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Biology Class 9 — Punjab Board (PECTAA)

CHAPTER 8

Bioenergetics

Key Concepts · Definitions · Short & Long Questions · MCQs · Diagrams · Exam Tips

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Chapter 8: Bioenergetics

Bioenergetics is the study of how living things obtain energy, change it from one form to another, store it and use it. Plants capture light energy in photosynthesis; all organisms release the energy stored in food by cellular respiration. In both processes energy is passed on through the cell's energy currency, ATP.

These notes explain oxidation-reduction reactions, the structure and working of ATP, the light and dark reactions of photosynthesis and the role of chlorophyll, aerobic and anaerobic respiration with the steps of glycolysis, the Krebs cycle and the electron transport chain, and finally compare respiration with photosynthesis.

Learning Objectives

- Explain oxidation-reduction reactions and their importance.
- Describe ATP as the energy currency of the cell and the ATP-ADP cycle.
- Describe photosynthesis, its equation, light and dark reactions and the role of chlorophyll.
- Describe aerobic and anaerobic respiration and the main steps of aerobic respiration.
- State the uses of respiratory energy and the importance of fermentation.
- Compare aerobic with anaerobic respiration and respiration with photosynthesis.

Key Concepts

Redox Reactions

In oxidation-reduction (redox) reactions electrons are transferred from one molecule to another. The molecule that loses electrons is oxidised; the molecule that gains them is reduced. The flow of electrons in redox reactions is what allows cells to make ATP in photosynthesis and respiration.

8.1 ATP: The Energy Currency

Adenosine triphosphate (ATP) is a nucleotide made of adenine (a nitrogenous base), ribose (a five-carbon sugar) and three phosphate groups. The bonds linking the outer phosphate groups are high-energy bonds. Fritz Lipmann proposed in 1941 that ATP is the main energy-carrying molecule of cells.

When the outermost phosphate is removed by hydrolysis, ATP becomes ADP (adenosine diphosphate) and an inorganic phosphate (Pi), releasing about 7.3 kcal of energy per mole. ADP can lose another phosphate to become AMP. Energy from the oxidation of food is used to join ADP and Pi back into ATP.

So ATP is made during energy-releasing processes and broken during energy-using processes. This continuous ATP-ADP cycle carries energy from where it is released to where it is needed.

8.2 Photosynthesis

Photosynthesis is the making of glucose from carbon dioxide and water using light energy absorbed by chlorophyll, with oxygen released as a by-product. It is carried out by plants, algae and some bacteria. Overall: $6CO_2 + 12H_2O + \text{light} \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$ (carbon dioxide + water → glucose + oxygen + water).

Light reactions take place on the thylakoid membranes. Chlorophyll absorbs light and releases high-energy electrons. These pass along an electron transport chain, and the energy they release is used to make ATP. Light energy also splits water: oxygen is released, and the hydrogen ions and electrons are used to reduce NADP to NADPH.

Dark reactions (the Calvin cycle, worked out by Melvin Calvin) take place in the stroma and do not need light directly. CO_2 combines with a five-carbon compound to form an unstable six-carbon compound that splits into two three-carbon compounds. These are reduced to three-carbon sugars using ATP and NADPH. Some of these sugars make glucose; the rest regenerate the five-carbon compound, again using ATP.

8.2 Role of Chlorophyll

The thylakoid membranes contain pigments, substances that absorb visible light. Chlorophyll a is the main pigment. Chlorophyll b and carotenoids are accessory pigments that absorb other wavelengths and pass the energy on.

Chlorophyll a absorbs mainly blue and red light and reflects green, which is why leaves look green. Blue and red light therefore drive the most photosynthesis. When a pigment absorbs light, its electrons are excited and leave it; their energy is used to make ATP and NADPH.

8.3 Cellular Respiration: Aerobic and Anaerobic

Cellular respiration is the oxidation of food, mainly glucose, inside cells to release energy by breaking its C-H bonds. Aerobic respiration uses oxygen and oxidises glucose completely to carbon dioxide and water, releasing the maximum energy: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O +$ energy (ATP).

Anaerobic respiration (fermentation) occurs without oxygen. Glucose is only partly oxidised and much less energy is released. The first stage is the same as in aerobic respiration (glucose → two pyruvic acid). In alcoholic fermentation, carried out by yeast and some bacteria, pyruvic acid becomes ethanol and CO_2. In lactic acid fermentation, carried out by human skeletal muscles when oxygen is short, pyruvic acid becomes lactic acid.

Fermentation was the way the earliest organisms obtained energy when Earth's atmosphere had no oxygen, and anaerobic bacteria and fungi still depend on it. Humans use it to make yogurt and cheese (bacteria), bread and alcohol (yeast) and soy sauce (a fungus).

8.3 Mechanism of Aerobic Respiration

Glycolysis takes place in the cytoplasm and needs no oxygen. One glucose (6C) is split into two pyruvic acid (3C), giving a net gain of 2 ATP and 2 NADH.

When oxygen is present, pyruvic acid enters the mitochondrial matrix and is converted into acetyl coenzyme A, CO_2 and NADH. In the Krebs cycle (discovered by Sir Hans Krebs) acetyl CoA is completely oxidised to CO_2, producing ATP and the energy-rich carriers NADH and $FADH_2$.

In the electron transport chain on the inner mitochondrial membrane, NADH and FADH2 hand over electrons and hydrogen ions. As electrons pass along the chain they release energy that makes most of the cell's ATP. At the end, electrons and hydrogen ions combine with oxygen to form water, which is why oxygen is essential.

Respiratory energy (ATP) is used for muscle contraction, active transport, building biomolecules, DNA replication and cell division, sending nerve impulses, keeping body temperature steady and breaking down toxins.

8.4 Comparisons

Aerobic vs anaerobic: aerobic respiration needs oxygen, occurs in cytoplasm and mitochondria, gives CO2 and water and about 36 ATP per glucose (textbook figure); anaerobic respiration needs no oxygen, occurs only in the cytoplasm, gives lactic acid or ethanol + CO2 and only 2 ATP per glucose.

Photosynthesis vs respiration: photosynthesis is anabolic, stores energy in glucose, happens only in green parts with chloroplasts and only in light, and is done by plants, algae and some bacteria. Respiration is catabolic, releases the energy of food as ATP, happens in the cytoplasm and mitochondria of all living cells, at all times, in all organisms.

Important Definitions

Bioenergetics
The study of energy changes and energy flow in living organisms.

Oxidation
Loss of electrons by a molecule.

Reduction
Gain of electrons by a molecule.

ATP
Adenosine triphosphate, the nucleotide that stores and transfers energy in cells.

ADP
Adenosine diphosphate, formed when ATP loses one phosphate.

Photosynthesis
Making of glucose from CO2 and water using light energy absorbed by chlorophyll, releasing oxygen.

Light reactions
The stage of photosynthesis on thylakoids in which light energy makes ATP and NADPH and water is split.

Calvin cycle (dark reactions)
The stage in the stroma in which CO2 is reduced to sugar using ATP and NADPH.

Pigment
A substance that absorbs visible light.

Accessory pigments
Pigments such as chlorophyll b and carotenoids that help chlorophyll a capture light.

Cellular respiration
Oxidation of food inside cells to release energy as ATP.

Aerobic respiration
Complete oxidation of glucose using oxygen.

Anaerobic respiration (fermentation)
Partial breakdown of glucose without oxygen.

Glycolysis
Splitting of glucose into two pyruvic acid molecules in the cytoplasm.

Krebs cycle
A cycle of reactions in the mitochondrial matrix that completely oxidises acetyl CoA to CO2.

Electron transport chain
A series of carriers on the inner mitochondrial (or thylakoid) membrane that use electron flow to make ATP.

Anaerobes
Organisms that obtain energy by anaerobic respiration.

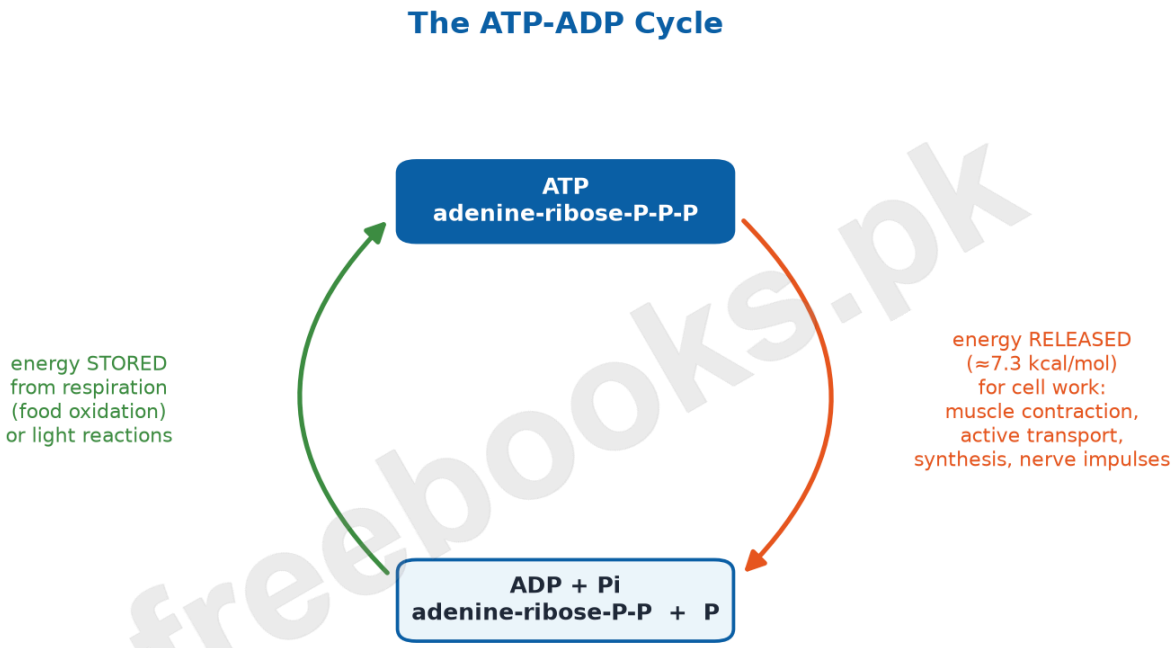
Key Facts at a Glance

Topic	Key point
ATP structure	Adenine + ribose + 3 phosphates
Energy from ATP → ADP	About 7.3 kcal per mole
ATP as energy carrier proposed by	Fritz Lipmann, 1941
Site of light reactions	Thylakoid membranes
Site of Calvin cycle	Stroma

Source of O2 in photosynthesis	Splitting of water
Main pigment	Chlorophyll a (absorbs blue and red)
Glycolysis	Cytoplasm; glucose → 2 pyruvic acid; net 2 ATP, 2 NADH
Krebs cycle	Mitochondrial matrix; Sir Hans Krebs
Electron transport chain	Inner mitochondrial membrane; O2 is final acceptor
ATP per glucose	Aerobic ≈36 (textbook) · Anaerobic 2
Alcoholic fermentation	Yeast: pyruvic acid → ethanol + CO2
Lactic acid fermentation	Muscles: pyruvic acid → lactic acid

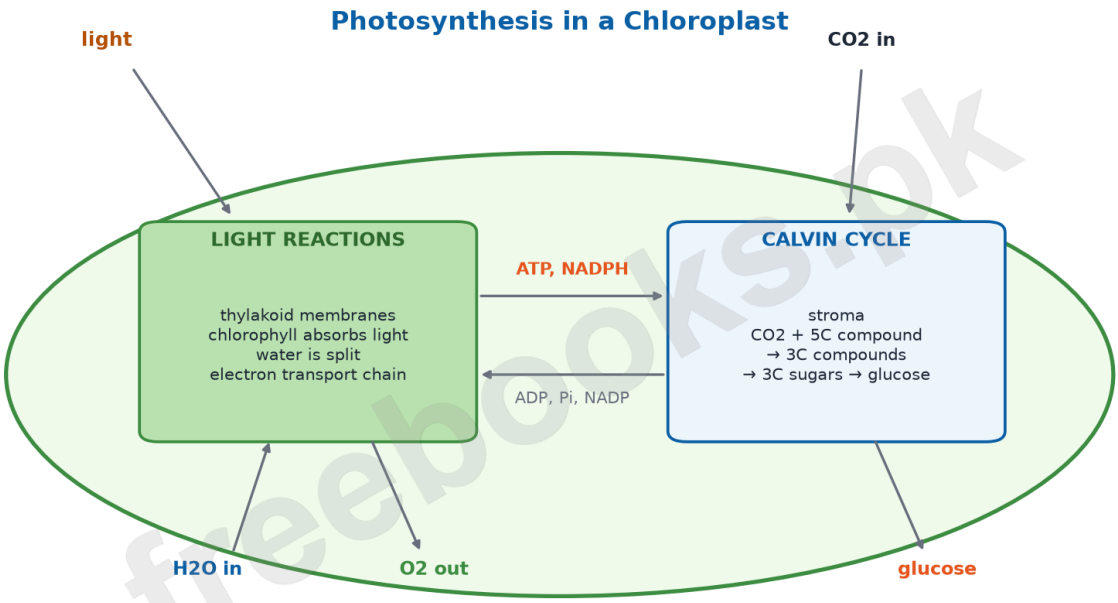
Diagrams

The ATP-ADP cycle: ATP releasing energy for cell work as it becomes ADP + Pi, and energy from food rebuilding ATP.

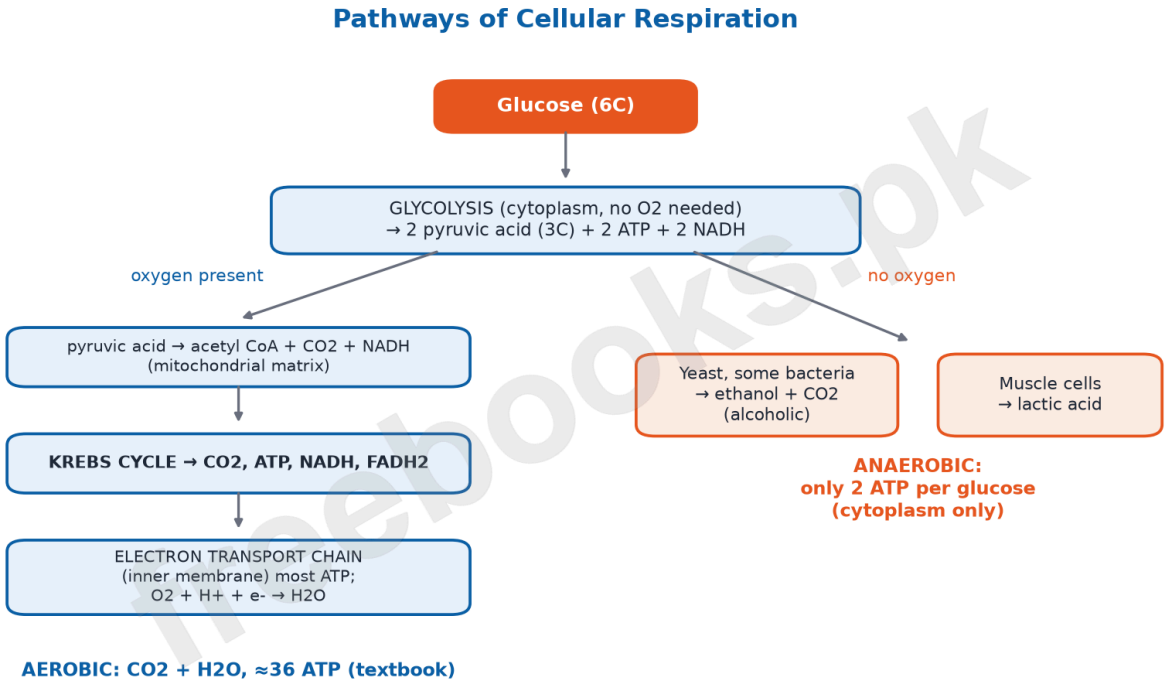


Photosynthesis in a chloroplast: Light reactions on the thylakoids producing ATP, NADPH and oxygen, feeding the Calvin cycle in the stroma that makes glucose.

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Pathways of cellular respiration: Glycolysis followed either by the Krebs cycle and electron transport chain (aerobic) or by alcoholic or lactic acid fermentation (anaerobic).



Short Questions and Answers

Why is ATP called the energy currency of the cell?

Like money, it is earned in energy-releasing reactions and spent in energy-using reactions, carrying energy between them in a form every cell can use.

What happens when ATP is converted into ADP?
The outer phosphate is removed by hydrolysis, releasing about 7.3 kcal of energy per mole, which the cell uses for its work.

Where does the oxygen released in photosynthesis come from?
From water molecules, which are split by light energy during the light reactions.

Why are the dark reactions called 'dark' if they occur in daylight?
Because they do not use light directly; they use the ATP and NADPH made by the light reactions, so they are light-independent.

What are the two products of the light reactions used in the Calvin cycle?
ATP, which supplies energy, and NADPH, which supplies hydrogen (electrons) to reduce CO2 to sugar.

Why do leaves look green?
Chlorophyll absorbs mainly blue and red light and reflects green light.

What is the role of accessory pigments?
They absorb wavelengths that chlorophyll a cannot absorb well and pass the energy to it, widening the range of light used.

Why is oxygen essential for aerobic respiration?
It is the final acceptor of electrons and hydrogen ions at the end of the electron transport chain, forming water; without it the chain stops.

Why does anaerobic respiration release less energy?
Glucose is only partly broken down; many C-H bonds remain in lactic acid or ethanol, so their energy is not released.

Why do muscles ache after very hard exercise?
When oxygen supply is too low, muscles respire anaerobically and lactic acid builds up, causing fatigue and discomfort.

Name two useful products of fermentation.
Yogurt and cheese made by bacterial fermentation, and bread made by yeast fermentation.

List four uses of ATP in the human body.
Muscle contraction, active transport, synthesis of proteins and other molecules, and transmission of nerve impulses.

Long Questions and Answers

Describe ATP and its role as the energy currency of the cell.

What is the structure of ATP?

ATP is a nucleotide made of adenine, the sugar ribose and three phosphate groups; the bonds between the phosphates are high-energy bonds.

How does ATP release energy?

Hydrolysis of the outer phosphate bond gives ADP + Pi and about 7.3 kcal/mole of energy. ADP can be further broken to AMP + Pi.

How is ATP made again?

Energy released by oxidising food in respiration, or captured from light in photosynthesis, is used to join ADP and Pi back into ATP.

Why is the ATP-ADP cycle important?

It links energy-releasing and energy-using reactions, so energy can be moved quickly to wherever the cell needs it.

Describe the mechanism of photosynthesis.

What is the overall reaction?

Carbon dioxide and water, using light absorbed by chlorophyll, form glucose and oxygen: $6CO_2 + 12H_2O + \text{light} \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$.

What happens in the light reactions?

On the thylakoids chlorophyll absorbs light and releases excited electrons, whose energy makes ATP through an electron transport chain. Water is split, releasing oxygen, and NADP is reduced to NADPH.

What happens in the dark reactions?

In the stroma CO_2 joins a five-carbon compound; the product splits into three-carbon compounds that are reduced to sugars using ATP and NADPH. Some sugars form glucose and the rest regenerate the five-carbon compound.

What is the role of chlorophyll?

Chlorophyll a, helped by accessory pigments, absorbs mainly blue and red light and converts it into the energy of excited electrons that drives ATP and NADPH formation.

Describe aerobic respiration and its stages.

What is glycolysis?

In the cytoplasm one glucose is broken into two pyruvic acid molecules, with a net gain of 2 ATP and 2 NADH. It needs no oxygen.

What happens in the Krebs cycle?

In the mitochondrial matrix pyruvic acid is first changed to acetyl CoA; the Krebs cycle then oxidises it fully to CO_2, forming ATP, NADH and $FADH_2$.

What happens in the electron transport chain?

On the inner mitochondrial membrane NADH and FADH2 release electrons, which pass along carriers releasing energy to make most of the ATP. Oxygen accepts the electrons and hydrogen to form water.

What is the overall equation and yield?

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy; the textbook gives about 36 ATP per glucose molecule.

Describe anaerobic respiration and its importance.

What is anaerobic respiration?

The breakdown of glucose without oxygen. Glycolysis gives two pyruvic acid, which is then converted to ethanol or lactic acid; only 2 ATP are gained.

What is alcoholic fermentation?

In yeast and some bacteria pyruvic acid is converted to ethanol and carbon dioxide.

What is lactic acid fermentation?

In human skeletal muscle during heavy exercise, when oxygen is short, pyruvic acid is converted to lactic acid.

Why is fermentation important?

It supplied energy to the first organisms before oxygen was present, it still powers anaerobes and oxygen-starved muscles, and it is used to make yogurt, cheese, bread and soy sauce.

Compare photosynthesis and cellular respiration.

How do they differ in type of metabolism?

Photosynthesis is anabolic and stores energy in glucose; respiration is catabolic and releases the energy of glucose as ATP.

Where do they occur?

Photosynthesis occurs only in the chloroplasts of green parts; respiration occurs in the cytoplasm and mitochondria of all living cells.

When and in which organisms?

Photosynthesis happens only in light, in plants, algae and some bacteria; respiration happens all the time in all organisms.

How are their raw materials and products related?

The products of one are the raw materials of the other: photosynthesis uses CO_2 and water and gives glucose and O_2, while respiration uses glucose and O_2 and gives CO_2 and water.

Multiple Choice Questions (MCQs)

A molecule that gains electrons is said to be: (A) Oxidised (B) Reduced (C) Hydrolysed (D)

Denatured
Correct answer: (B) Reduced. Gain of electrons = reduction.

The sugar present in ATP is: (A) Glucose (B) Deoxyribose (C) Ribose (D) Sucrose
Correct answer: (C) Ribose. ATP contains ribose.

When ATP loses one phosphate it becomes: (A) AMP (B) ADP (C) NADP (D) FAD
Correct answer: (B) ADP. ATP → ADP + Pi.

Light reactions take place in the: (A) Stroma (B) Thylakoid membranes (C) Cytoplasm (D) Matrix
Correct answer: (B) Thylakoid membranes. Pigments are in thylakoids.

The oxygen given out by plants comes from: (A) CO_2 (B) Water (C) Glucose (D) Chlorophyll
Correct answer: (B) Water. Water is split in light reactions.

The Calvin cycle uses which products of the light reactions? (A) O_2 and glucose (B) ATP and NADPH (C) CO_2 and water (D) Pyruvic acid
Correct answer: (B) ATP and NADPH. ATP and NADPH drive CO_2 reduction.

Chlorophyll a mainly absorbs: (A) Green and yellow light (B) Blue and red light (C) Only green light (D) Infrared
Correct answer: (B) Blue and red light. It reflects green.

Glycolysis takes place in the: (A) Mitochondrial matrix (B) Cytoplasm (C) Chloroplast (D) Nucleus
Correct answer: (B) Cytoplasm. Glycolysis is cytoplasmic.

The final acceptor of electrons in aerobic respiration is: (A) NAD (B) Oxygen (C) CO_2 (D) Glucose
Correct answer: (B) Oxygen. O_2 forms water at the end of the chain.

Yeast in the absence of oxygen produces: (A) Lactic acid (B) Ethanol and CO_2 (C) Water only (D) Glucose
Correct answer: (B) Ethanol and CO_2. Alcoholic fermentation.

Net ATP gained from anaerobic breakdown of one glucose is: (A) 2 (B) 4 (C) 36 (D) 38
Correct answer: (A) 2. Only glycolysis yields ATP.

The Krebs cycle occurs in the: (A) Cytoplasm (B) Mitochondrial matrix (C) Thylakoid (D) Ribosome
Correct answer: (B) Mitochondrial matrix. It is in the matrix.

Which process occurs in all living cells all the time? (A) Photosynthesis (B) Respiration

(C) Calvin cycle (D) Transpiration
Correct answer: (B) Respiration. Respiration is universal.

Making yogurt depends on: (A) Alcoholic fermentation in yeast (B) Lactic acid fermentation by bacteria (C) Photosynthesis (D) Krebs cycle
Correct answer: (B) Lactic acid fermentation by bacteria. Bacteria ferment milk sugar.

Quick Revision Summary

- Redox: oxidation = loss of electrons; reduction = gain. Electron flow powers ATP formation.
- ATP = adenine + ribose + 3 phosphates; ATP → ADP + Pi + ≈7.3 kcal/mol. ATP-ADP cycle links energy release and use.
- Photosynthesis: $6CO_2 + 12H_2O$ + light → $C_6H_{12}O_6 + 6O_2 + 6H_2O$. Light reactions (thylakoids): ATP, NADPH, O_2 from water. Calvin cycle (stroma): CO_2 → sugar using ATP + NADPH.
- Chlorophyll a = main pigment (blue, red); chlorophyll b and carotenoids = accessory pigments.
- Aerobic respiration: glycolysis (cytoplasm, 2 ATP) → Krebs cycle (matrix) → ETC (inner membrane, O_2 → H_2O); ≈36 ATP (textbook).
- Anaerobic: glycolysis → ethanol + CO_2 (yeast) or lactic acid (muscles); 2 ATP.
- Photosynthesis = anabolic, green cells, light only; respiration = catabolic, all cells, always.

Exam Tips

- Write both equations (photosynthesis and aerobic respiration) correctly balanced; they are almost always asked.
- Link each stage to its site: light reactions → thylakoid; Calvin cycle → stroma; glycolysis → cytoplasm; Krebs → matrix; ETC → inner membrane.
- In comparison questions use a table with at least five rows: type, energy, site, time, organisms.
- Remember: oxygen in photosynthesis comes from water, not from CO_2.
- Learn the two fermentation products by organism: yeast → ethanol + CO_2; muscle → lactic acid.

Note on Facts

The textbook writes the formula of lactic acid as $C_2H_6O_3$. The correct formula is $C_3H_6O_3$.

The textbook says only about 1% of the light falling on a leaf is absorbed. In fact a leaf absorbs most of the visible light that falls on it; it is only about 1% (or a few percent) of the light energy that ends up stored in sugar by photosynthesis.

The textbook gives 36 ATP per glucose in aerobic respiration. This is the traditional textbook value; current estimates are lower, about 30–32 ATP, because some energy is lost in moving materials across mitochondrial membranes. Use 36 in exams, as given in your book.