How Cells Harvest Chemical Energy

Global Athlete Outreach Program

US CytoThesis Systems Medicine Center

www.CytoThesis.US

US OncoTherapy Systems BioMedicine Group

CytoThesis Bioengineering Research Group

General Biology – Dept Mathematics

How is a Marathoner Different from a Sprinter ?

- Long-distance runners have many slow muscle fibers in their muscles
  - Slow muscle fibers break down glucose for ATP production aerobically using oxygen
  - These muscle cells can sustain repeated, long contractions

- Sprinters have more fast muscle fibers
  - Fast fibers make ATP without oxygen—anaerobically
  - They can contract quickly and supply energy for short bursts of intense activity

- The dark meat of a cooked turkey is an example of slow fiber muscle
  - Leg muscles support sustained activity
  - The white meat consists of fast fibers (less myoglobin)
  - Wing muscles allow for quick bursts of flight

INTRODUCTION TO CELLULAR RESPIRATION

- Nearly all the cells in our body break down sugars for ATP production
- Most cells of most organisms harvest energy aerobically, like slow muscle fibers
  - The aerobic harvesting of energy from sugar is called cellular respiration
  - Cellular respiration yields CO_2, H_2O, and a large amount of ATP

6.1 Breathing supplies oxygen to our cells and removes carbon dioxide

- Breathing and cellular respiration are closely related

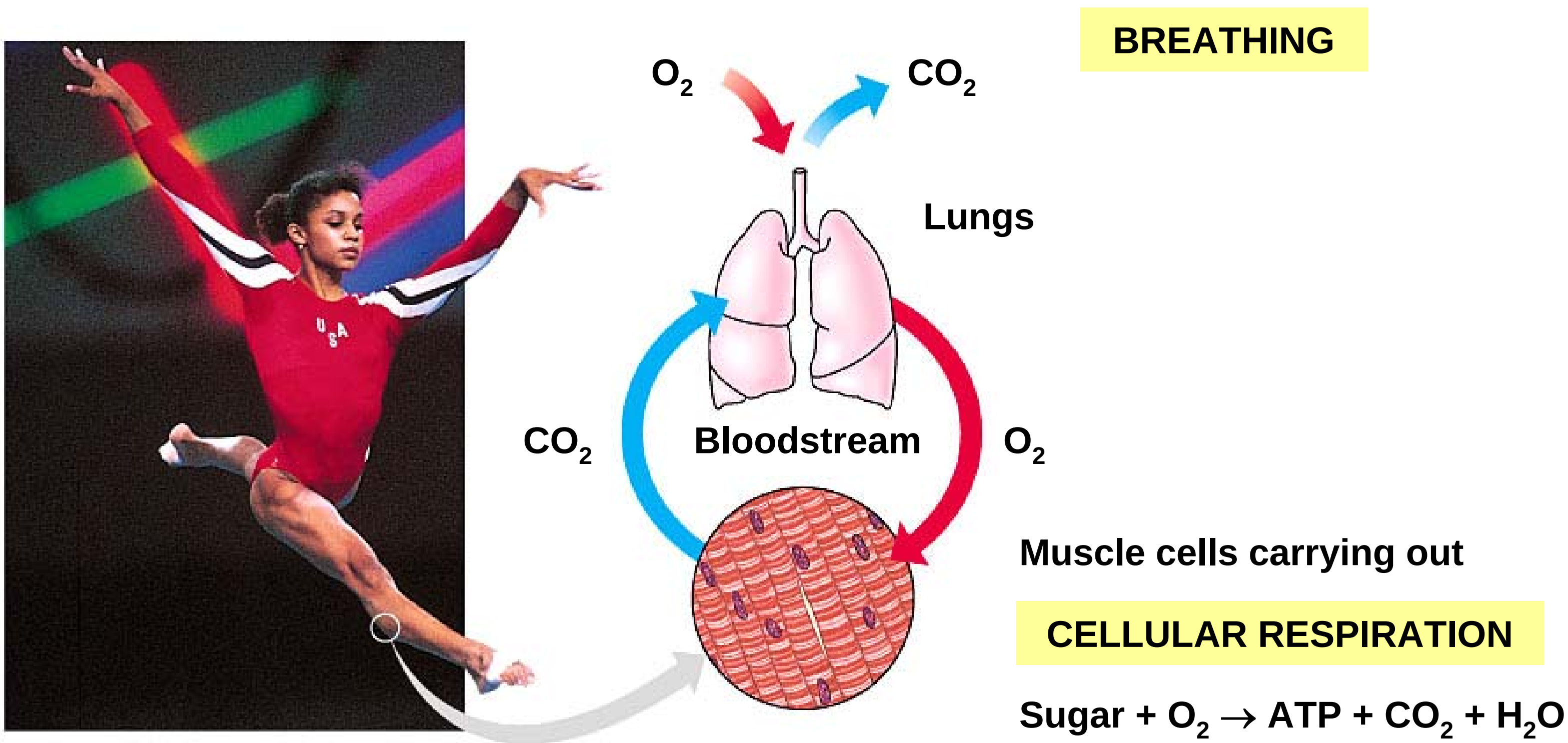


Figure 6.1

6.2 Cellular respiration banks energy in ATP molecules

- Cellular respiration breaks down glucose molecules and banks their energy in ATP
  - The process uses O_2 and releases CO_2 and H_2O

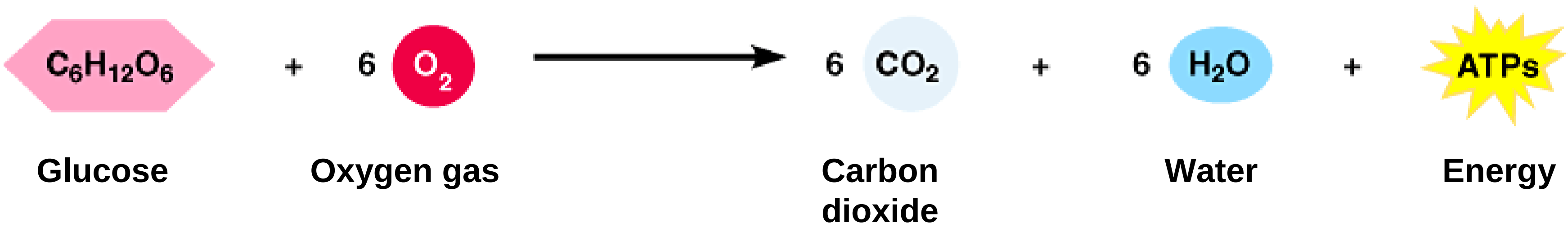


Figure 6.2A

- The efficiency of cellular respiration (and comparison with an auto engine)

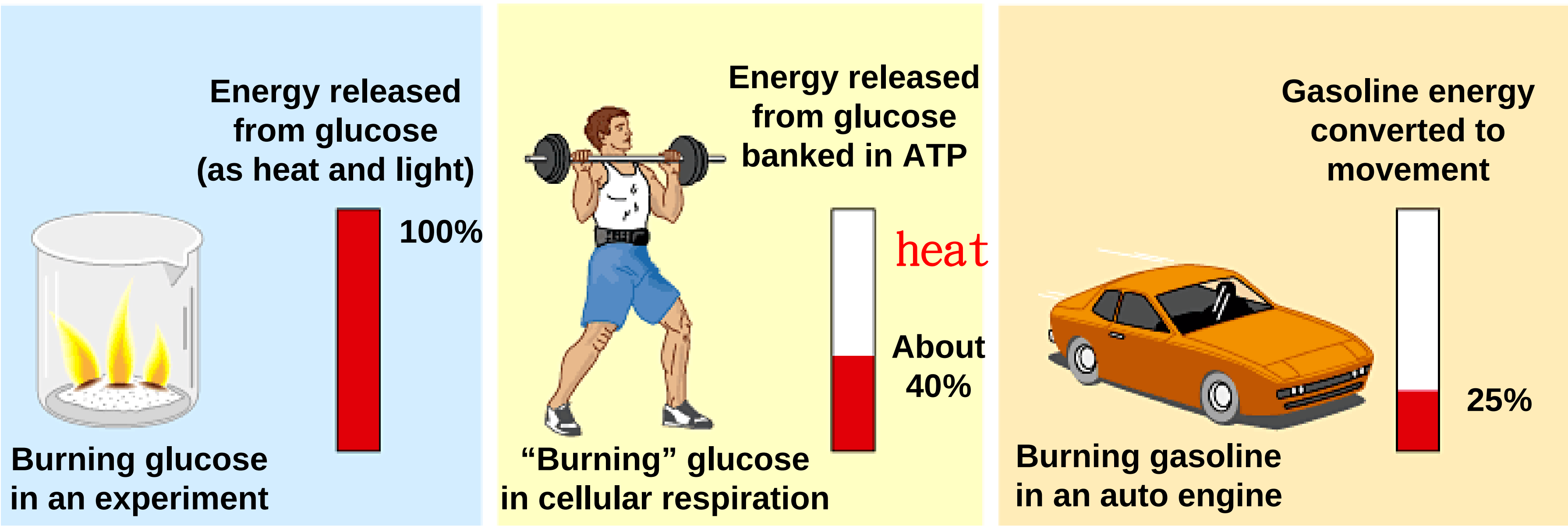


Figure 6.2B

6.3 Connection: The human body uses energy from ATP for all its activities

- ATP powers almost all cell and body activities

ENERGY CONSUMED BY VARIOUS ACTIVITIES (IN KCAL)

Activity	Kcal Consumed per Hour by a 67.5-kg (150-lb) Person*
Bicycling (racing)	514
Bicycling (slowly)	170
Dancing (slow)	202
Dancing (fast)	599
Driving a car	61
Eating	28
Gymnastics	186
Laboratory work	73
Piano playing	73
Running (7 min/mi)	865
Sitting (writing)	28
Sitting (playing chess)	30
Sleeping or lying still	0
Standing (relaxed)	32
Swimming (2 mph)	535
Walking (3 mph)	158
Walking (4 mph)	231

* Not including kcal needed for body maintenance

Table 6.3

BASIC MECHANISMS OF ENERGY RELEASE AND STORAGE

6.4 Cells tap energy from electrons transferred from organic fuels to oxygen

- Glucose gives up energy as it is oxidized

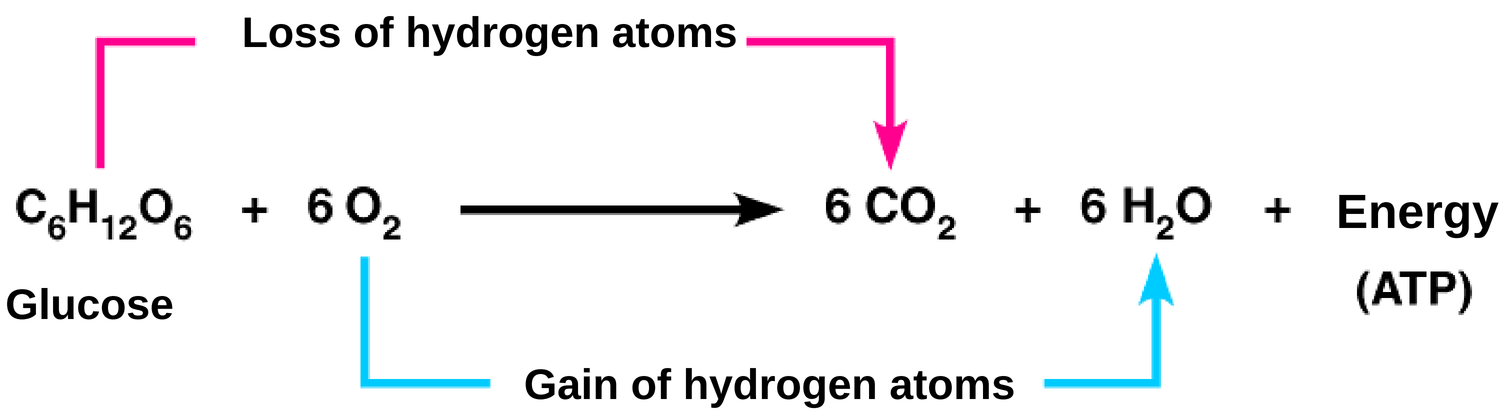
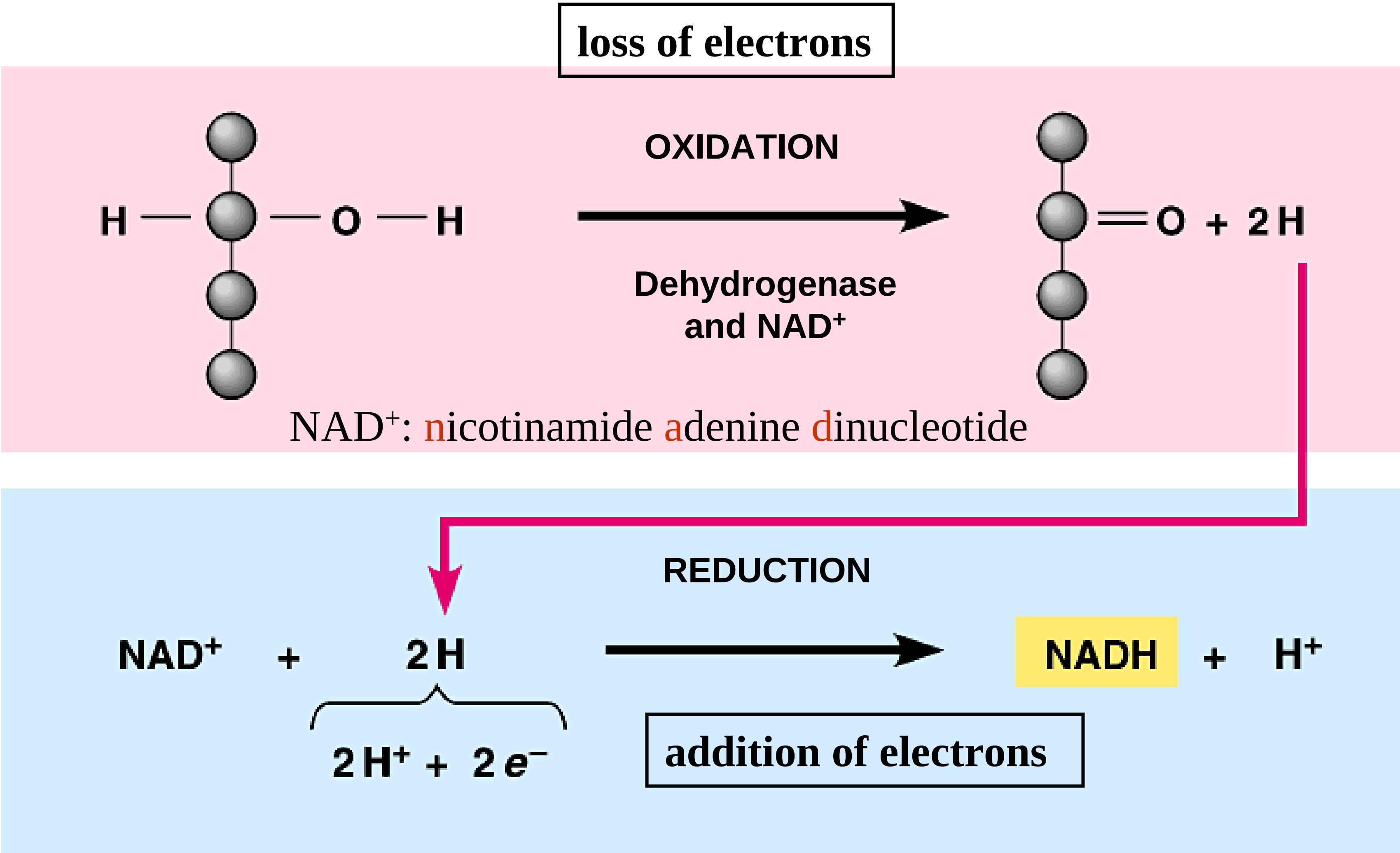


Figure 6.4

6.5 Hydrogen carriers such as NAD^+ shuttle electrons in redox reactions

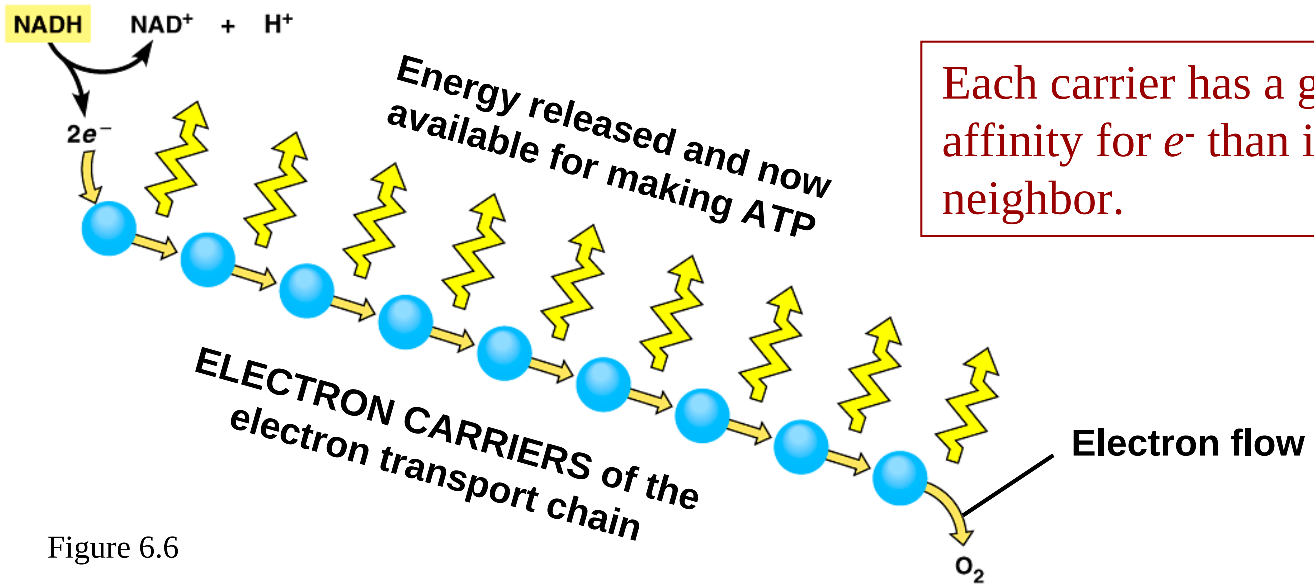
- The movement of electrons from one molecule to another is an oxidation-reduction reaction, or **redox reaction**
- In a redox reaction, the loss of electrons from one substance is called oxidation, and the addition of electrons to another substance is called reduction
- Enzymes remove electrons from glucose molecules and transfer them to a coenzyme

Figure 6.5


loss of electrons
OXIDATION
H — C — O — H
Dehydrogenase
and NAD+
=O + 2H
NAD+: nicotinamide adenine dinucleotide
REDUCTION
NAD+ + 2H
2H+ + 2e−
NADH + H+
addition of electrons

6.6 Redox reactions release energy when electrons "fall" from a hydrogen carrier to oxygen

- NADH delivers electrons to a series of electron carriers in an electron transport chain
  - As electrons move from carrier to carrier, their energy is released in small quantities



Each carrier has a greater affinity for e^- than its uphill neighbor.

Figure 6.6

- In an explosion, 0_2 is reduced in one step.
- All the energy is released as heat and light.

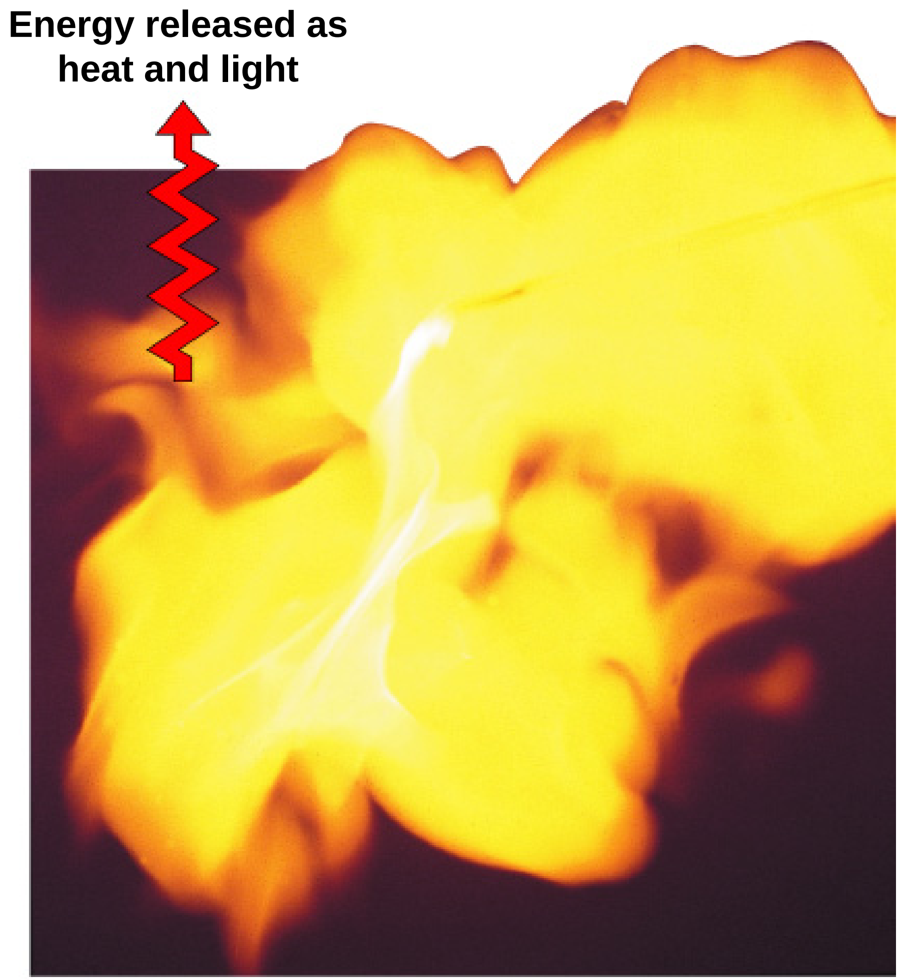


Figure 6.6B

6.7 Two mechanisms generate ATP

- Cells use the energy released by “falling” electrons to pump H^+ ions across a membrane
  - The energy of the gradient is harnessed to make ATP by the process of chemiosmosis

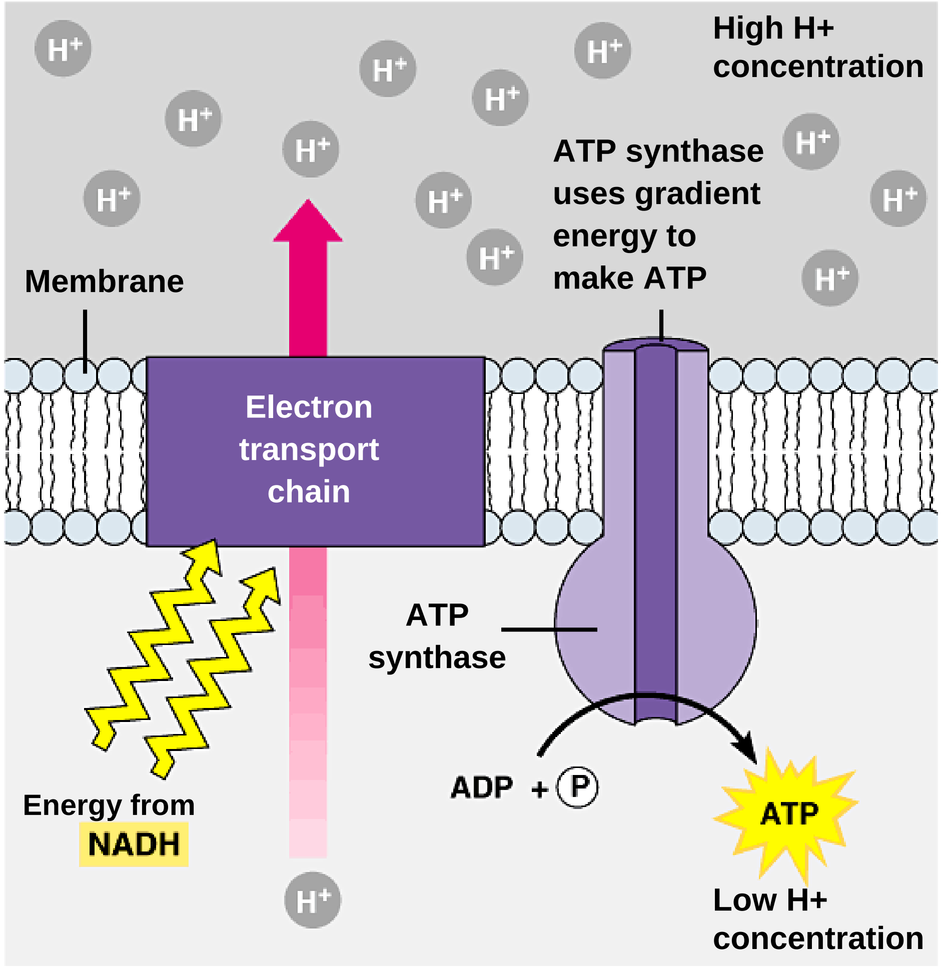


Figure 6.7A

- ATP can also be made by transferring phosphate groups from organic molecules to ADP
  - This process is called substrate-level phosphorylation

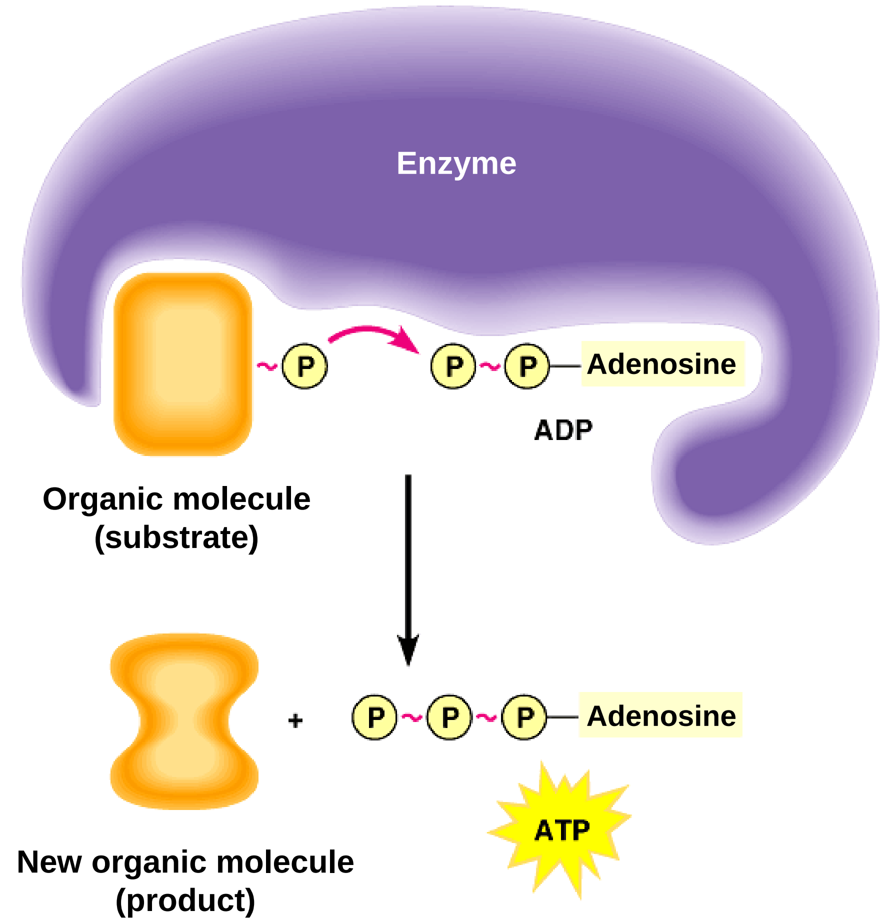


Figure 6.7B

6.8 Overview: Respiration occurs in three main stages

- Cellular respiration oxidizes sugar and produces ATP in three main stages
  - Glycolysis occurs in the cytoplasm
  - The Krebs cycle and the electron transport chain occur in the mitochondria

- An overview of cellular respiration

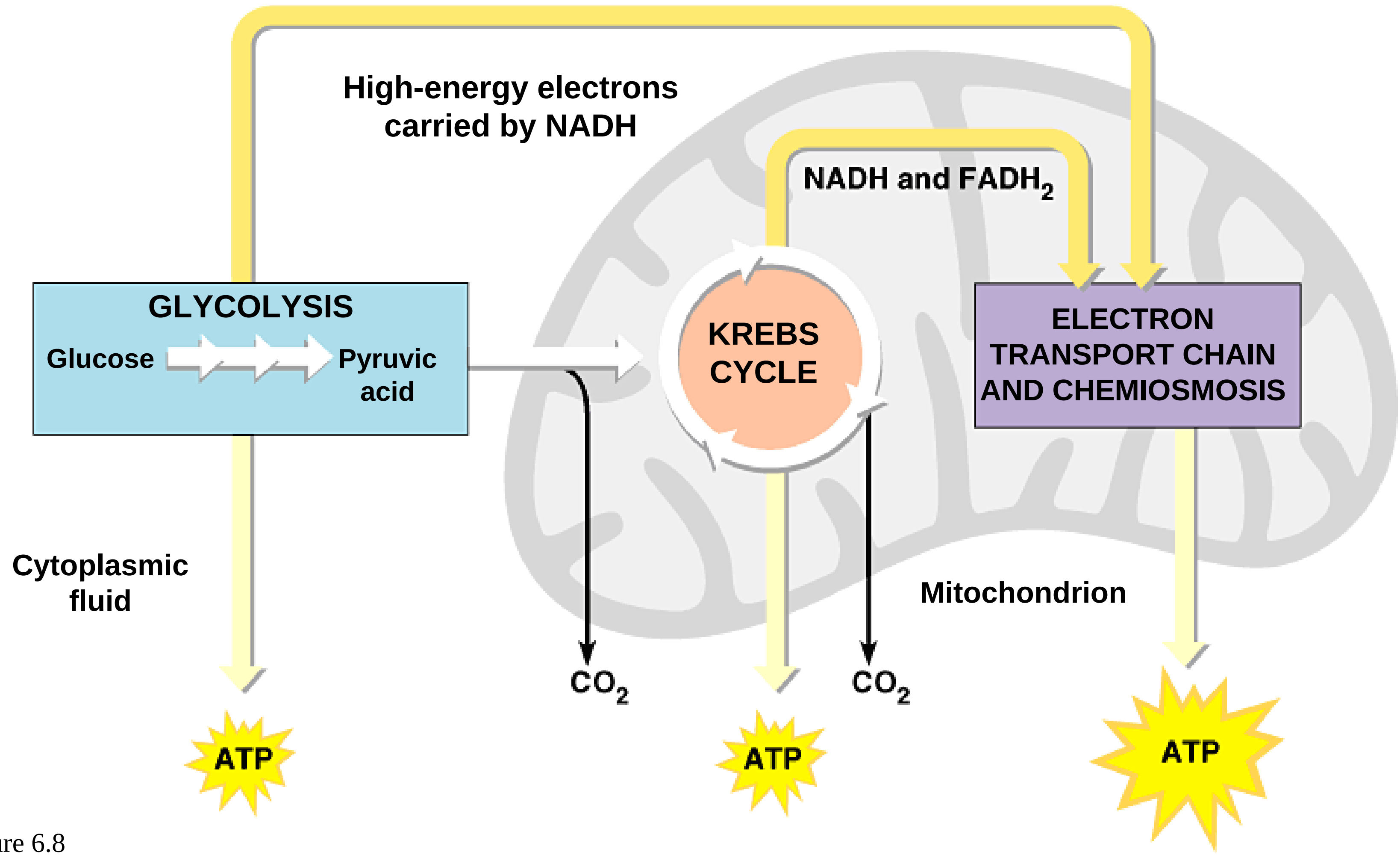


Figure 6.8

6.9 Glycolysis harvests chemical energy by oxidizing glucose to pyruvic acid

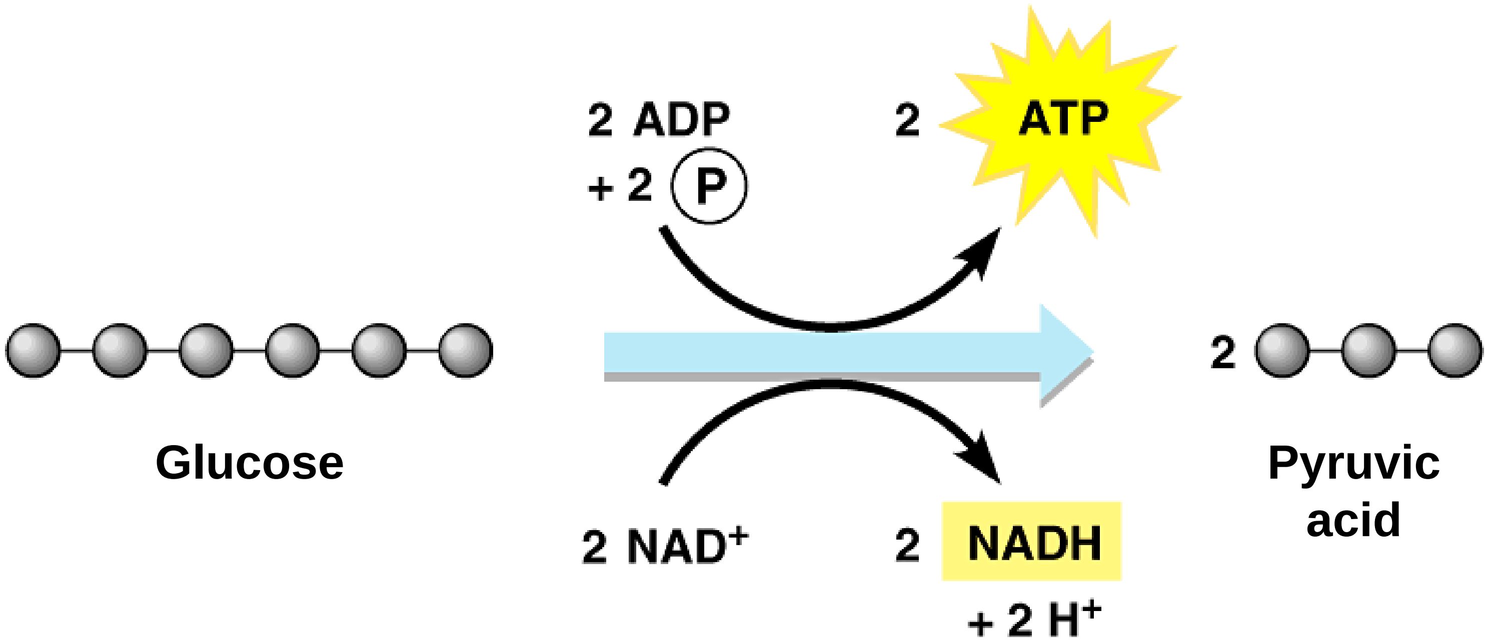


Figure 6.9A

- Details of glycolysis

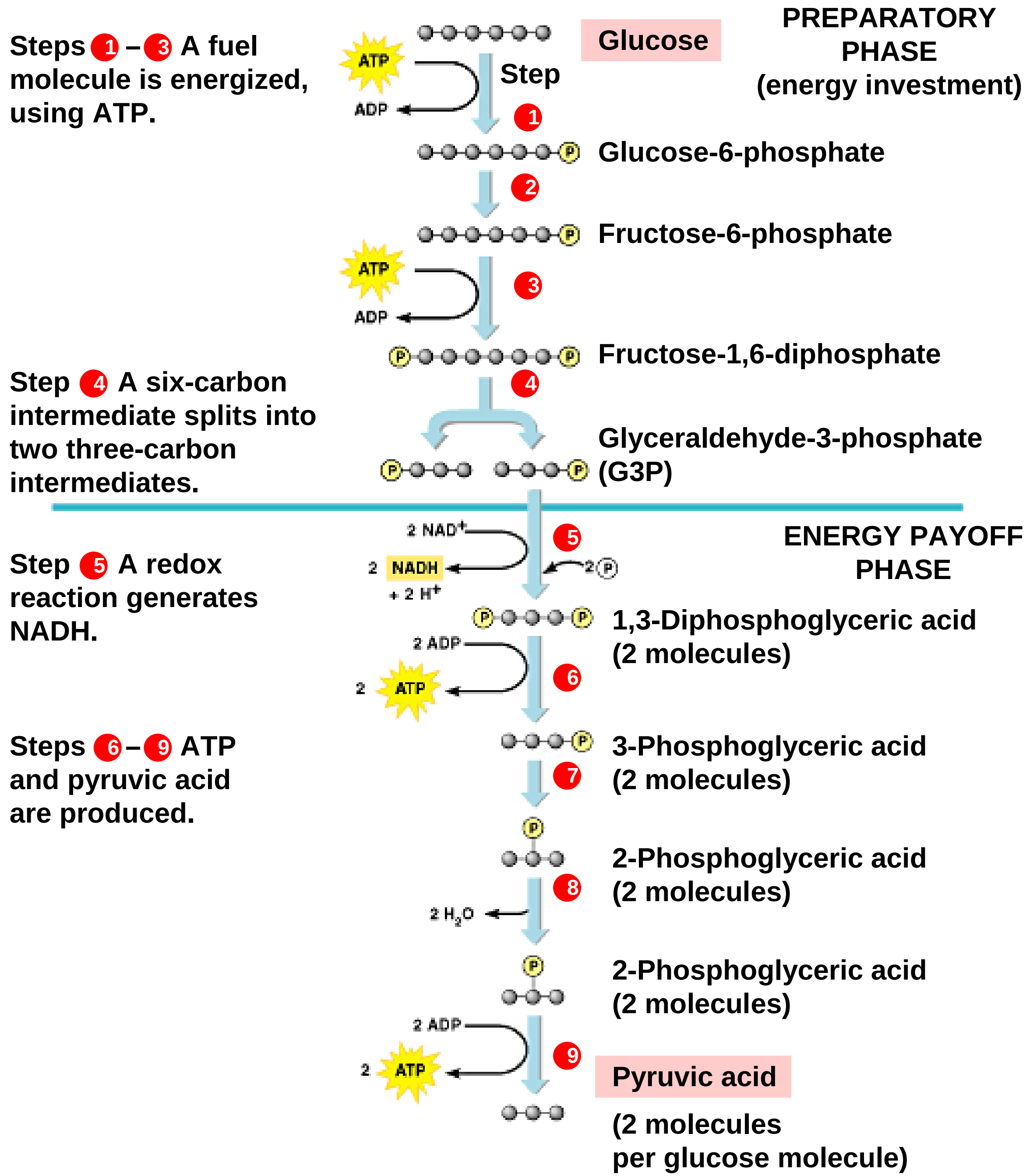


Figure 6.9B

6.10 Pyruvic acid is chemically groomed for the Krebs cycle

- Each pyruvic acid molecule is broken down to form CO_2 and a two-carbon acetyl group, which enters the Krebs cycle

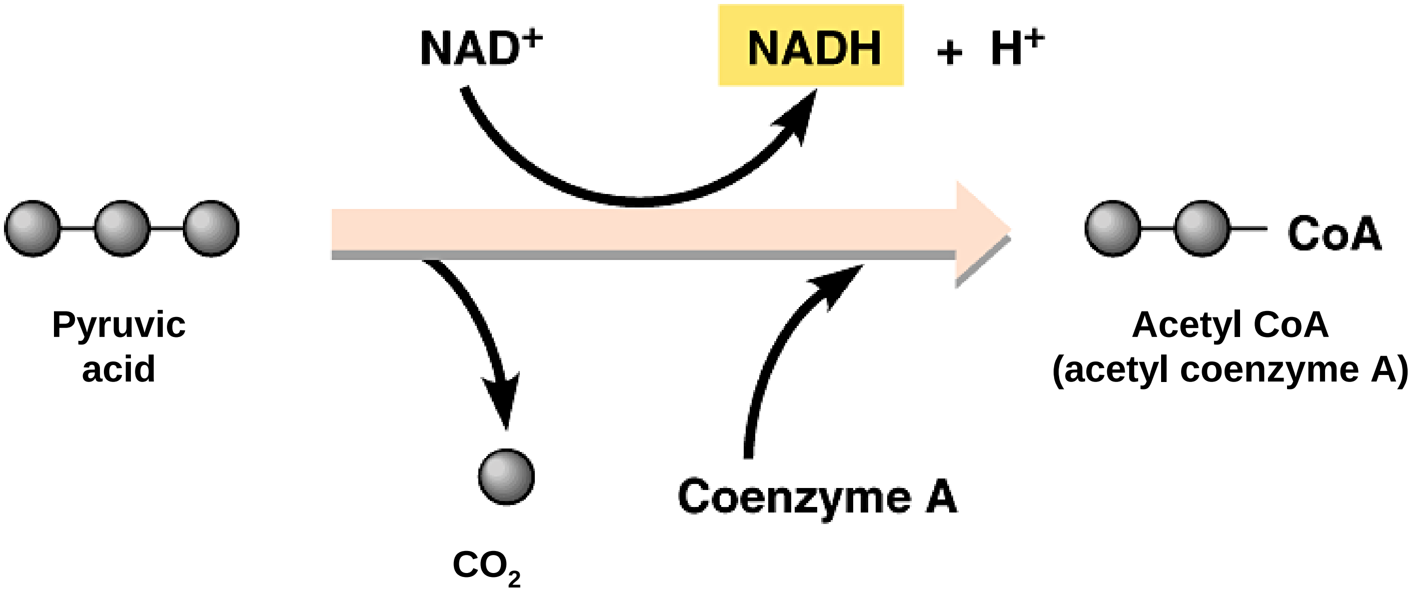


Figure 6.10

6.11 The Krebs cycle completes the oxidation of organic fuel, generating many NADH and $FADH_2$ molecules

- The Krebs cycle is a series of reactions in which enzymes strip away electrons and H^+ from each acetyl group

$FADH_2$: flavin adenine dinucleotide
- reduced

FAD: flavin adenine dinucleotide
- oxidized

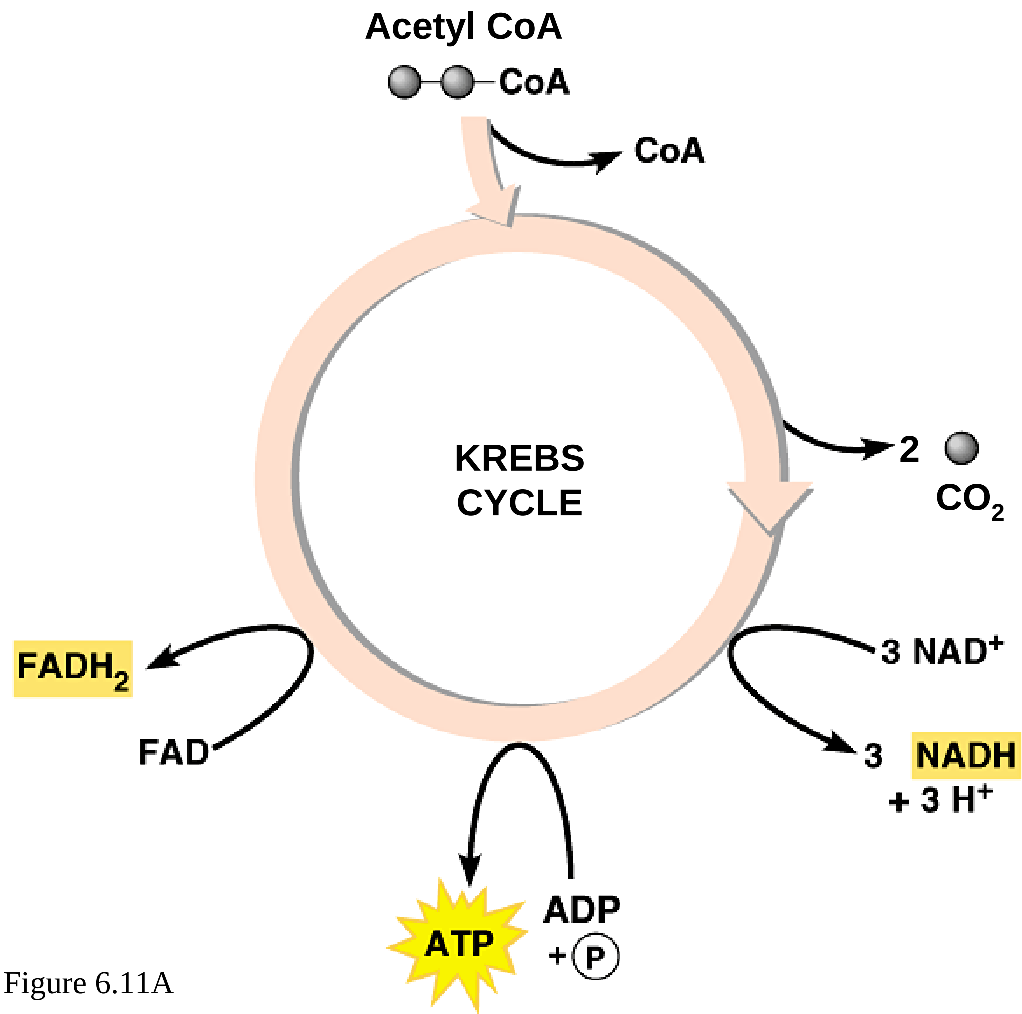
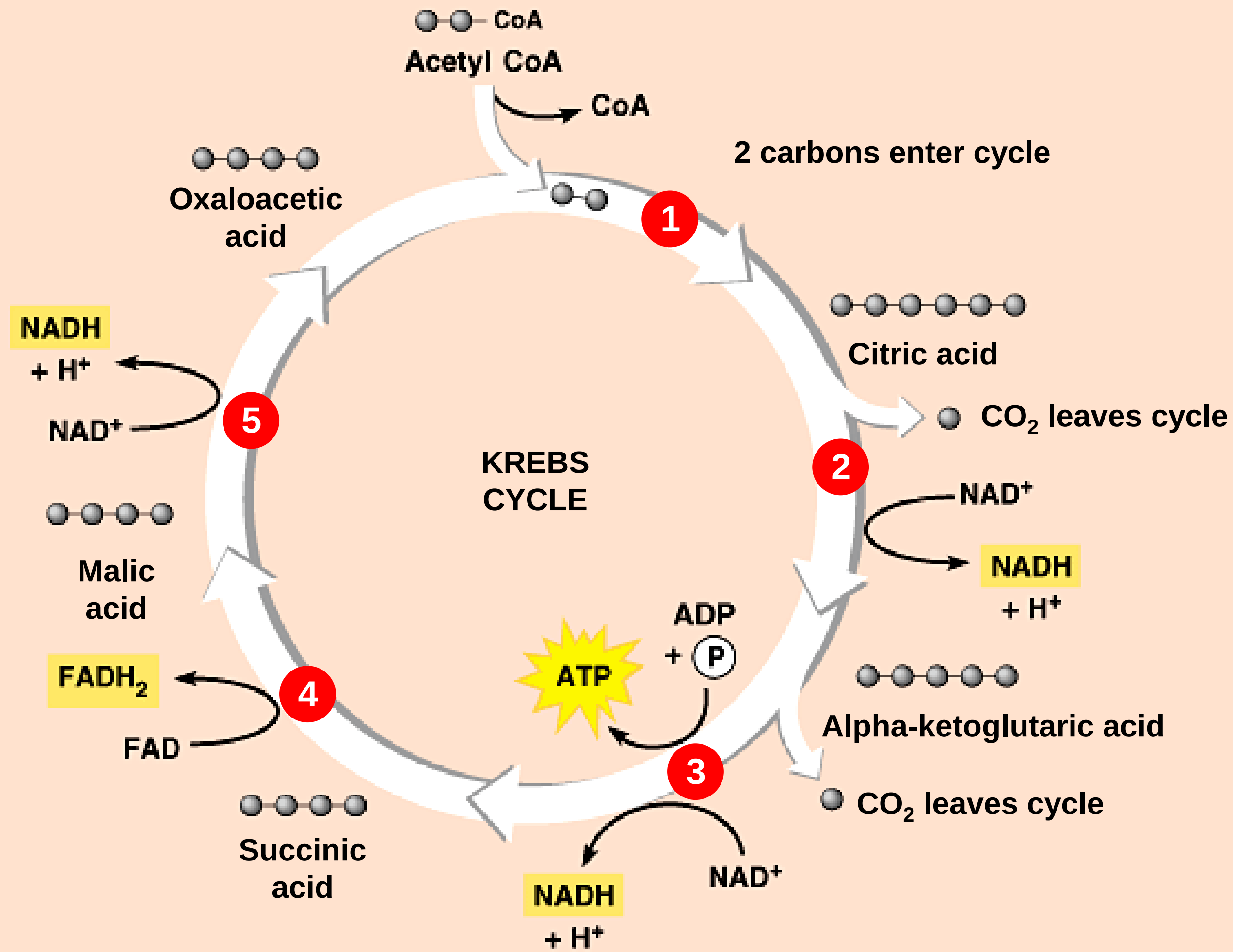


Figure 6.11A



Step 1
Acetyl CoA stokes the furnace

Steps 2 and 3
NADH, ATP, and CO_2 are generated during redox reactions.

Steps 4 and 5
Redox reactions generate $FADH_2$ and NADH.

Figure 6.11B

6.12 Chemiosmosis powers most ATP production

- The electrons from NADH and $FADH_2$ travel down the electron transport chain to oxygen
- Energy released by the electrons is used to pump H^+ into the space between the mitochondrial membranes
- In chemiosmosis, the H^+ ions diffuse back through the inner membrane through ATP synthase complexes, which capture the energy to make ATP

- Chemiosmosis in the mitochondrion

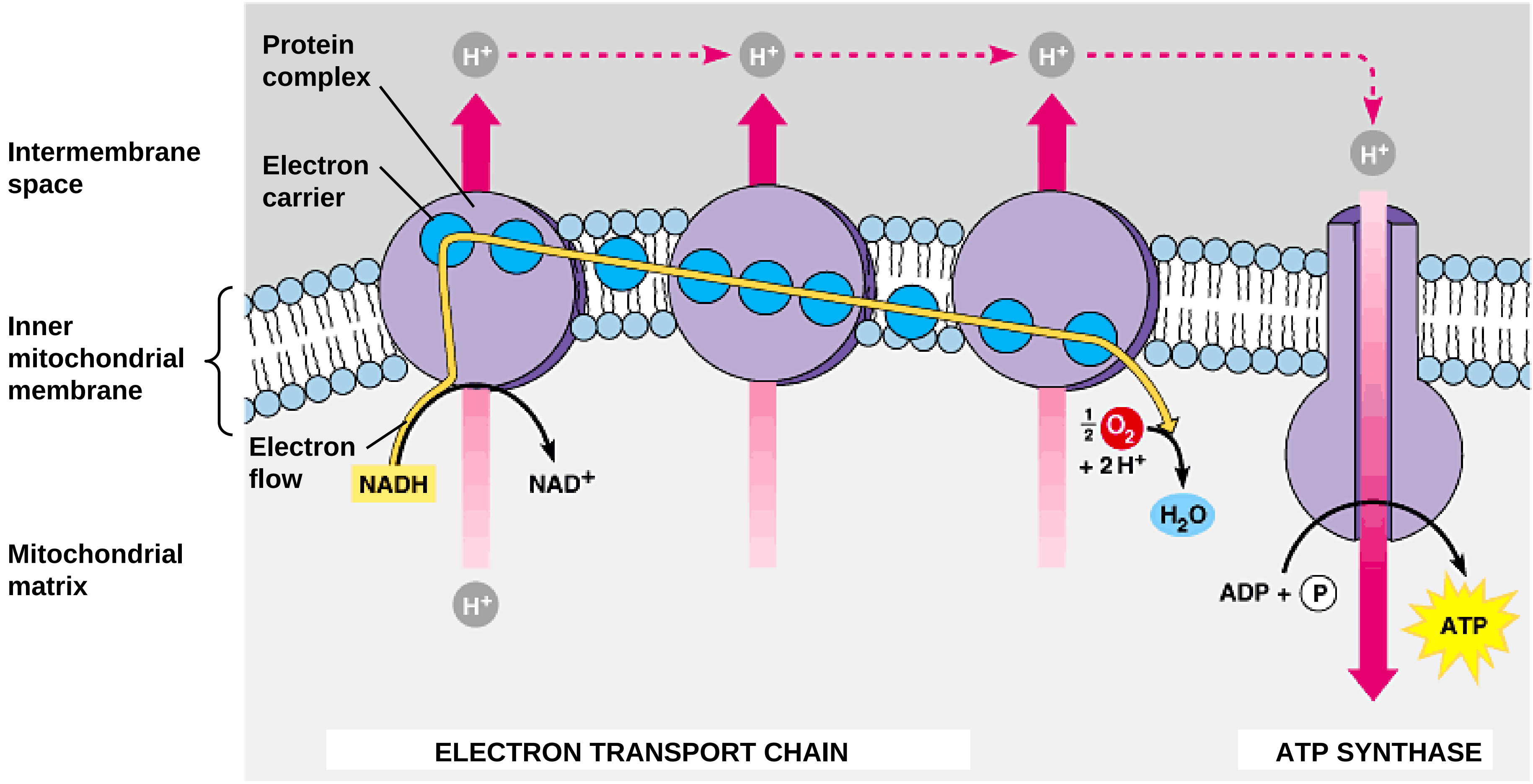


Figure 6.12

6.13 Connection: Certain poisons interrupt critical events in cellular respiration

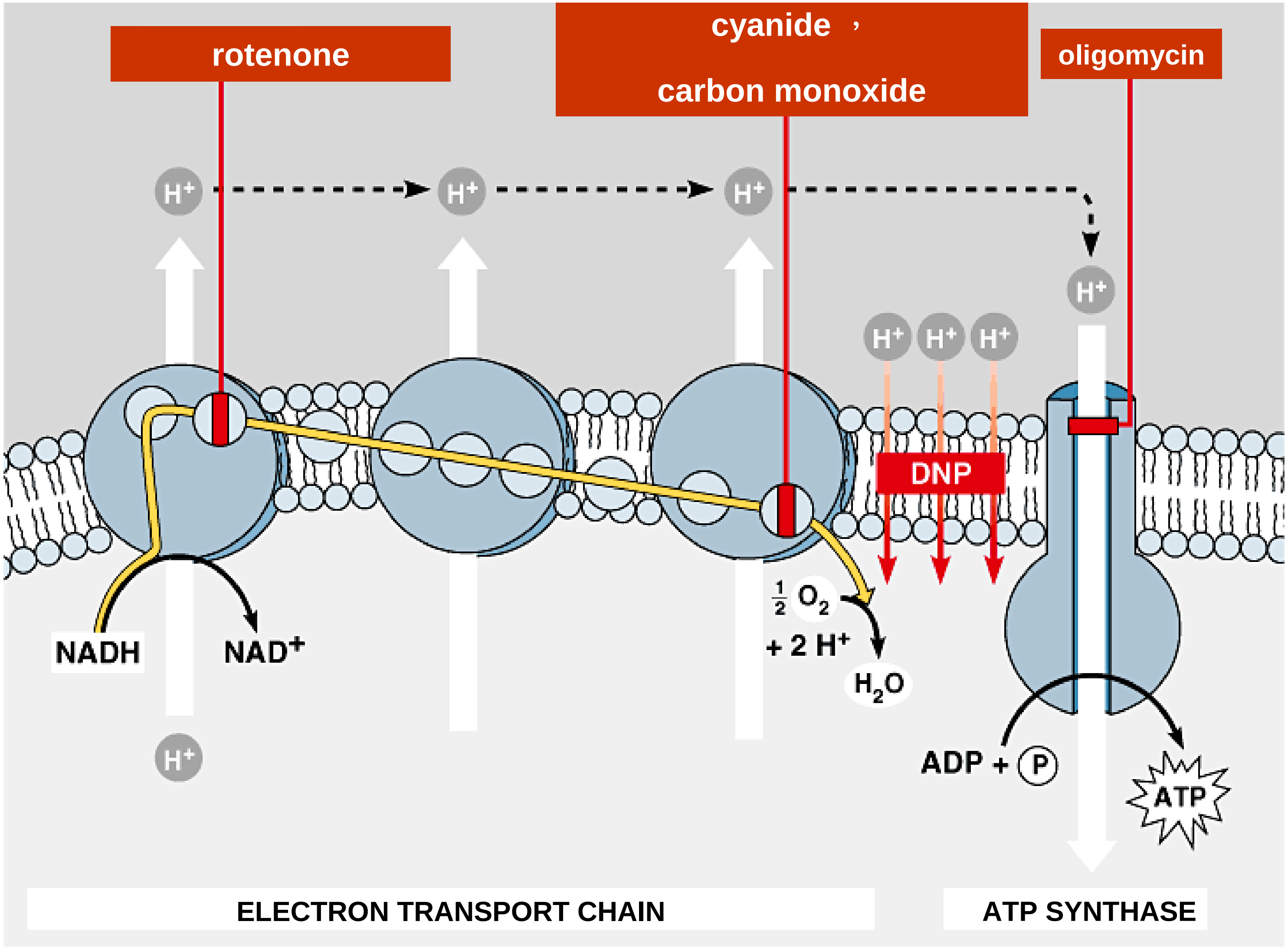


Figure 6.13

6.14 Review: Each molecule of glucose yields many molecules of ATP

- For each glucose molecule that enters cellular respiration, chemiosmosis produces up to 38 ATP molecules

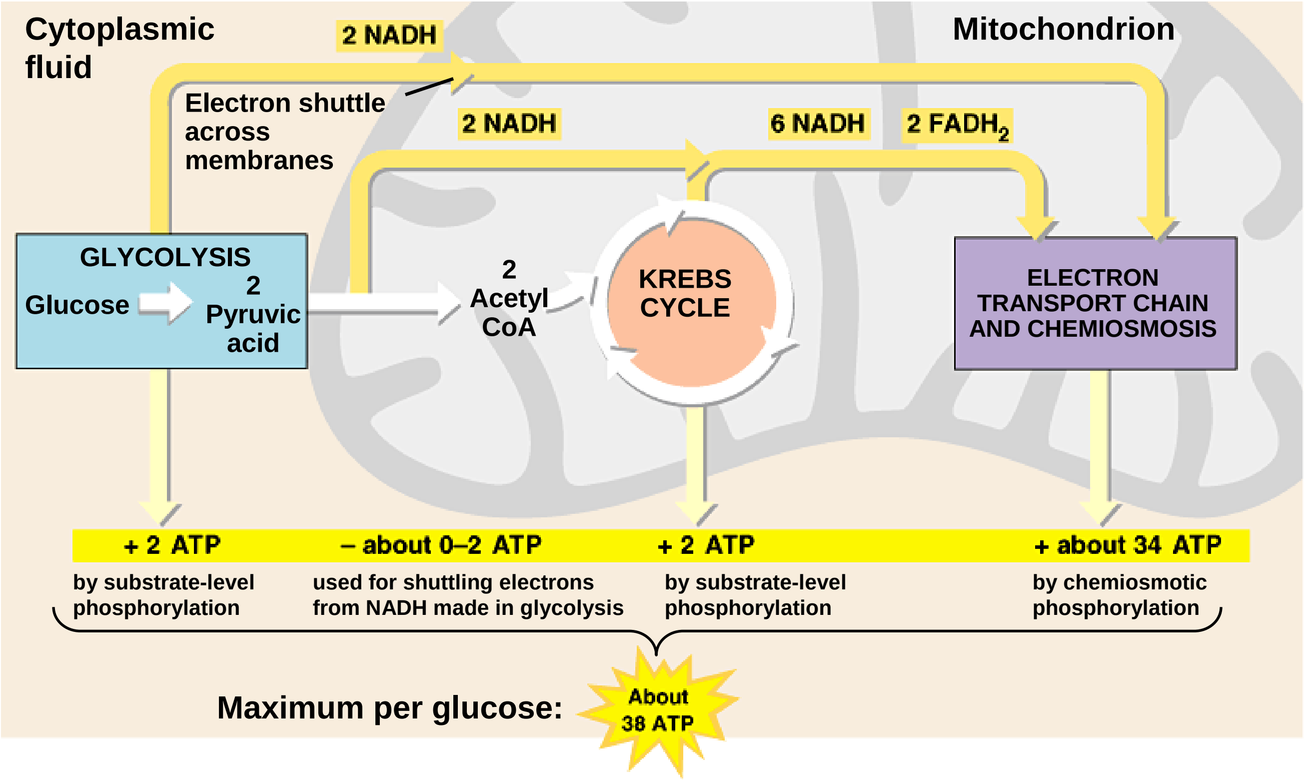


Figure 6.14

6.15 Fermentation is an anaerobic alternative to aerobic respiration

- Under anaerobic conditions, many kinds of cells can use glycolysis alone to produce small amounts of ATP
  - But a cell must have a way of replenishing NAD+

- In alcoholic fermentation pyruvic acid is converted to CO_2 and ethanol
  - This recycles NAD^+ to keep glycolysis working

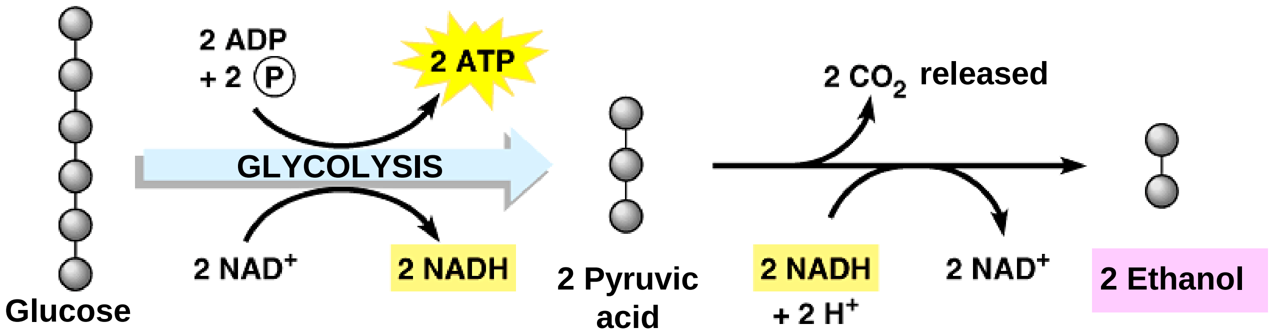


Figure 6.15A

Figure 6.15C

- In lactic acid fermentation pyruvic acid is converted to lactic acid
  - As in alcoholic fermentation, NAD^+ is recycled
- Lactic acid fermentation is used to make cheese and yogurt

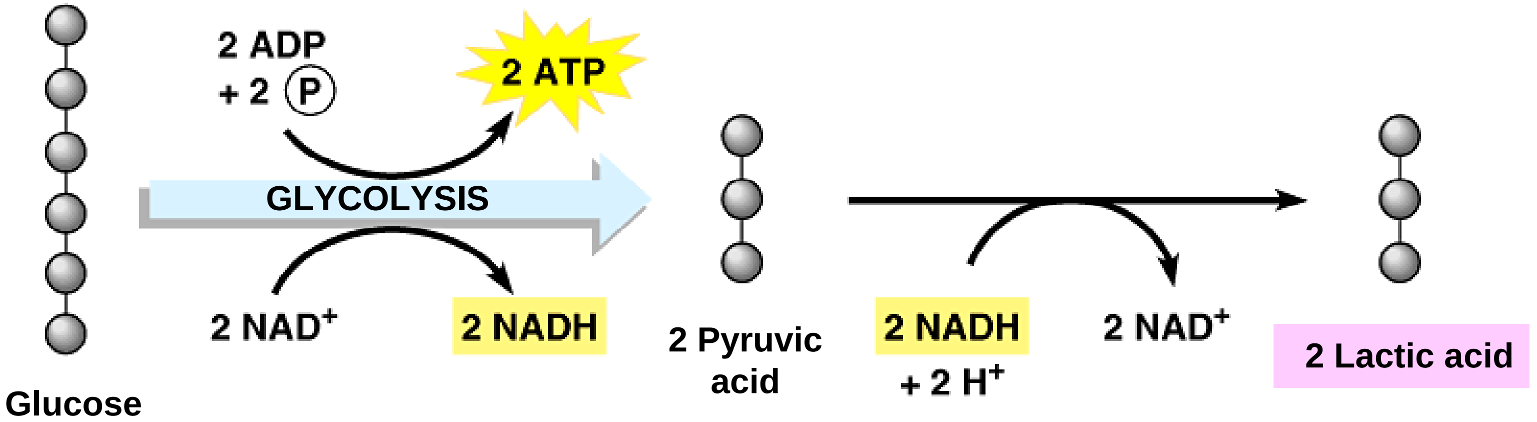


Figure 6.15B

INTERCONNECTIONS BETWEEN MOLECULAR BREAKDOWN AND SYNTHESIS

6.16 Cells use many kinds of organic molecules as fuel for cellular respiration

- Polysaccharides can be hydrolyzed to monosaccharides and then converted to glucose for glycolysis
- Proteins can be digested to amino acids, which are chemically altered and then used in the Krebs cycle
- Fats are broken up and fed into glycolysis and the Krebs cycle

- Pathways of molecular breakdown

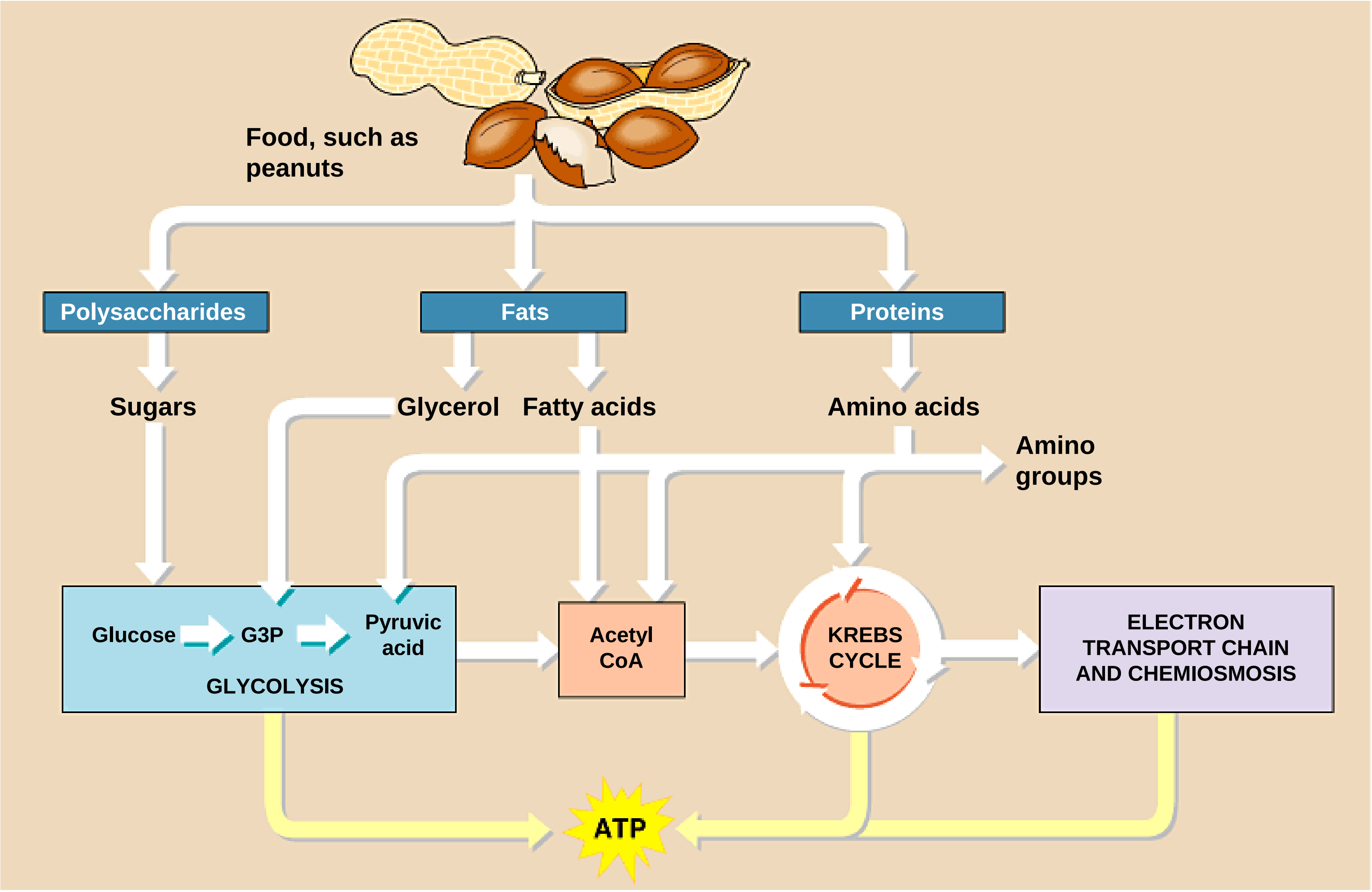


Figure 6.16

6.17 Food molecules provide raw materials for biosynthesis

- In addition to energy, cells need raw materials for growth and repair
  - Some are obtained directly from food
  - Others are made from intermediates in glycolysis and the Krebs cycle
- Biosynthesis consumes ATP

- Biosynthesis of macromolecules from intermediates in cellular respiration

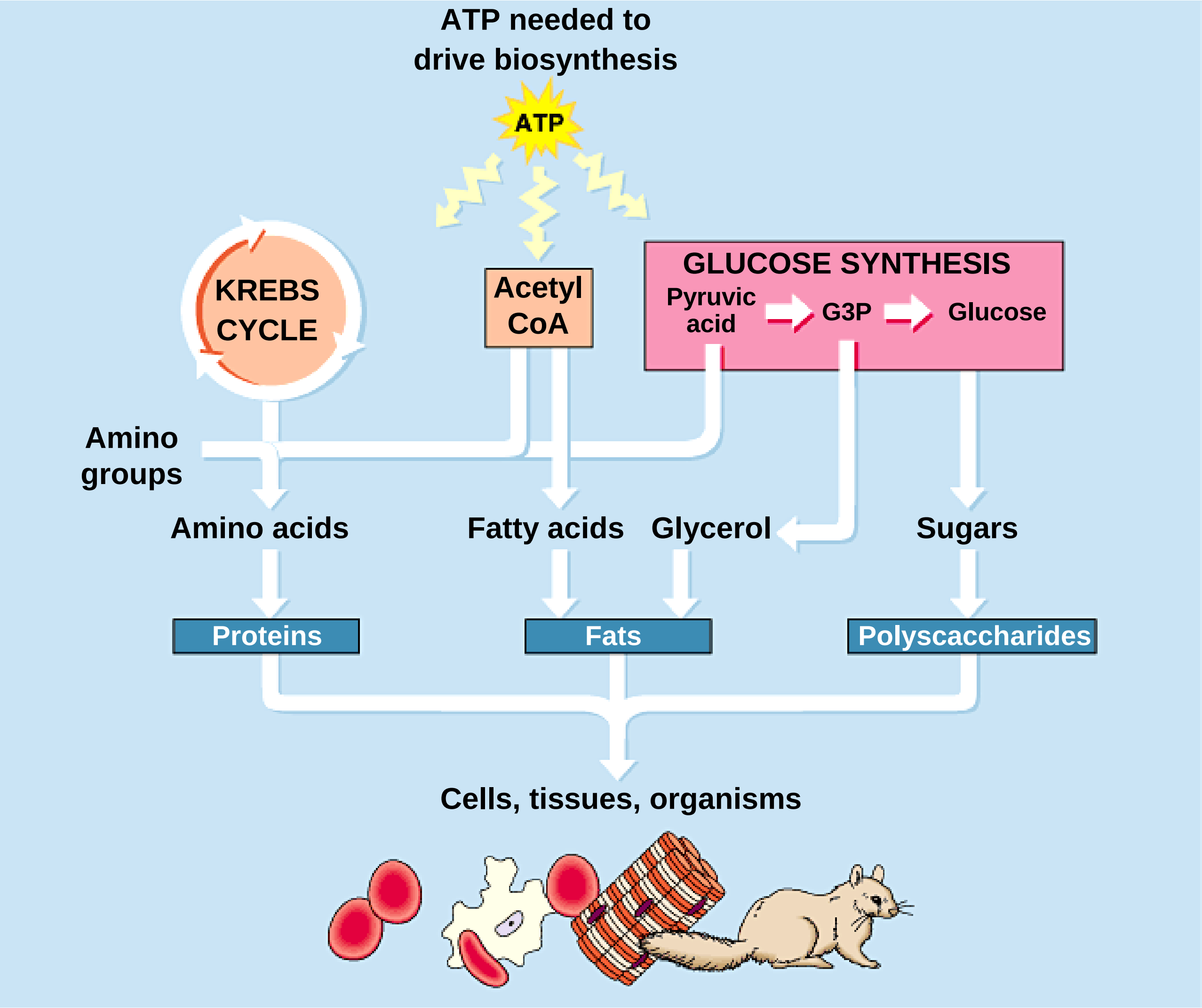


Figure 6.17

6.18 The fuel for respiration ultimately comes from photosynthesis

- All organisms have the ability to harvest energy from organic molecules
  - Plants, but not animals, can also make these molecules from inorganic sources by the process of photosynthesis

Figure 6.18