Chapter 14
Respiration in Plants

Question 1:
Differentiate between
(a) Respiration and Combustion
(b) Glycolysis and Krebs' cycle
(c) Aerobic respiration and Fermentation

Solution 1:
(a) Differences between respiration and combustion are as follows:

	Respiration	Combustion
(i)	It occurs inside living cells.	It is a non-cellular process.
(ii)	Respiration is a biochemical process.	Combustion is a physio-chemical process.
(iii)	Energy is released in stages as chemical bonds are broke in steps.	Energy is released in a single step as all chemical steps occur simultaneously.
(iv)	Most of the energy is trapped in ATP molecules.	ATP is not formed.
(v)	Oxidation occurs at the end of reaction (terminal oxidation) between reduced co-enzymes and oxygen.	The substrate is directly oxidized in combustion.
(vi)	A number of intermediates are formed. They are used in the synthesis of different organic compounds.	No intermediates are produced in combustion.
(vii)	A number of enzymes are required, one for each step or reaction.	Burning is a non-enzymatic process.
(viii)	Less than 50% energy is liberated in the form of heat energy. Light is rarely produced.	Energy is liberated in the form of both light and heat energy.
(ix)	Temperature is not allowed to rise.	Temperature becomes very high.

(b) Differences between glycolysis and Krebs' cycle are as follows:

	Glycolysis	Krebs' cycle
(i)	It occurs inside the cytoplasm.	Krebs' cycle operates inside mitochondria.
(ii)	Glycolysis is the first step of respiration in which glucose is broken down to the level of pyruvate.	Krebs' cycle is the second step in respiration where an active acetyl group is broken down completely.

(iii)	The process is common to both aerobic and anaerobic modes of respiration.	It occurs only in aerobic respiration.
(iv)	It degrades a molecule of glucose into two molecules of an organic substance, pyruvate.	It degrades pyruvate completely into inorganic substances (CO_2 + H_2O).
(v)	Glycolysis consumes 2 ATP molecules for the initial phosphorylation of substrate molecule.	It does not consume ATP.
(vi)	In glycolysis, one glucose molecule liberates 4 ATP molecules through substrate level phosphorylation.	In Krebs' cycle, two acetyl residues liberate two ATP or GTP molecules through substrate level phosphorylation.
(vii)	Net gain is two molecules of NADH and two molecules of ATP for every molecule of glucose broken down.	Krebs' cycle produces six molecules of NADH, and 2 molecules of $FADH_2$ for every two molecules of acetyl CoA oxidized by it. Two molecules of NADH are liberated during conversion of two pyruvates to acetyl CoA.
(viii)	The net gain of energy is equal to 8 ATP.	The net gain of energy is equal to 24 molecules of ATP. Six molecules of ATP can be produced from $2NADH_2$ formed during dehydrogenation of two pyruvates.
(ix)	No carbon dioxide is evolved in glycolysis.	Carbon dioxide is evolved in Krebs' cycle.
(x)	Oxygen is not required for glycolysis.	Krebs' cycle uses oxygen as terminal oxidant.

(c) Differences between aerobic respiration and fermentation are as follows:

	Aerobic respiration	Fermentation
(i)	It uses oxygen for breaking the respiratory material into simpler substances.	Oxygen is not used in the breakdown of respiratory substrate.
(ii)	Respiratory material is completely oxidized.	Respiratory material is incompletely broken.
(iii)	The end products are inorganic.	At least one of the end products is organic. Inorganic substances may or may not be produced.

(iv)	Aerobic respiration is the normal made of respiration of plants and animals.	It is the normal mode of respiration in some parasitic worms and microorganisms. In others, anaerobic respiration is a stop-gap arrangement.
(v)	Aerobic respiration consists of three step – glycolysis, Krebs' cycle and terminal oxidation.	Anaerobic respiration or fermentation consists of two steps – glycolysis and incomplete breakdown of pyruvic acid.
(vi)	Every carbon atom of the food is oxidized and a large quantity of carbon dioxide is evolved.	Less quantity of carbon dioxide is evolved.
(vii)	Water is formed.	Water is usually not formed.
(viii)	686 kcal of energy are produced per gm mole of glucose.	Only 39-59 kcal of energy are formed per gm mole of glucose.
(ix)	It continues indefinitely.	It cannot continue indefinitely (except in some micro-organisms) because of the accumulation of poisonous compounds and less availability of energy per gm mole of food broken.

Question 2:
What are respiratory substrates? Name the most common respiratory substrate.

Solution 2:
Respiratory substrates are those organic substances which are oxidised during respiration to liberate energy inside the living cells. The common respiratory substrates are carbohydrates, proteins, fats and organic acids. The most common respiratory substrates is glucose. It is hexose monosaccharide.

Question 3:
Give the schematic representation of glycolysis.

Solution 3:

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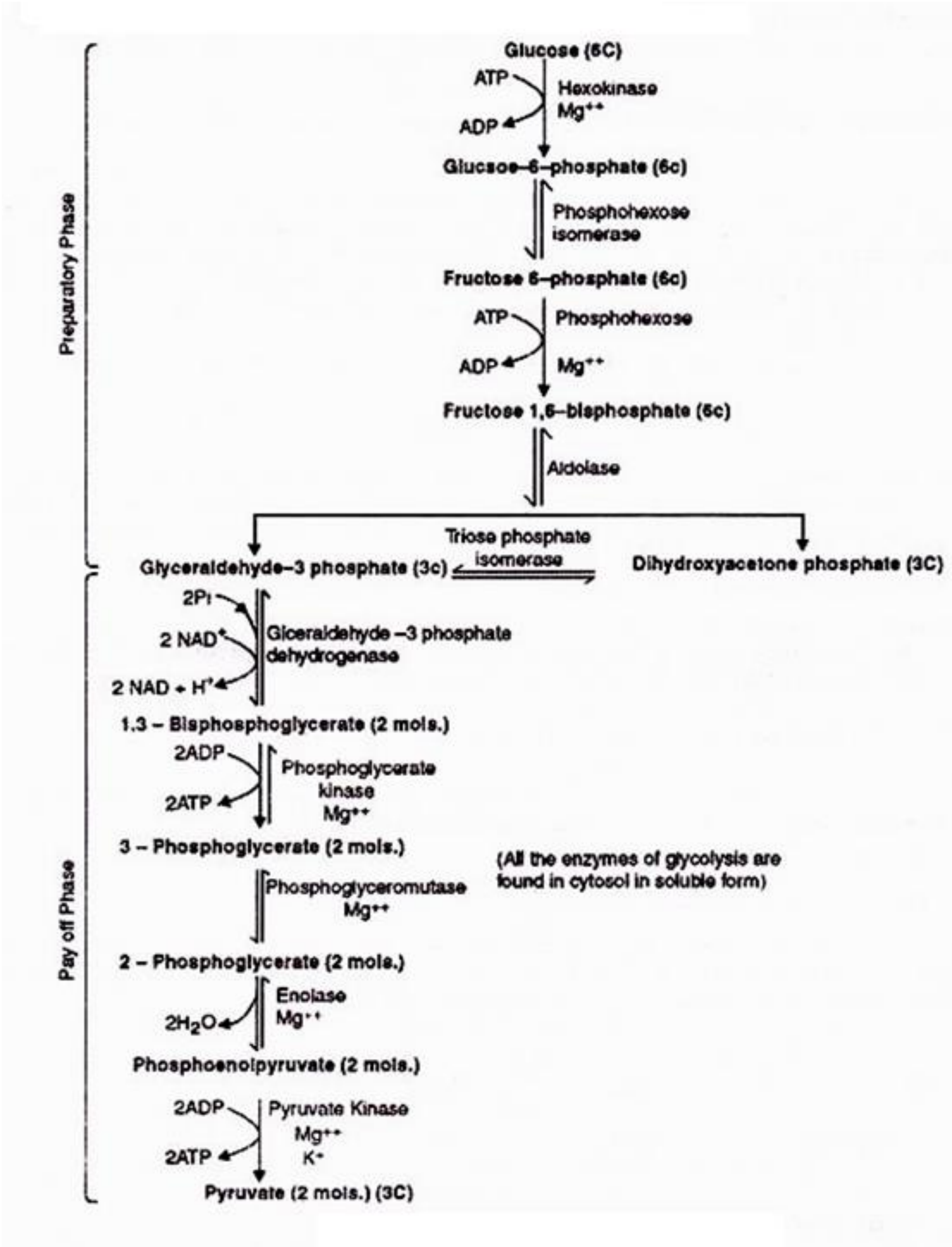


Question 4:
What are the main steps in aerobic respiration? Where does it take place?

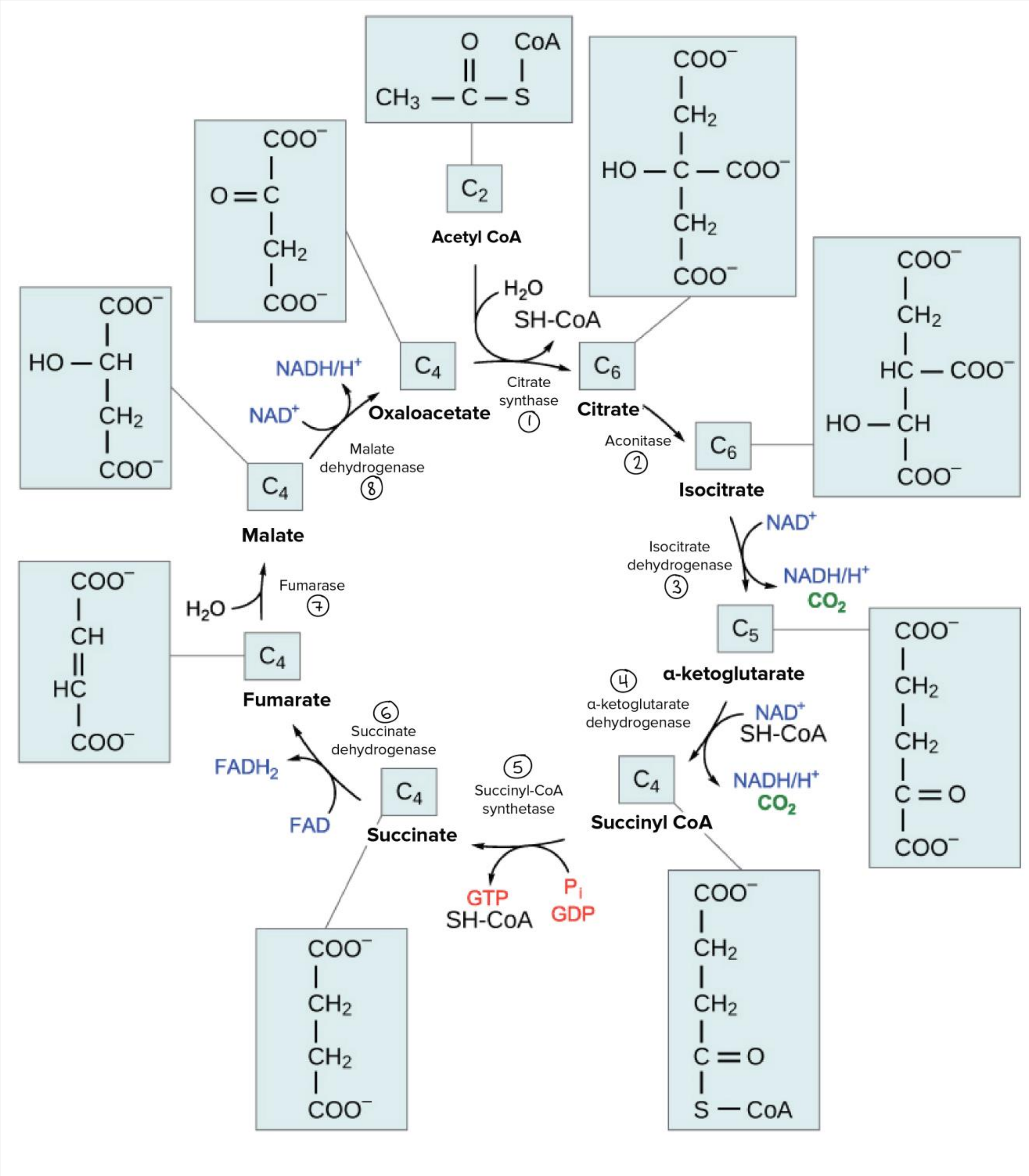
Solution 4:

Aerobic respiration is an enzymatically controlled release of energy in a stepwise catabolic process of complete oxidation of organic food into carbon dioxide and water with oxygen acting as terminal oxidant. It occurs by two methods, common pathway and pentose phosphate pathway. Common pathway is known so because its first step, called glycolysis, is common to both aerobic and anaerobic modes of respiration. The common pathway of aerobic respiration consists of three steps – glycolysis, Krebs' cycle and terminal oxidation. Aerobic respiration takes place within mitochondria. The final product of glycolysis, pyruvate is transported from the cytoplasm into the mitochondria.

Question 5:

Give the schematic representation of an overall view of Krebs' cycle.

Solution 5:



Question 6:

Explain ETS.

Solution 6:

ETS can be explained through the following points:

1. ETS (Electron Transport System) also called Oxidative Phosphorylation is a metabolic pathway through which electrons pass from one carrier to another.
2. It takes place in the inner mitochondrial membrane where electrons from NADH produced in the inner mitochondrial matrix during citric acid cycle are oxidized by and NADH dehydrogenase (complex I).
3. Post this, electrons are transferred to Ubiquinone which receives reducing equivalents via FADH2 (complex II).
4. Ubiquinol (reduced ubiquinone) is then oxidized with the transfer of electron to cytochrome c via cytochrome bc1complex (complex III).
5. Cytochrome c oxidase complex (complex IV) contains cytochromes a and a3 and two Cu centres. When electrons pass from one carrier to another via complex I to IV in the ET chain, they are coupled to ATP synthase (complex V).
6. Complex V consists of components like F1 (peripheral membrane protein complex) and F0 (integral membral protein complex). At F1 ATP is synthesised from ADP and Pi. Protons pass through channel formed by F0 are coupled to the catalytic site of F1.
7. One molecule of NADH (oxidized) gives 3 molecules of ATP. One molecule of FADH2 produces 2 molecules of ATP.

Question 7:

Distinguish between the following:

(a) Aerobic respiration and Anaerobic respiration.
(b) Glycolysis and Fermentation.
(c) Glycolysis and Citric acid cycle.

Solution 7:

(a) Differences between aerobic and anaerobic respiration are as follows:

Aerobic respiration	Anaerobic respiration
Aerobic respiration is a type of respiration in which food stuffs (usually carbohydrates) are completely oxidized to carbon dioxide and water, with the release of chemical energy, in a process requiring atmospheric oxygen. The reaction can be summarized by the equation:	Anaerobic respiration is a type of respiration in which food stuffs (usually carbohydrates) are partially oxidized, with the release of chemical energy, in a process not involving atmospheric oxygen. Since the substrate is never completely oxidized the energy yield of this type of respiration is lower than that of aerobic respiration. It occurs in some yeasts and

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + energy$	bacteria and in muscle tissue when oxygen is absent.

(b) Differences between glycolysis and fermentation are as follows:

	Glycolysis	**Fermentation**
(i)	It is the first step of respiration which occurs without the requirement of oxygen and is common to both aerobic and anaerobic modes of respiration.	It is anaerobic respiration or respiration which does not require oxygen.
(ii)	Glycolysis produces pyruvic acid.	Fermentation produces different products. The common ones are ethanol (and CO_2) and lactic acid.
(iii)	It produces two molecules of NADH per glucose molecule.	It generally utilises NADH produced during glycolysis.
(iv)	It forms 2 ATP molecules per glucose molecule.	It does not produce ATP.

(c)Differences between Glycolysis and Citric Acid Cycle

	Glycolysis	Citric Acid Cycle
(i)	First step of respiration	Second step of respiration
(ii)	Occurs in cytoplasm	Occurs in mitochondria
(iii)	Carbon-di-oxide is not evolved	Carbon-di-oxide is evolved
(iv)	Occurs both aerobically and anaerobically	Occurs anaerobically
(v)	Two ATPs are consumed	No consumption of ATP
(vi)	Net gain of ATP is 8 (including NADH)	Net gain of ATP is 24
(vii)	Oxidative phosphorylation is not involved	Oxidative phosphorylation is involved
(viii)	Linear pathway	Circular pathway

Question 8:

What are the assumptions made during the calculation of net gain of ATP?

Solution 8:

It is possible to make calculations of the net gain of ATP for every glucose molecule oxidised; but in really this can remain only a theoretical exercise. These calculations can be made only on certain assumptions that:

- There is a sequential, orderly pathway functioning, with one substrate forming the next and with glycolysis, TCA cycle and ETS pathway following one after another.
- The NADH synthesized in glycolysis is transferred into the mitochondria and undergoes oxidative phosphorylation. None of the intermediates in the pathway are utilised to synthesise any other compound.
- Only glucose is being respired – no other alternative substrates are entering in the pathway at any of the intermediary stages.

But these kind of assumptions are not really valid in a living system; all pathway work simultaneously and do not take place one after another; substrates enter the pathways and are withdrawn from it as and when necessary; ATP is utilised as and when needed; enzymatic rates are controlled by multiple means. Hence, there can be a net gain of 36 ATP molecules during aerobic respiration of one molecule of glucose.

Question 9:

Discuss "The respiratory pathway is an amphibolic pathway".

Solution 9:

Amphibolic pathway is the one which is used for both breakdown (catabolism) and build-up (anabolism) reactions. Respiratory pathways is mainly a catabolic process which serves to run the living system by providing energy. The pathway produces a number of intermediates. Many of them are raw materials for building up both primary and secondary metabolites. Acetyl CoA is helpful not only in Krebs' cycle but is also raw material for synthesis of fatty acids, steroids, terpenes, aromatic compounds and carotenoids, a-ketoglutarate is organic acid with forms glutamate (an important amino acid) on amination. OAA (Oxaloacetic acid) on amination produces asparate. Both aspartate and glutamate are components of proteins. Pyrimidines and alkaloids are other products. Succinyl CoA forms cytochromes and chlorophyll.
Hence, fatty acids would be broken down to acetyl CoA before entering the respiratory pathway when it is used as a substrate. But when the organism needs to synthesise fatty acids, acetyl CoA would be withdrawn from the respiratory pathway for it. Hence, the respiratory pathway comes into the picture both during breakdown and synthesis of fatty acids. Similarly, during breakdown and synthesis of proteins too, respiratory intermediates form the link. Breaking down processes within the living organism is catabolism, and synthesis is anabolism. Because the respiratory

pathway is involved in both anabolism and catabolism, it would hence be better to consider the respiratory pathway as an amphibolic pathway rather than as a catabolic one.

Question 10:
Define RQ. What is its value for fats?

Solution 10:
Respiratory quotient (RQ) is the ratio of the volume of carbon dioxide produced to the volume of oxygen consumed in respiration over a period of time. Its value can be one, zero, more than 1 or less than one.

$$RQ = \frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ consumed}}$$

RQ is less than one when the respiratory substrate is either fat or protein.

$$C_{57}H_{104}O_6 + 80\ O_2 \rightarrow 57\,CO_2 + 52\ H_2O$$

$$RQ = 57\ CO_2 / 80\ O_2 = 0.71$$

RQ is about 0.7 for most of the common fats.

Question 11:
What is oxidative phosphorylation?

Solution 11:
Oxidative phosphorylation is the synthesis of energy rich ATP molecules with the help of energy liberated during oxidation of reduced co-enzymes (NADH. $FADH_2$) produced in respiration. The enzyme required for this synthesis is called ATP synthase. It is considered to be the fifth complex of electron transport chain.
Note: Question is “What is oxidative phosphorylation?”, hence a simple definition will suffice.

Question 12:
What is the significance of step-wise release of energy in respiration?

Solution 12:
The utility of step-wise release of energy in respiration are given as follows:
(i) There is a step-wise release of chemical bond energy which is very easily trapped in forming ATP molecules.

(ii) Cellular temperature is not allowed to rise.
(iii) Wastage of energy is reduced.
(iv) There are several intermediates which can be used in production of a number of biochemicals.
(v) Through their metabolic intermediates different substances can undergo respiratory catabolism.
(vi) Each step of respiration is controlled by its own enzyme. The activity of different enzymes can be enhanced or inhibited by specific compounds.

This helps in controlling the rate of respiration and the amount of energy liberated by it.