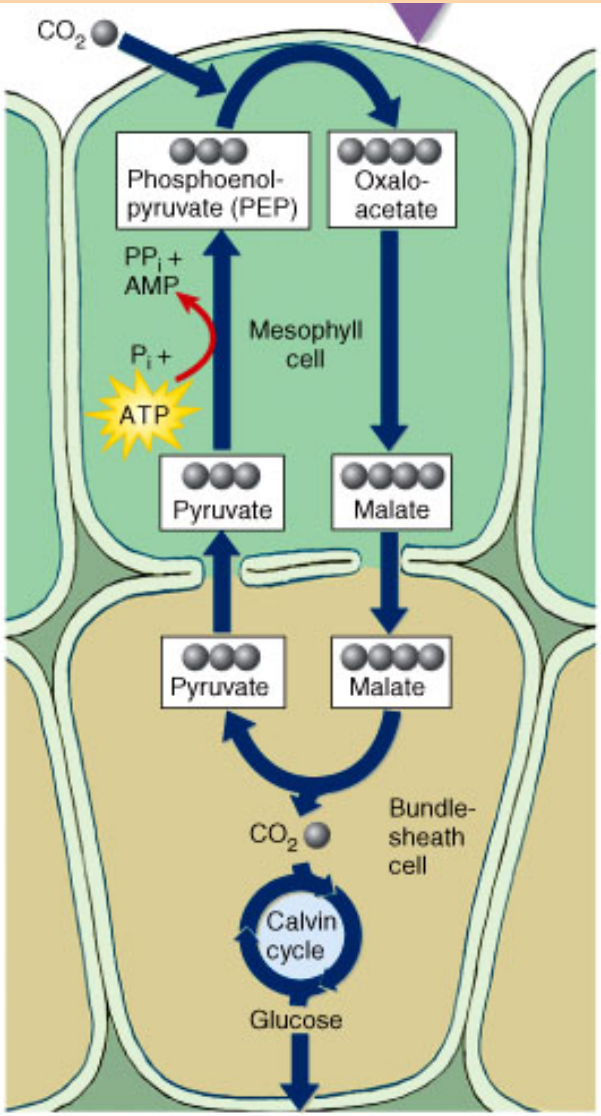


Fig. 6.14*a*

- The C_4 pathway is used by two types of plants
  - C_4 plants
    - Examples: Sugarcane, corn
    - CO_2 fixation and the Calvin cycle are separated in space, occurring in two different cells
  - CAM plants
    - Examples: Cacti, pineapples
    - Initial CO_2 fixation is called crassulacean acid metabolism (CAM)
    - CO_2 fixation and the Calvin cycle are separated in time, occurring in two different parts of the day

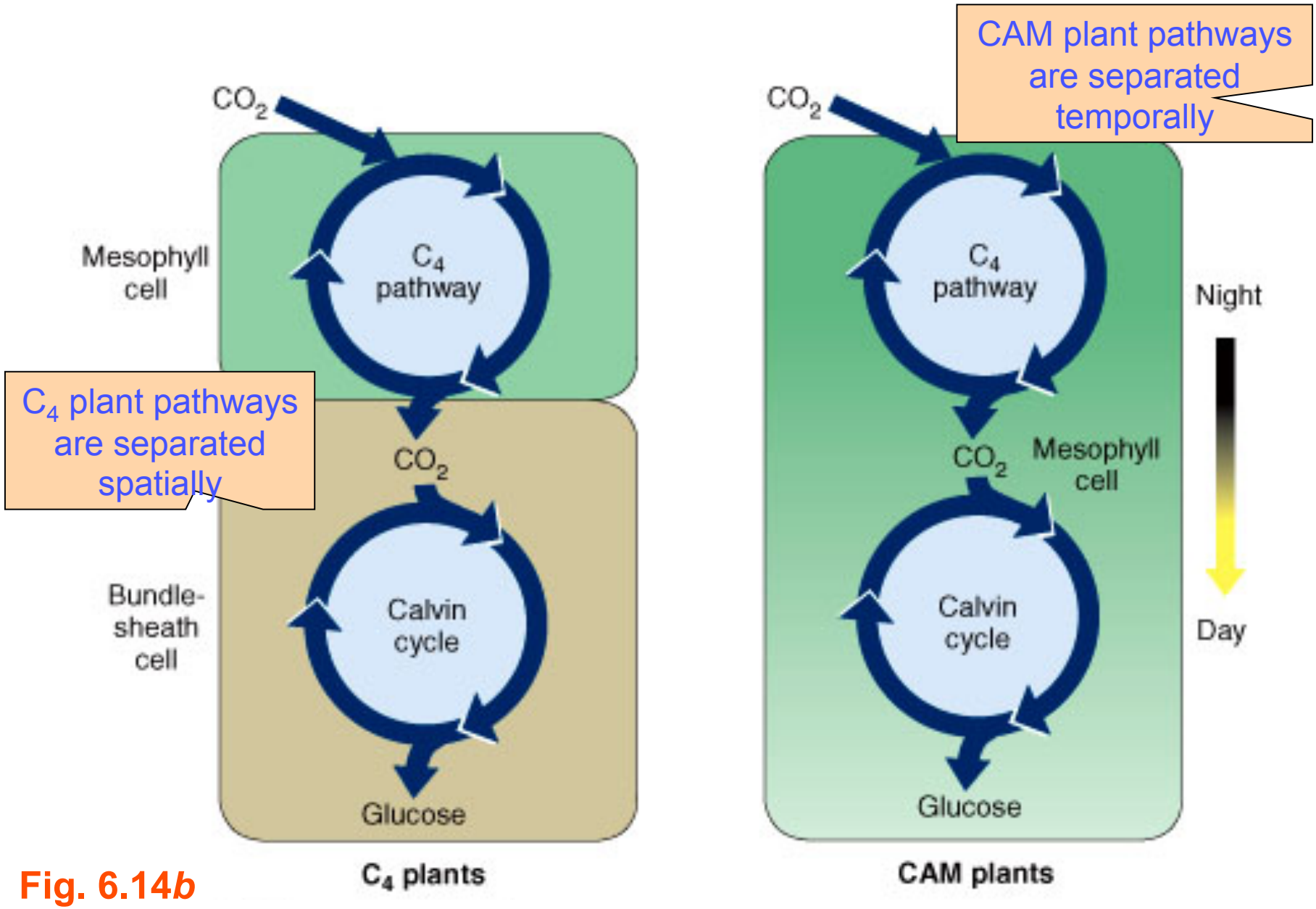


Fig. 6.14*b*

6.6 An Overview of Cellular Respiration

- Cellular respiration is the harvesting of energy from breakdown of organic molecules produced by plants

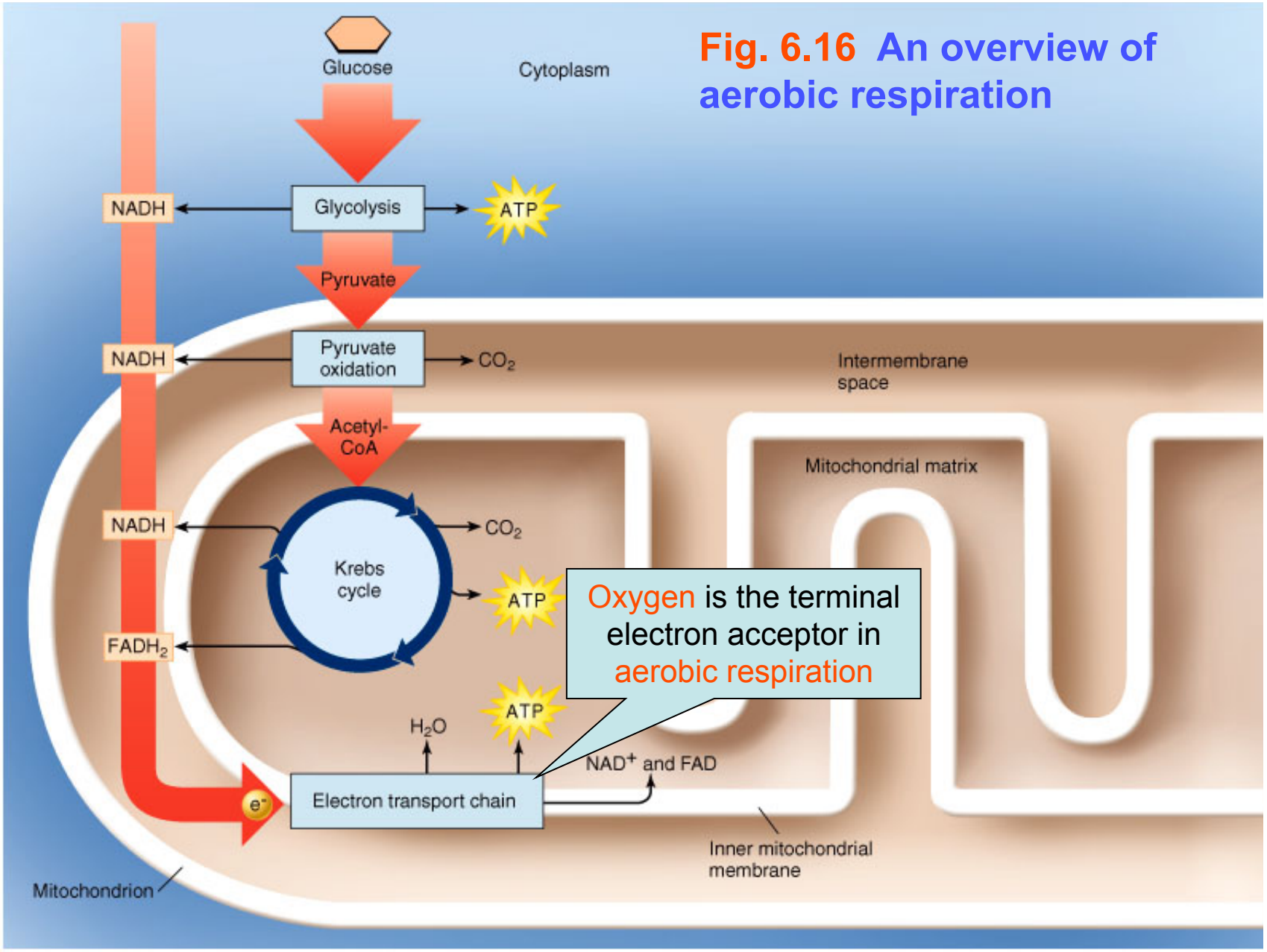
- The overall process may be summarized as

$$C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O + \text{energy}$$

glucose — oxygen — carbon dioxide — water — (heat or ATP)

- Cellular respiration is carried out in two stages:
  - 1. Glycolysis — Occurs in the cytoplasm
  - 2. Oxidation — Occurs in the mitochondria

Fig. 6.16 An overview of aerobic respiration



6.7 Using Coupled Reactions to Make ATP

- Glycolysis is the first stage in cellular respiration
  - Takes place in the cytoplasm
  - Occurs in the presence or absence of oxygen
  - Involves ten enzyme-catalyzed reactions
    - These convert the 6-carbon glucose into two 3-carbon molecules of pyruvate

Fig. 6.17 How glycolysis works

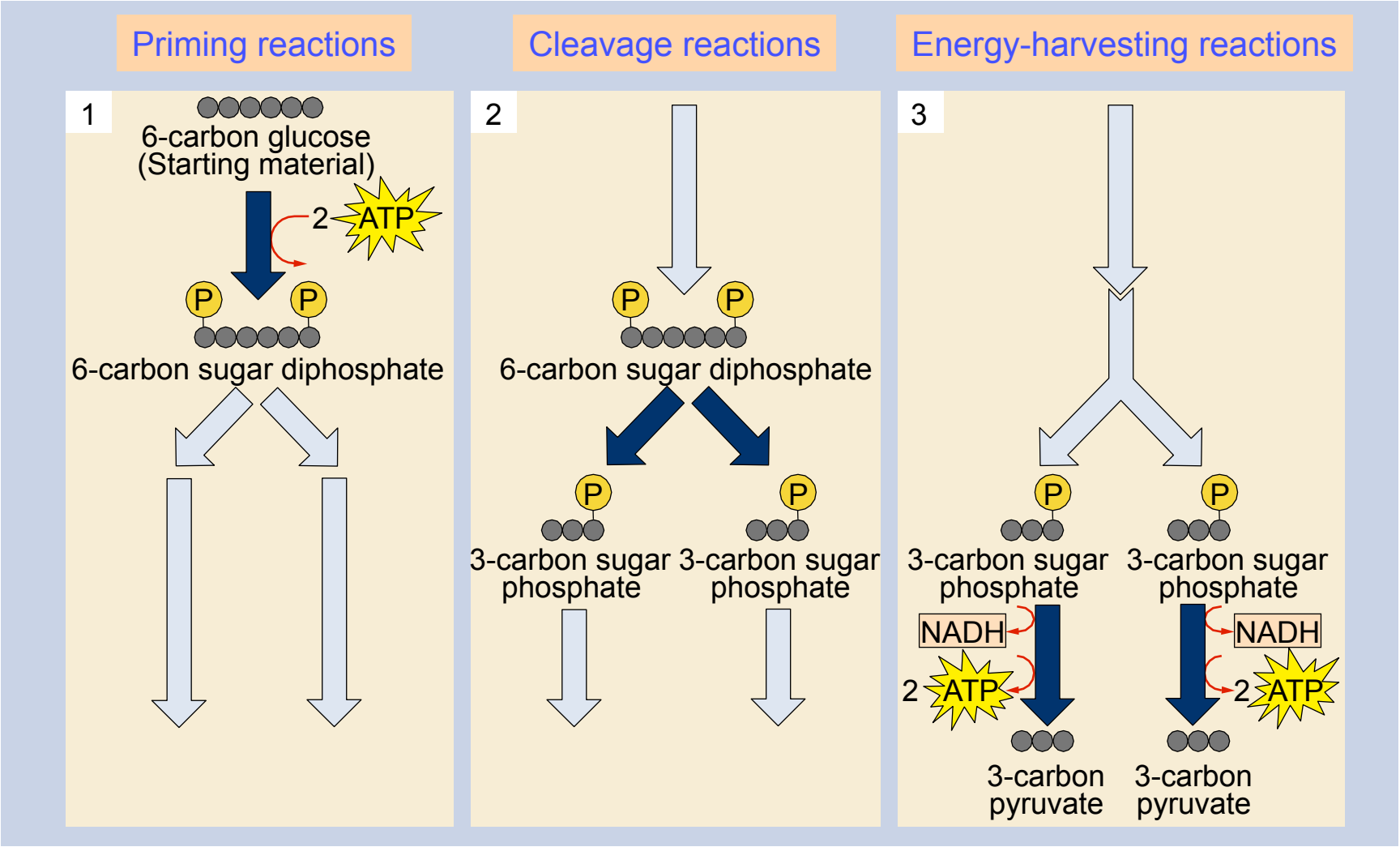


Fig. 6.18 Glycolysis

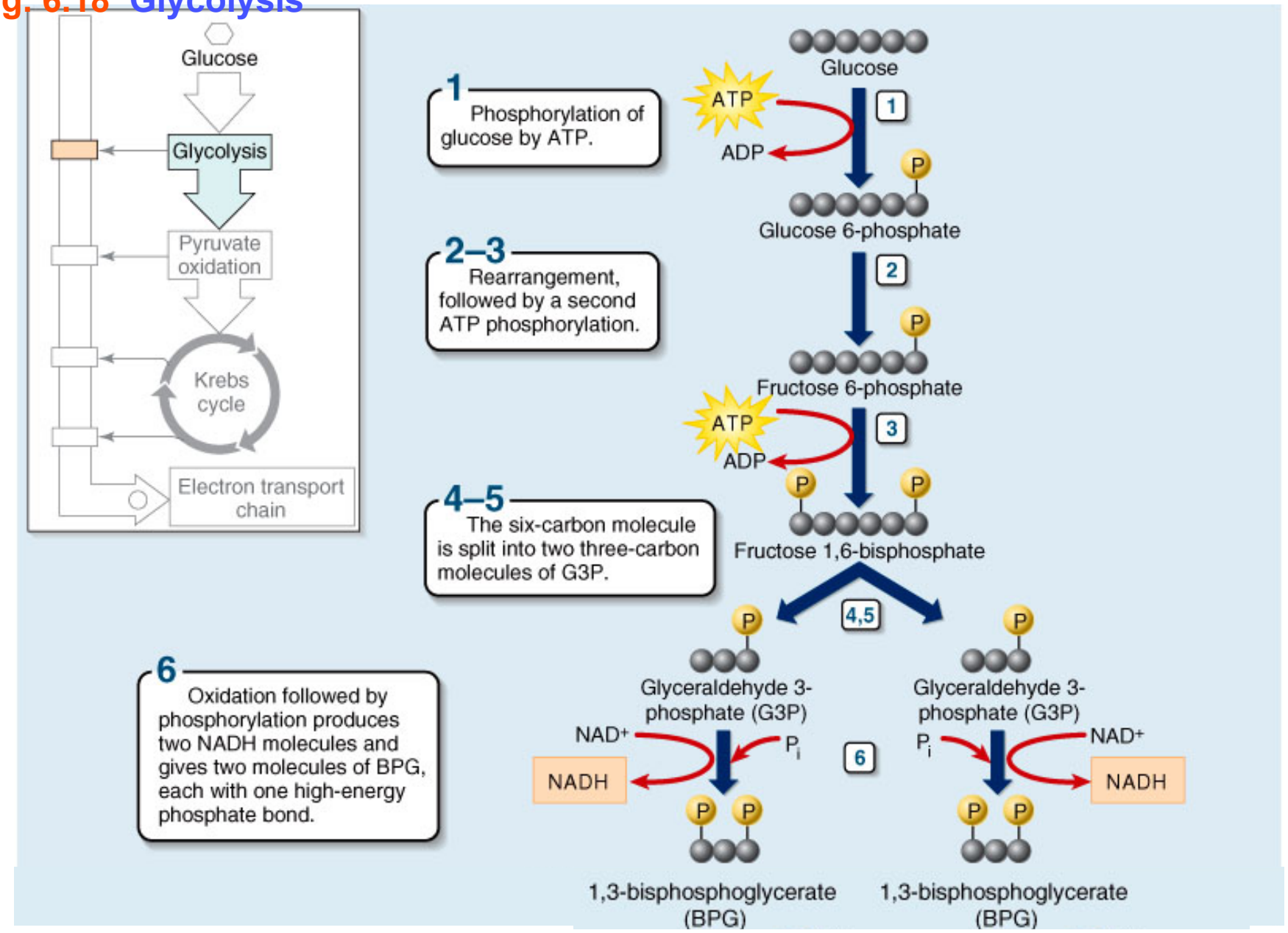
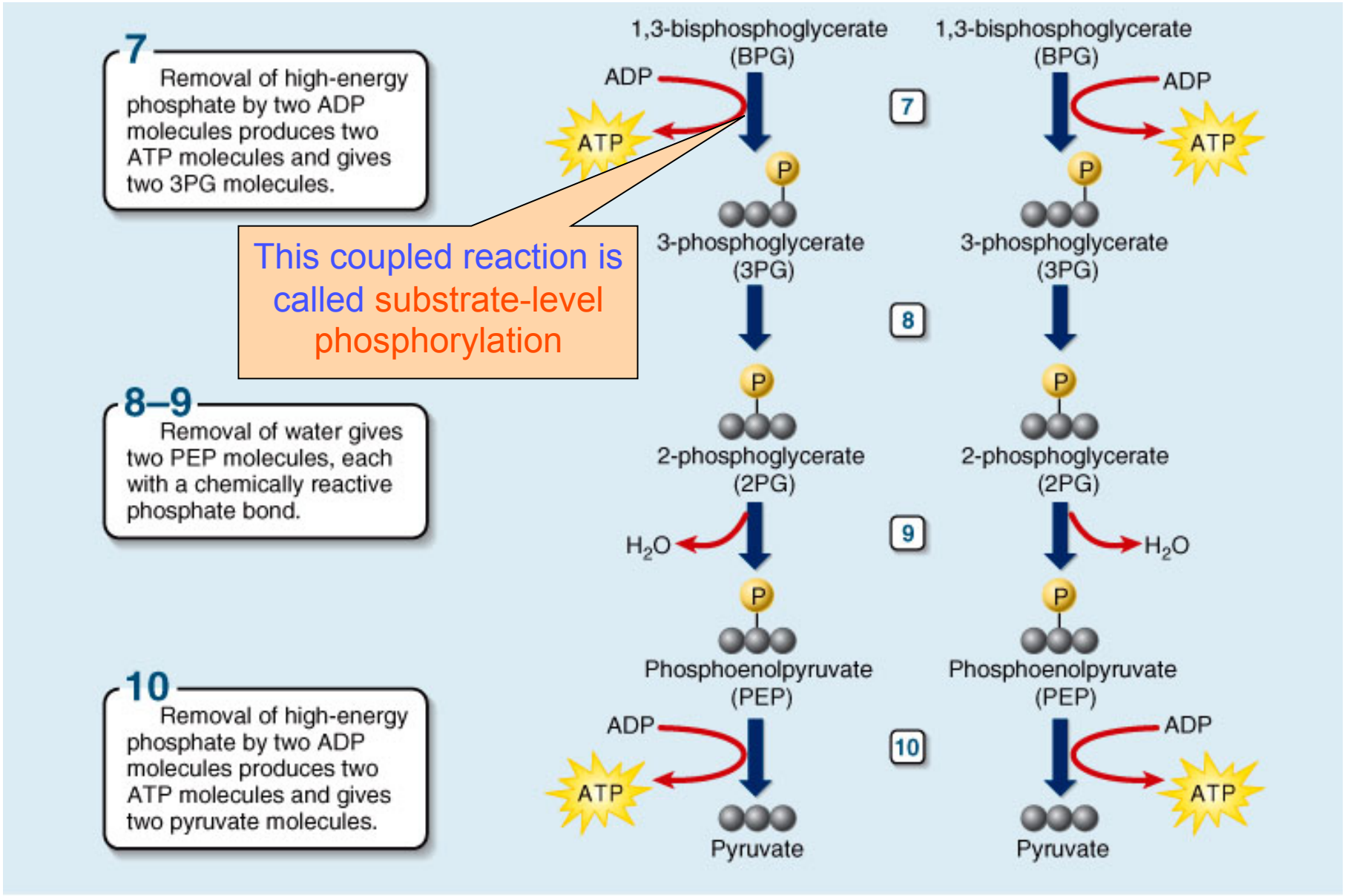


Fig. 6.18 Glycolysis



Anaerobic Respiration

- The use of *inorganic* terminal electron acceptors other than oxygen

Organism	TEA	Reduced Product
Methanogens Archaea	CO_2	CH_4 Methane
Sulfur bacteria	SO_4 Sulfate	H_2S Hydrogen sulfide

Fermentation

- The use of *organic* terminal electron acceptors
- The electrons carried by NADH are donated to a derivative of pyruvate
  - This allows the regeneration of NAD^+ that keeps glycolysis running
- Two types of fermentation are common among eukaryotes
  - Lactic fermentation
  - Ethanolic fermentation

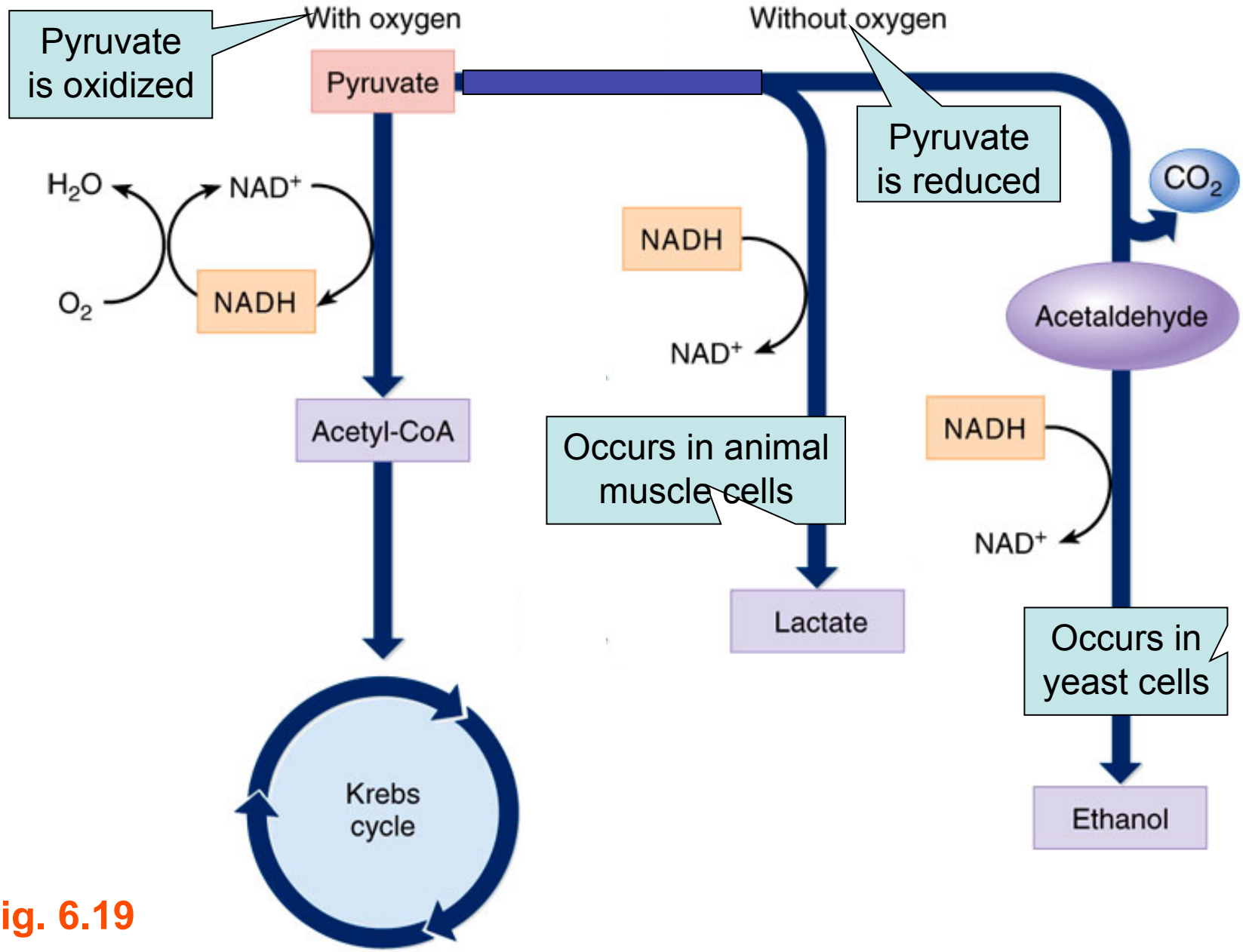
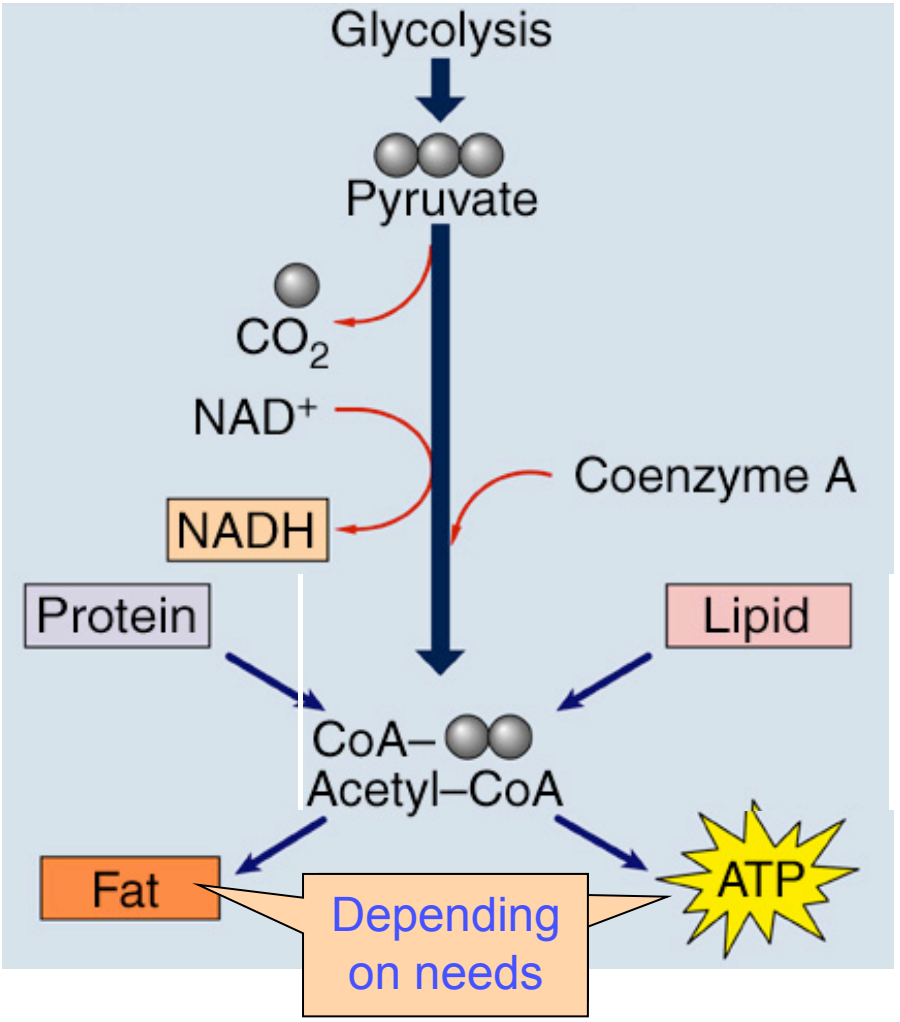


Fig. 6.19

6.8 Harvesting Electrons from Chemical Bonds

Fig. 6.20



- The oxidative stage of aerobic respiration occurs in the mitochondria
- It begins with the conversion of pyruvate into acetyl coA

6.8 Harvesting Electrons from Chemical Bonds

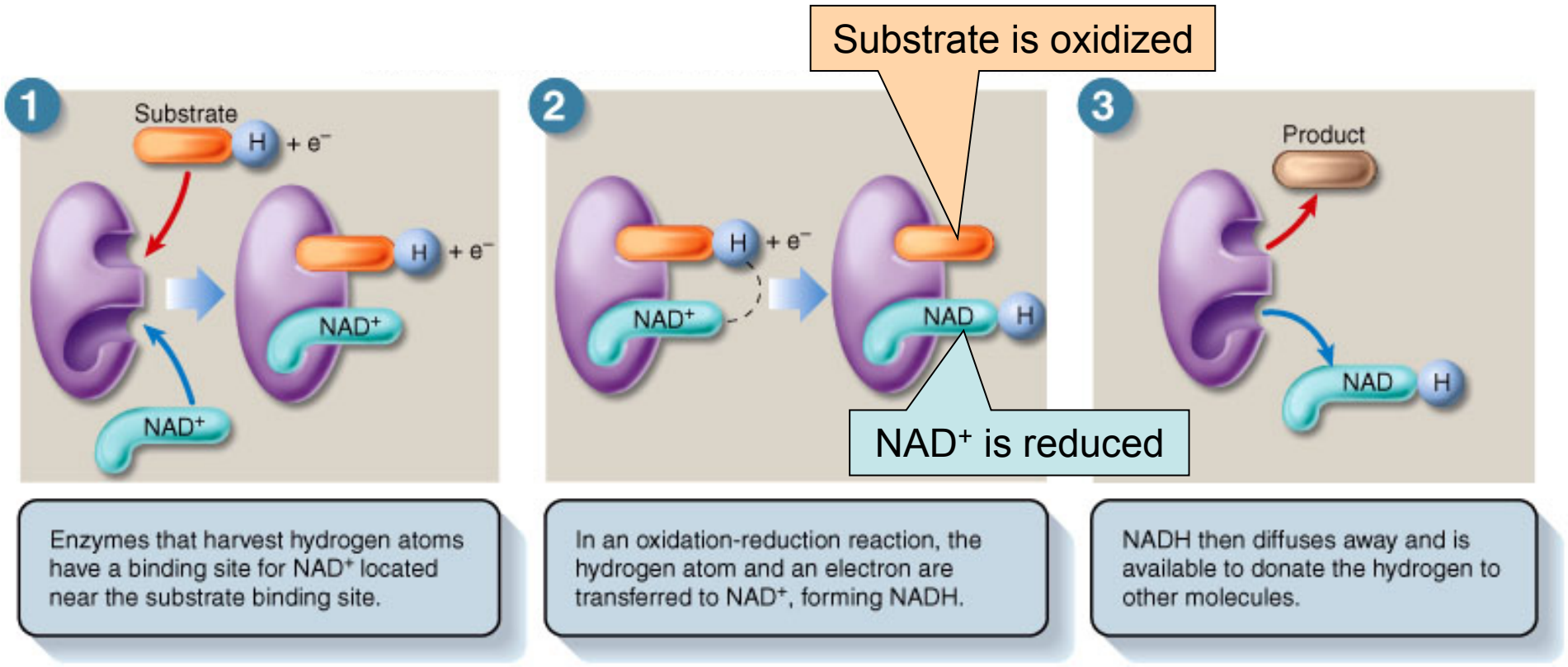


Fig. 6.21 How NAD⁺ works

The Krebs Cycle

- Takes place in the mitochondria
- It consists of nine enzyme-catalyzed reactions that can be divided into three stages
  - Stage 1
    - Acetyl coA binds a four-carbon molecule producing a six-carbon molecule
  - Stage 2
    - Two carbons are removed as CO_2
  - Stage 3
    - The four-carbon starting material is regenerated

Fig. 6.22 How the Krebs cycle works

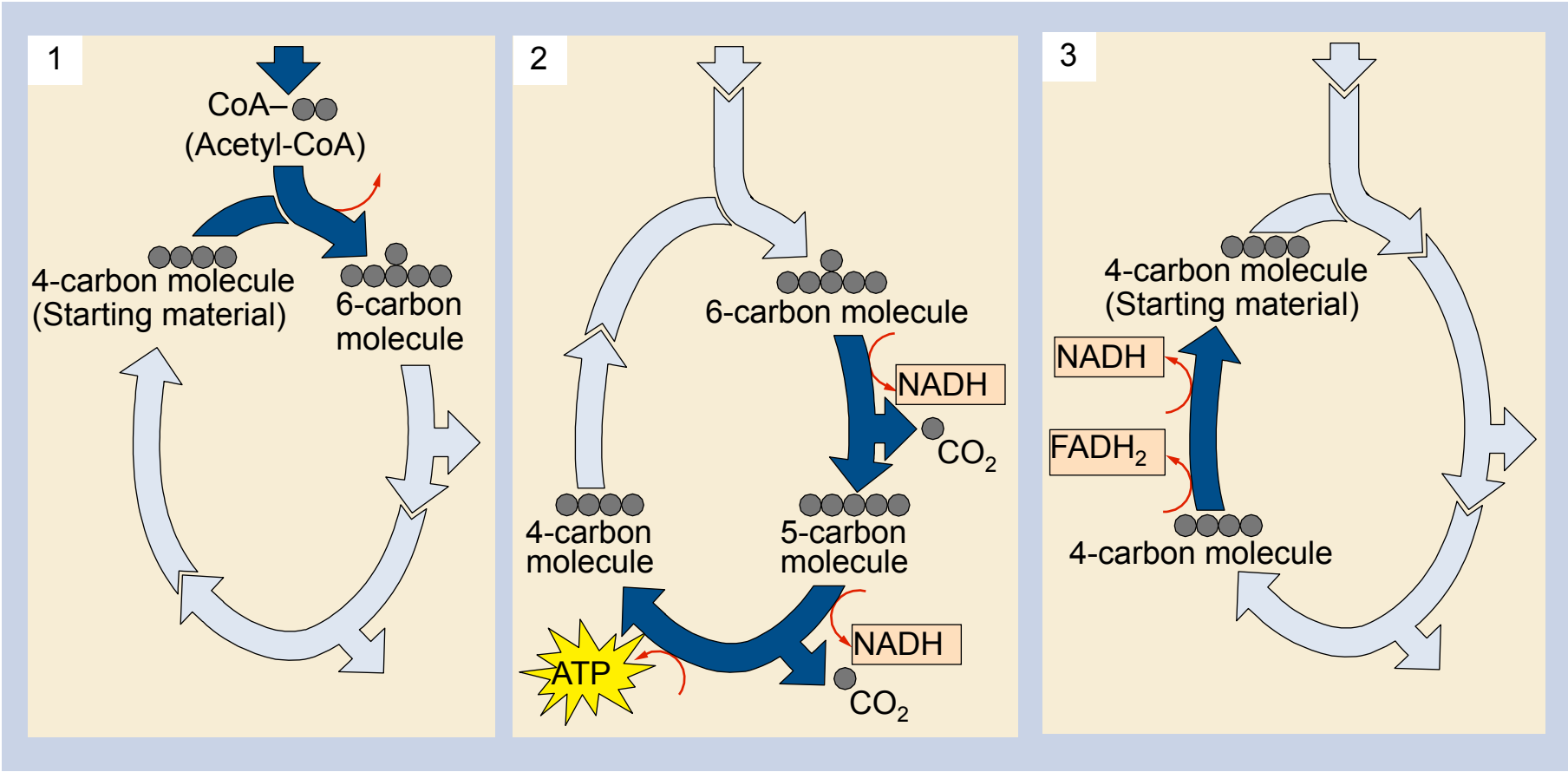
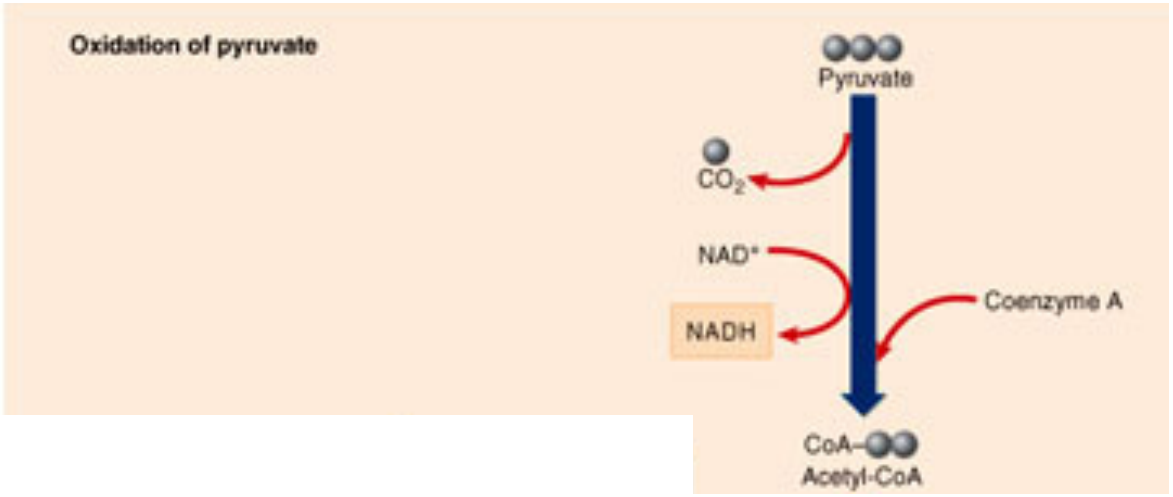
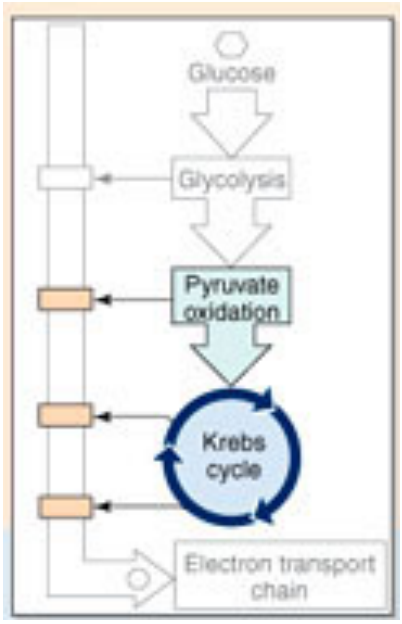
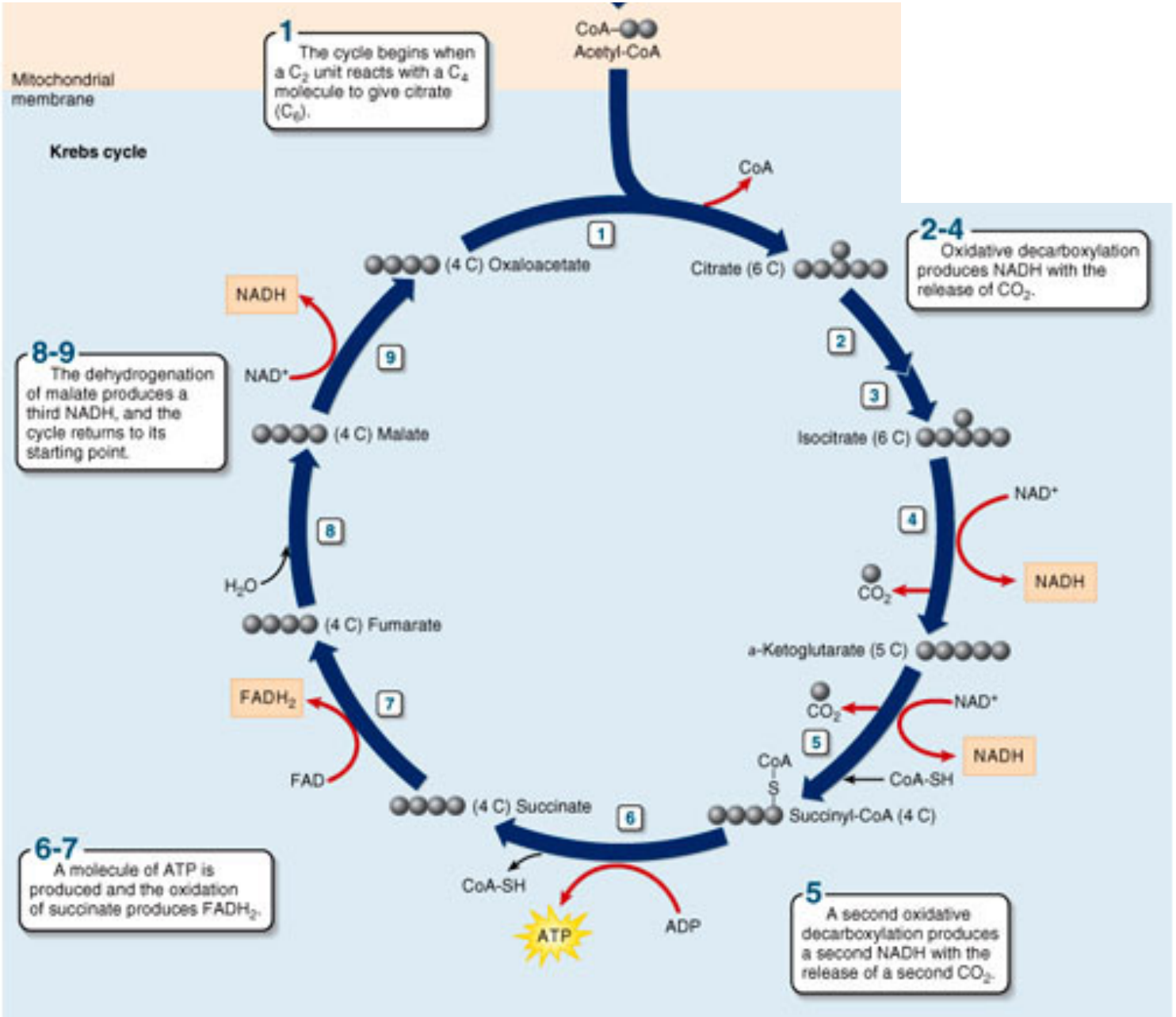


Fig. 6.23 The Krebs cycle







Fate of Glucose

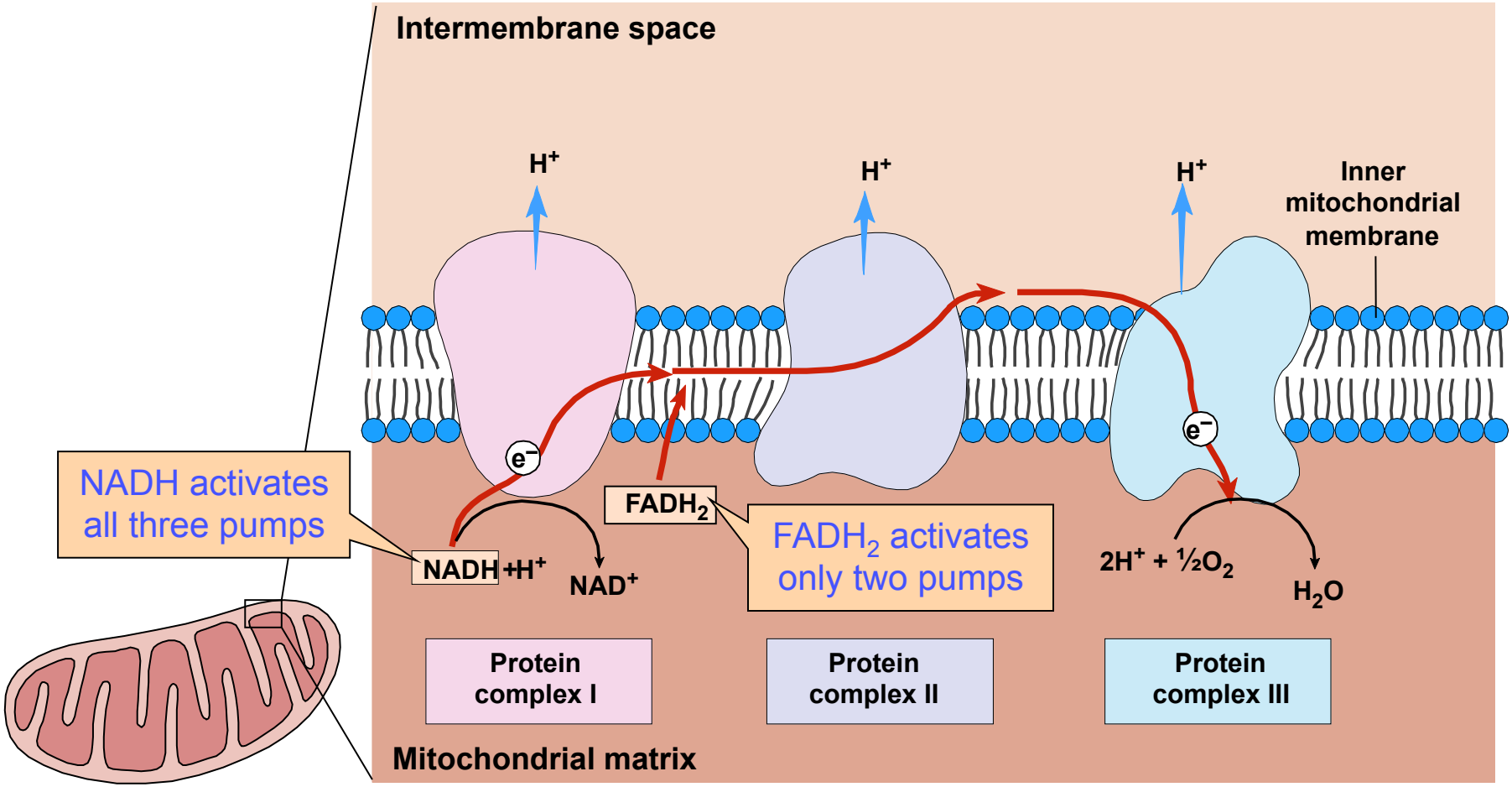
- Glucose is entirely consumed in the process of cellular respiration
  - It is converted to six molecules of CO_2

- Its energy is preserved in
  - Four ATP molecules
  - Ten NADH electron carriers
  - Two $FADH_2$ electron carriers

6.9 Using the Electrons to Make ATP

- The NADH and $FADH_2$ carry their high-energy electrons to the inner mitochondrial membrane
- There they transfer them to a series of membrane-associated carriers – the electron transport chain
  - Three of these carriers are protein complexes that pump protons out of the matrix
- The electrons are finally donated to oxygen to form water

Fig. 6.24 The electron transport chain



- The proton pumps lead to an increase in proton concentration in the intermembrane space

- The proton gradient induces the protons to reenter the matrix through ATP synthase channels

- The proton reentry drives the synthesis of ATP by chemiosmosis

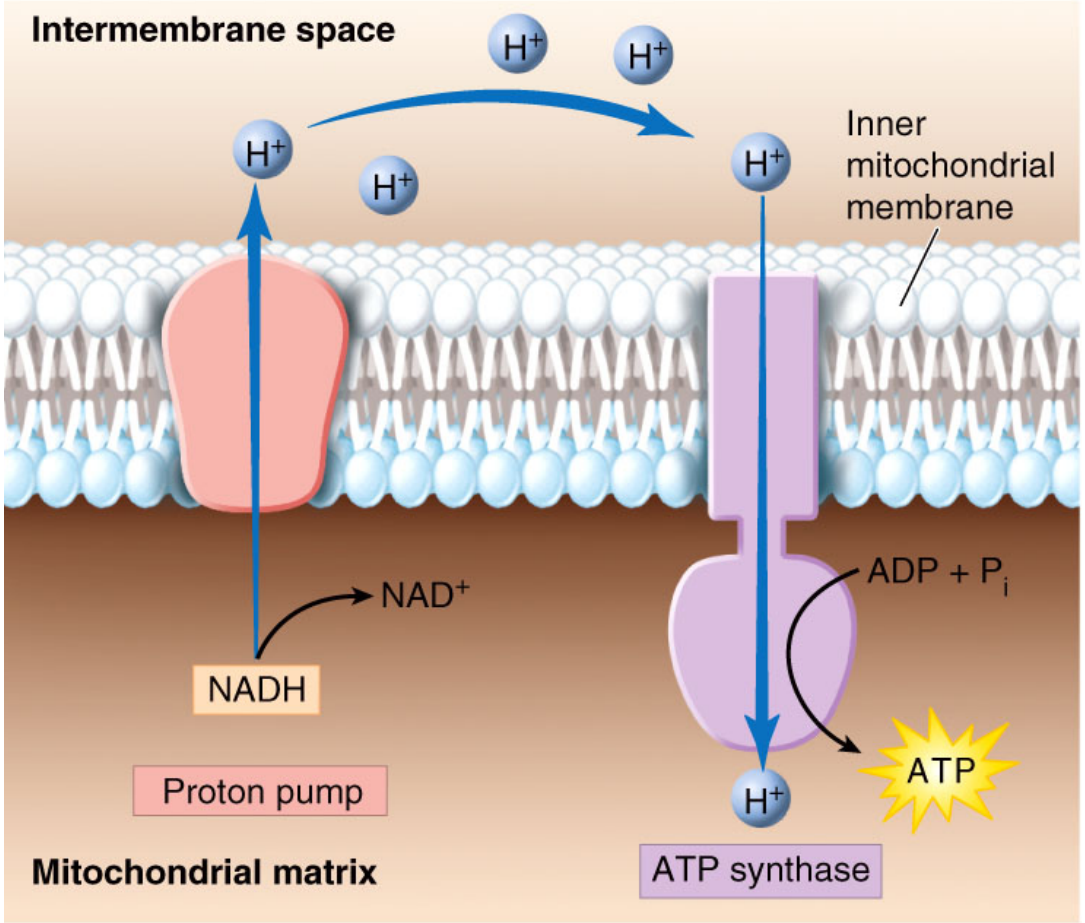
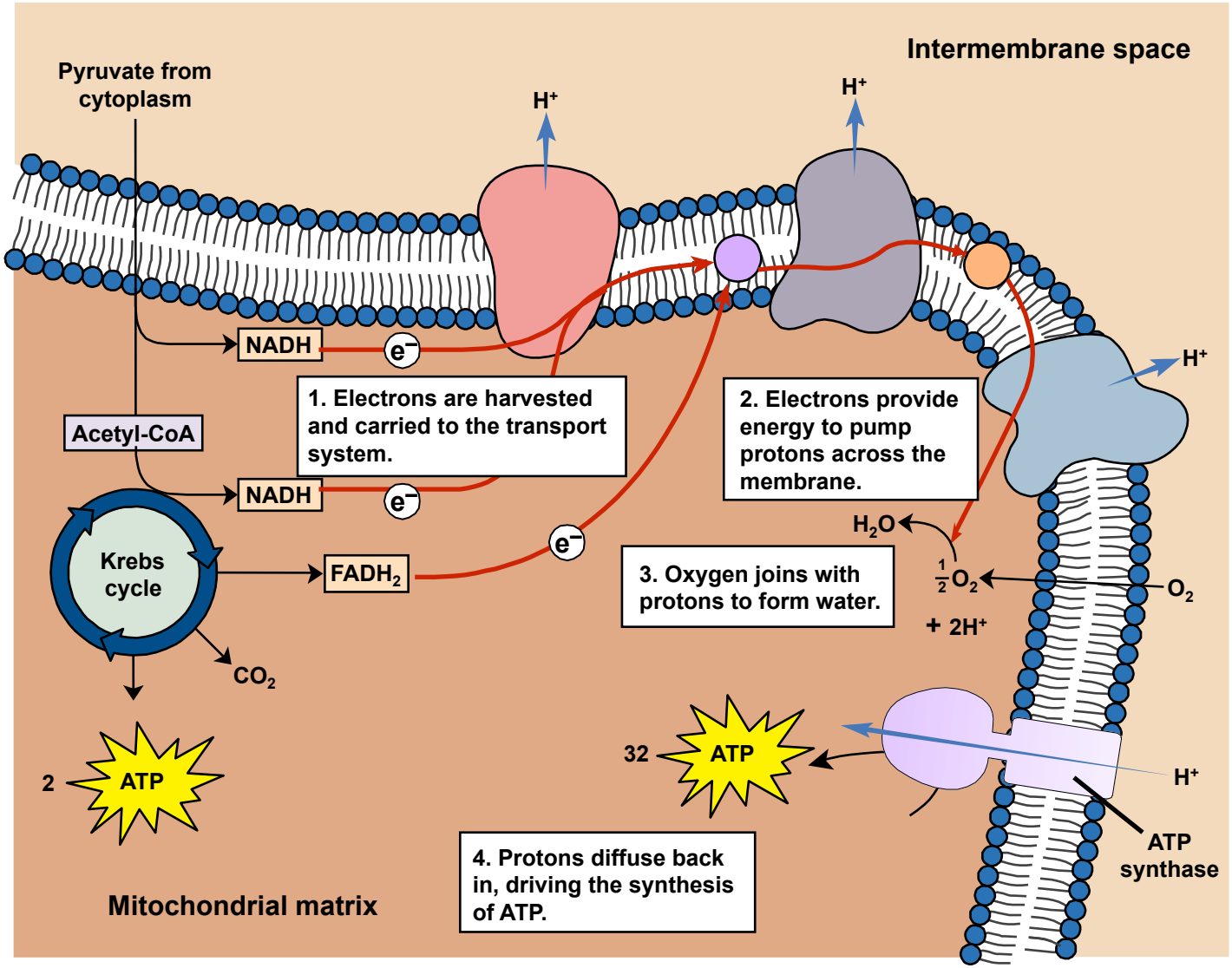


Fig. 6.25

Fig. 6.26 An overview of the electron transport chain and chemiosmosis



Other Sources of Energy

- Food sources, other than sugars, can be used in cellular respiration

- These complex molecules are first digested into simpler subunits
  - These subunits are modified into intermediates
    - These intermediates enter cellular respiration at different steps

Fig. 6.27
How cells obtain energy from foods