Respiration in Plants

OBJECTIVE TYPE QUESTIONS

Multiple Choice Questions (MCQs)

1. Respiratory quotient (R.Q.) is
(a) volume of O_2 evolved/volume of CO_2 consumed
(b) volume of CO_2 evolved/volume of O_2 consumed
(c) volume of O_2 consumed/volume of CO_2 evolved
(d) volume of CO_2 consumed/volume of O_2 evolved.

2. If R.Q. is less than 1.0 in a respiratory metabolism, it would mean that
(a) carbohydrates are used as respiratory substrate
(b) organic acids are used as respiratory substrate
(c) the oxidation of the respiratory substrate consumed more oxygen than the amount of CO_2 released
(d) the oxidation of the respiratory substrate consumed less oxygen than the amount of CO_2 released.

3. In glycolysis, enzyme enolase produces
(a) phosphoglyceric acid
(b) phosphoenol pyruvate
(c) phosphoglyceraldehyde
(d) pyruvate.

4. In which one of the following do the two names refer to tricarboxylic acid cycle?
(a) α-ketoglutaric acid and Krebs' cycle
(b) Malic acid cycle and Kornberg cycle
(c) Citric acid cycle and Krebs' cycle
(d) Oxaloacetic acid and Kornberg cycle

5. The reaction involved in reduction of NAD^+ is
(a) Glucose ⟶ Glucose 6–Phosphate
(b) Fructose 1, 6–diphosphate ⟶ PGAL+DHAP
(c) Glucose 6–Phosphate ⟶ Fructose 6–Phosphate
(d) Glyceraldehyde 3-phosphate ⟶ 1, 3-biphosphoglycerate.

6. In electron transport system (ETS) which of the following cytochromes reacts with oxygen?
(a) Cyt a_3 (b) Cyt b
(c) Cyt b_3 (d) Cyt b_6

7. The mobile electron carrier that transfers electrons between
(a) complex I and II (b) complex II and III
(c) complex III and IV (d) complex I and IV.

8. Electron transport system (ETS) is present in
(a) inner mitochondrial membrane
(b) mitochondrial matrix
(c) chlorophyll
(d) cytosol.

9. Which product of glycolysis is consumed in alcoholic fermentation?
(a) NADH (b) ATP
(c) ATP and NADH (d) CO_2

10. Common phase between aerobic and anaerobic modes of respiration is
(a) Krebs' cycle
(b) EMP/glycolysis
(c) oxidative phosphorylation
(d) PPP.

11. Which one is correct sequence in glycolysis?
(a) G-6-P → PEP → 3-PGAL → 3-PGA
(b) G-6-P → 3-PGAL → 3-PGA → PEP
(c) G-6-P → PEP → 3-PGA → 3-PGAL
(d) G-6-P → 3-PGA → 3-PGAL → PEP

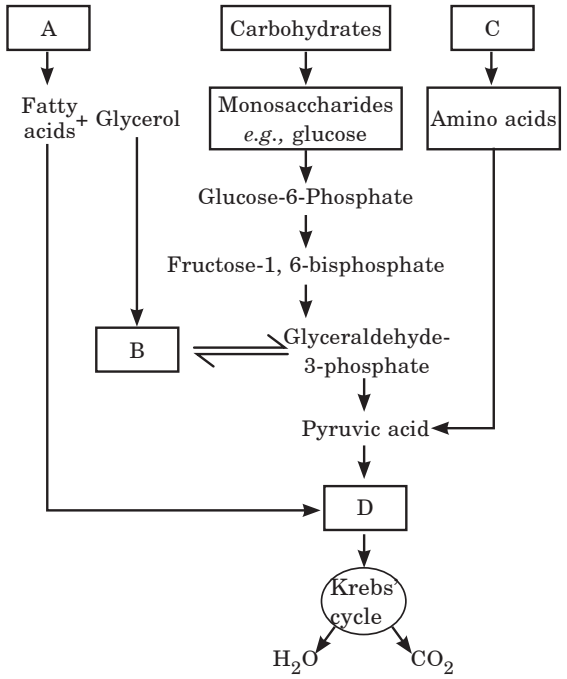
12. Refer to the given equation.
$2(C_{51}H_{98}O_6) + 145O_2 \rightarrow 102CO_2 + 98H_2O$ + Energy
The R.Q. in this case is
(a) 1 (b) 0.7
(c) 1.45 (d) 1.62.

13. Identify A and B in the given reaction.

$$\text{Pyruvic acid} + \text{CoA} + NAD^+ \xrightarrow[\text{Pyruvate dehydrogenase}]{Mg^{2+}} A + B + NADH + H^+$$

	A	B
(a)	PEP	CO_2
(b)	Acetyl CoA	CO_2
(c)	CO_2	H_2O
(d)	Acetyl CoA	H_2O

14.



The above figure indicates the inter-relationship among metabolic pathways. Now identify A to D.

	A	B	C	D
(a)	Protein	Acetyl CoA	Fat	DHAP
(b)	Fat	DHAP	Protein	Acetyl CoA
(c)	Acetyl CoA	Fat	DHAP	Protein
(d)	Fat	DHAP	Acetyl CoA	Protein

15. In respiration,

(a) 2 PGA are formed in glycolysis and none in Krebs' cycle

(b) 6 PGA in glycolysis, 3 PGA in Krebs' cycle

(c) 8 PGA in glycolysis, 3 PGA in Krebs' cycle

(d) PGA formation does not occur in respiration.

16. Amount of energy released during hydrolysis of a high energy bond of ATP is

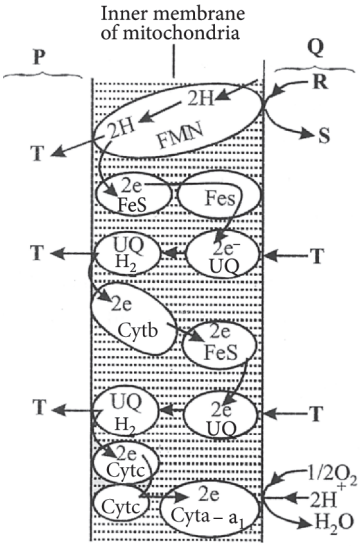
(a) 73 kcal mol^{-1}

(b) 0.73 kcal mol^{-1}

(c) 3.4 kcal mol^{-1}

(d) 7.3 kcal mol^{-1}.

17. The adjoining diagram refers to mitochondrial electron transport chain. Identify P, Q, R, S, T.



(a) P-Matrix, Q-Outer membrane, R-$FADH_2$, S-NADH+H^+, T-$2H^+$

(b) P-Inter membrane space, Q-Matrix, R-NADH + H^+, S-NAD^+, T-$2H^+$

(c) P-Outer membrane, Q-Cristae, R-NAD, D-NADH + H^+, T-H^+

(d) P-Cristae, Q-Outer chamber, R-NADH+H^+, S-NAD^+, T-$2H^+$

18. Select the incorrectly matched pair.

(a) End products of alcoholic fermentation – Ethanol + CO_2

(b) End products of lactic acid fermentation – Lactic acid + CO_2

(c) Obligate anaerobe – *Clostridium tetani*

(d) Ethyl alcohol fermentation – *Rhizopus*

19. Select the incorrect statement regarding an overview of the electron transport system (ETS).

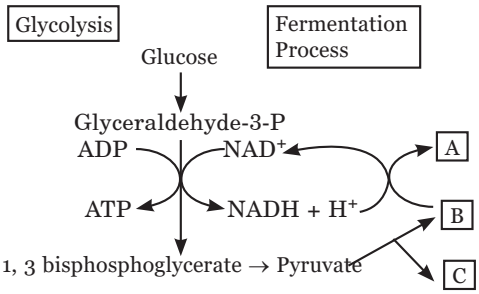
(a) Ubiquinone receives reducing equivalents *via* $FADH_2$ (complex II) that is generated during oxidation of succinate in the TCA cycle.

(b) As the electrons move down the system, energy is released and used to form ATP.

(c) 2ATPs are formed for every pair of electrons that enters by way of NADH and 3ATPs are formed for every pair of electrons that enters by way of $FADH_2$.

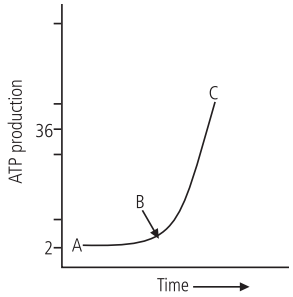
(d) Oxygen, the final e^- acceptor, becomes a part of water.

20. Choose the correct combination of labelling of the molecules involved in the pathway of anaerobic respiration in yeast.



(a) A-Ethanol, B-CO_2, C-Acetaldehyde
(b) A-Ethanol, B-Acetaldehyde, C-CO_2
(c) A-CO_2, B-Ethanol, C-Acetaldehyde
(d) A-CO_2, B-Acetaldehyde, C-Ethanol

21. Cells are suspended in a culture medium that contains excess glucose. The graph below shows glucose utilisation under different growth conditions. (A), (B), and (C) in the graph indicate



(a) A – Anaerobic respiration
B – Introduction of O_2 to culture medium
C – Aerobic respiration
(b) A – Aerobic respiration
B – Introduction of CO_2 to culture medium
C – Anaerobic respiration
(c) A – Aerobic respiration
B – Supply of organic triphosphate
C – Aerobic respiration
(d) A – Aerobic respiration
B – Introduction of CO_2 to culture medium
C – Anaerobic respiration

22. During glycolysis, fructose 1, 6-biphosphate splits into
(a) dihydroxyacetone phosphate and 2-phosphoglyceraldehyde
(b) dihydroxyacetone phosphate and 1-phosphoglyceraldehyde
(c) dihydroxyacetone phosphate and 2- phosphoglycerate
(d) dihydroxyacetone phosphate and 3-phosphoglyceraldehyde.

23. The last product of glycolysis is degraded to CO_2 and H_2O in
(a) matrix of chloroplasts
(b) cytoplasm
(c) matrix of mitochondria
(d) inner membrane of mitochondria.

24. Select the option that correctly fills the blanks in the following statements.
A. Glucose has (i) carbon atoms, pyruvic acid has (ii) carbon atoms and the acetyl group has (iii) carbon atoms.
B. Electrons enter the electron transport system as parts of hydrogen atoms attached to (i) and (ii).

	A	B
(a)	(i)-6, (ii)-4, (iii)-3	(i)-NADH, (ii)-$FADH_2$
(b)	(i)-6, (ii)-3, (iii)-2	(i)-NADH, (ii)-$FADH_2$
(c)	(i)-6, (ii)-3, (iii)-2	(i)-ATP, (ii)-GTP
(d)	(i)-6, (ii)-4, (iii)-3	(i)-ATP, (ii)-GTP

25. Consider the first reaction of TCA cycle.

$$\text{Acetyl CoA} + \text{OAA} + H_2O \xrightarrow[\text{synthase}]{\text{Citrate}} \text{(A)} + \text{CoA}$$

What is true about compound **A**?
(a) First product of TCA cycle
(b) Tricarboxylic acid and six carbon compound
(c) It undergoes reorganisation in the presence of enzyme aconitase to form *cis*-aconitate
(d) All of these.

26. Dough kept overnight in warm weather becomes soft and spongy due to
(a) absorption of CO_2 from atmosphere
(b) imbibition
(c) fermentation
(d) all of these.

27. Select the wrong statement with respect to glycolysis.
(a) It occurs outside mitochondria.
(b) It is an anaerobic phase.
(c) Glucose undergoes partial oxidation to form two molecules of pyruvic acid.
(d) Glucose is phosphorylated to glucose-6-phosphate by isomerase enzyme.

28. During the process of respiration which of the following are released as a product?
(a) CO_2, H_2O and O_2
(b) CO_2, O_2 and energy
(c) CO, H_2O and energy
(d) CO_2, H_2O and energy

29. In aerobic respiration, one glucose molecule produces
(a) 10NADH + 4$FADH_2$ + 4 ATP
(b) 12NADH + 4$FADH_2$ + 4ATP + GTP
(c) 12NADH + 4GTP + 2$FADH_2$
(d) 10NADH +2$FADH_2$ + 4ATP.

30. Cytochromes are ____ containing compounds.
(a) manganese (Mn) (b) magnesium (Mg)
(c) iron (Fe) (d) nickel (Ni)

31. The number of molecules of pyruvic acid formed from one molecule of glucose at the end of glycolysis is
(a) 1 (b) 2 (c) 3 (d) 4.

32. Succinate is oxidised to fumarate in Krebs' cycle by
(a) removal of hydrogen
(b) loss of electrons
(c) addition of oxygen
(d) removal of oxygen.

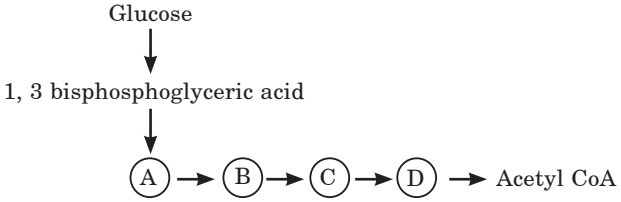
33. Net gain of ATP in glycolysis is
(a) 6 (b) 2 (c) 4 (d) 8.

34. Enzyme helping in oxidative decarboxylation of pyruvic acid is
(a) pyruvate kinase
(b) pyruvate dehydrogenase
(c) malate dehydrogenase
(d) succinate dehydrogenase.

35. Respiration is
(a) anabolic + exergonic
(b) catabolic + exergonic
(c) catabolic + endergonic
(d) anabolic + endergonic.

36. R.Q. can vary due to
(a) temperature
(b) respiratory substrate
(c) light and oxygen
(d) respiratory product.

37. Study the given flow chart and identify A-D.



(a) A–3-phosphoglycerate, B–2-phosphoglycerate, C–pyruvic acid, D–phosphoenolpyruvate
(b) A–2-phosphoglycerate, B–3-phosphoglycerate, C–pyruvic acid, D–phosphoenolpyruvate
(c) A–phosphoenolpyruvate, B–2-phosphoglycerate C–3-phosphoglycerate, D–pyruvic acid
(d) A–3-phosphoglycerate, B–2-phosphoglycerate, C–phosphoenolpyruvate, D–pyruvic acid

38. Select the incorrect options regarding anaerobic respiration or fermentation?
(a) Occurs inside the mitochondria
(b) Partial breakdown of glucose occurs
(c) Net gain of only 2 ATP molecules
(d) None of these

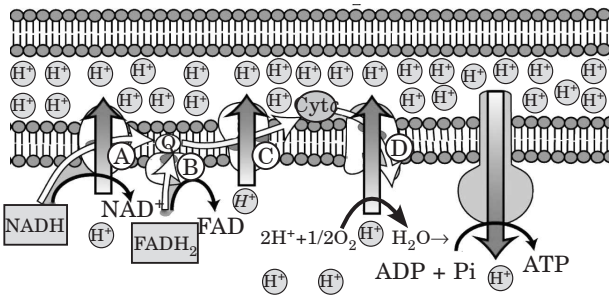
39. The fruits stored in refrigerator or cold storage maintain their flavour and taste for longer period due to
(a) presence of excess of carbon dioxide
(b) non-availability of oxygen
(c) slower rate of respiration
(d) presence of excess humidity.

40. Various electron carriers are arranged in ETS in the order of their
(a) decreasing energy level
(b) increasing energy level
(c) decreasing stability level
(d) increasing stability level.

Case Based MCQs

Case I : Study the following passage and given figure and answer the questions from 41 to 45.

The inner mitochondrial membrane contains groups of electron and proton acceptors. Each of these groups are arranged in specific sequence forming electron transport chain or system.



41. What does *c* represent in the given figure?
(a) Succinate - *UQ* - reductase complex
(b) Cytochrome *c* oxidase complex
(c) NADH - *UQ* reductase complex
(d) UQH_2 - Cytochrome *c* reductase complex

42. Electron transport chain includes
(a) FMN (b) coenzyme-Q
(c) cytochromes (d) all of these.

43. Which one of the following is complex V of the ETS?
(a) NADH dehydrogenase
(b) ATP synthase
(c) Succinate dehydrogenase
(d) Ubiquinone

44. The electron transport chain helps to
(a) cycle $NADH+H^+$ back to NAD^+
(b) maintain surplus of hydrogen ions in the intermembrane space of mitochondria
(c) synthesise ATP through ATP synthase
(d) all of these.

45. Which component of this system is not a protein?
(a) Cytochrome (b) Ubiquinone
(c) Cytochrome oxidase (d) All of these

Case II : Read the following passage and answer the questions from 46 to 50 given below.

Anaerobic respiration is the exclusive mode of respiration in parasitic worms, many prokaryotes, several unicellular eukaryotes and moulds. Based on major organic product formed, anaerobic respiration is divided into alcoholic fermentation and lactic acid fermentation. Anaerobic respiration cannot continue indefinitely (except in some micro-organisms) because of accumulation of poisonous compounds and less availability of energy per gram mole of food broken.

46. Anaerobic respiration takes place in
(a) mitochondrion (b) nucleus
(c) cytoplasm (d) vacuole.

47. Identify A and B in the given reaction.

Pyruvic acid + NADH $\xrightarrow[\text{FMN, 'A'}]{\text{Lactate dehydrogenase}}$ lactic acid + B.

(a) Fe^{3+}, $NADH_2$ (b) Mg^{2+}, $FADH_2$
(c) Zn^{2+}, NAD^+ (d) Fe^+, ATP

48. Select the correct option for the production of very little energy during anaerobic respiration?
(I) Incomplete breakdown of respiratory substrate.
(II) Electron transport chain is present.
(III) Oxygen is used for receiving electrons and protons.
(IV) NADH produced during glycolysis is used up
(a) I and IV (b) II and III
(c) I only (d) I and II

49. In alcoholic fermentation the set of enzyme required are
(a) pyruvic are acid oxygenase and alcohol dehydrogenase
(b) lactate dehydrogenase and Phosphokinase
(c) phospho and pyruvate carboxylase and lactate dehydrogenase
(d) pyruvic acid decarboxylase and alcohol dehydrogenase.

50. In both lactic acid and alcoholic fermentation ATP released is less in amount as
(a) not all of energy is trapped in high energy bonds of ATP
(b) complete oxidation of organic substances occur in the presence of oxygen.
(c) no enzyme is used in this process
(d) fermentation is energy consuming process.

Assertion & Reasoning Based MCQs

For question numbers 51-60, two statements are given-one labelled Assertion and the other labelled Reason. Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

(a) Both assertion and reason are true and reason is the correct explanation of assertion.
(b) Both assertion and reason are true but reason is not the correct explanation of assertion.
(c) Assertion is true but reason is false.
(d) Assertion is false but reason is true.

51. Assertion : Respiratory pathway is an amphibolic pathway.
Reason : In respiration, there is breakdown of many substances (catabolism) and synthesis of many substances (anabolism) by respiratory intermediates.

52. Assertion : Substrate level phosphorylation is present in glycolysis.
Reason : Substrate level phosphorylation causes synthesis of ATP.

53. Assertion : The pentose phosphate pathway is not a mainline pathway for the oxidation of glucose.
Reason : PPP generates energy in the form of ATP.

54. Assertion : Oxidative phosphorylation is the synthesis of energy rich ATP.
Reason : The enzyme required for ATP synthesis is called ATP synthase.

55. Assertion : Electron transport chain is also called cytochrome system.
Reason : Electron transport chain involves redox reactions.

56. Assertion : Krebs' cycle is a high energy producing process.
Reason : 2 ATP molecules are produced itself in Krebs' cycle.

57. Assertion : Respiratory quotient provides important information regarding the nature of respiratory substrate being respired.
Reason : RQ of germinating seeds of cereal is less than unity.

58. Assertion : Krebs' cycle occurs in aerobic respiration.
Reason : Krebs' cycle occurs in mitochondria.

59. Assertion : Glycolysis is the first step of respiration in which glucose is completely broken into CO_2 and H_2O.
Reason : In this, there is net gain of eight molecules of ATP.

60. Assertion : Terminal oxidation occurs at terminal step of respiration.
Reason : Terminal oxidation occurs both in aerobic and anaerobic conditions.

SUBJECTIVE TYPE QUESTIONS

Very Short Answer Type Questions (VSA)

1. Write the overall equation of respiration.

2. Why does anaerobic respiration/fermentation yield less energy than aerobic respiration?

3. How many $NADH_2$ molecules are produced form one molecule of acetyl CoA in TCA cycle?

4. List two instances where lactic acid is formed by fermentation.

5. At which step of respiration, hydrogen of $NADH_2$ is used?

6. What is the respiratory quotient when fats are used in respiration?

7. Name the unit of oxidative phosphorylation.

8. What are the end products of alcoholic fermentation?

9. Enumerate the first step in cellular respiration.

10. Mention the number of protons that passes through complex V for the synthesis of 2 molecules of ATP.

Short Answer Type Questions (SA-I)

11. What is meant by the statement 'aerobic respiration is more efficient'?

12. What are respiratory substrates? Name the most common respiratory substrate.

13. Write two energy yielding reactions of glycolysis.

14. (i) What is the end product of glycolysis in aerobes and where does this process occur?
(ii) List the conditions under which fermentation occurs in plant cells.

15. What are the main steps in aerobic respiration? Where does it take place?

16. What would be the *RQ* value of yeast if it were to respire glucose anaerobically?

17. (i) Where is the respiratory electrons transport system located in a cell?
(ii) What compound is the terminal electron acceptor in aerobic respiration?

18. Give examples of organisms where anaerobic respiration serves as exclusive mode of respiration.

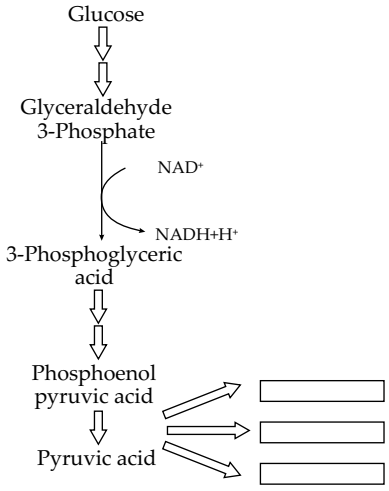
19. Some amino acids also enter the Krebs' cycle after their deamination. Name two amino acids and the compounds formed by them.

20. How many ATP molecules are generated from oxidative decarboxylation of 2 molecules of pyruvate?

Short Answer Type Questions (SA-II)

21. Describe the three phases of respiration.

22. Pyruvic acid is the end product of glycolysis. What are the three metabolic fates of pyruvic acid under aerobic and anaerobic conditions? Write in the space provided in the diagram.



23. In which type of fermentation no CO_2 is released? Name the enzyme required for it. Give its complete reaction.

24. Give an account of four complexes and their respective components present in an electron transport chain (ETS). What is the significance of each of these complex in ETS?

25. How many ATP are produced during cellular respiration during - Glycolysis, Oxidative decarboxylation and Krebs' cycle? What is the net production of ATP?

26. Give an account of various intermediates in Krebs' cycle.

27. Give, three aerobic conditions where RQ is more than unity.

28. Write a short note on pyruvate dehydrogenase complex.

29. (a) Which complex of ETS possess two copper centres?
(b) Name any three inhibitors that block electron transport by acting on NADH dehydrogenase.

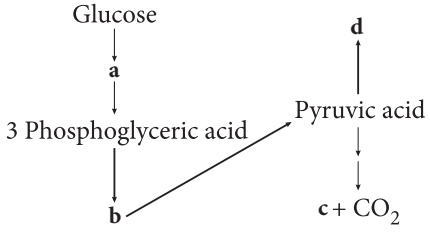
30. What do you understand by substrate level phosphorylation? At which step in glycolysis, substrate level phosphorylation occurs?

31. Anaerobic respiration produces very little energy as compared to aerobic respiration. Give reasons.

32. Differentiate between glycolysis and fermentation.

Long Answer Type Questions (LA)

33. In the following flow chart, replace the symbols a,b,c and d with appropriate terms. Briefly explain the process and give any two applications of it.



34. Respiratory pathway is believed to be a catabolic pathway. However, nature of TCA cycle is amphibolic. Explain.

35. Draw a schematic representation of citric acid cycle.

36. Where does glycolysis occur in cell? Describe the sequence of reactions in it. Mention the end product.

37. Elucidate the formation or production of 36 or 38 molecules per glucose molecule oxidised in an aerobic cell. Also mention why there is difference in net gain of ATP even in aerobic respiration.

ANSWERS

OBJECTIVE TYPE QUESTIONS

1. (b) : Respiratory quotient is the ratio of the volume of carbon dioxide produced to the volume of oxygen consumed in respiration over a period of time, *i.e.*,

$$\text{R.Q.} = \frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ consumed}}$$

2. (c)

3. (b) : In glycolysis, during dehydration reaction 2-phosphoglycerate is converted into phosphoenol pyruvate (PEP) in the presence of enzyme enolase.

4. (c) : The other names of tricarboxylic acid cycle are citric acid cycle as the first stable compound of this cycle is citric acid and it is also called Kreb's cycle because firstly discovered by Hans Kreb.

5. (d)

6. (a) : Cytochrome c oxidase is complex of cytochrome a and cytochrome a_3 that react with oxygen to make it reactive.

7. (c)

8. (a) : Inner mitochondrial membrane contains groups of electron and proton transporting enzymes. In each group, the enzymes are arranged in a specific series called Electron Transport System (ETS).

9. (a) : NADH produce during glycolysis is consumed to obtain hydrogen.

10. (b) : Glycolysis is a common step to both aerobic and anaerobic modes of respiration. It is the first stage of breakdown of glucose in aerobic respiration and the only step for glucose breakdown in anaerobic respiration.

11. (b) : Glucose – 6-phosphate → 3-phosphoglyceraldehyde → 3-phosphoglyceric acid → phosphoenolpyruvate → pyruvic acid.

12. (b) : When fats are used in respiration, the R.Q. is less than 1, *e.g.,* for breakdown of tripalmitin,

$$\text{R.Q.} = \frac{102CO_2}{145O_2} = 0.7$$

13. (b) : During aerobic respiration, pyruvic acid which is formed during glycolysis enters mitochondrial matrix. It undergoes oxidative decarboxylation to produce CO_2 and NADH. The product combines with sulphur containing co-enzyme A to form acetyl CoA. This reaction is catalysed by an enzyme complex pyruvate dehydrogenase. This step is called link reaction or gateway step as it links glycolysis with Krebs' cycle.

$$\text{Pyruvic acid} + \text{CoA} + NAD^+ \xrightarrow[\text{Pyruvate dehydrogenase}]{Mg^{2+}} \text{Acetyl CoA} + CO_2 + \text{NADH} + H^+$$

14. (b) **15. (a)**

16. (d) : Adenosine triphosphate (ATP) is the energy currency of the cell. It is the most important energy carrier which carries energy in the two terminal phosphate bonds (called as high energy bonds or energy rich bonds). Equal amounts of usable energy are released per mole of ATP or ADP hydrolysis:

$ATP + H_2O \rightleftharpoons ADP + P_i + 7.3 \text{ kcal mol}^{-1}$

$ADP + H_2O \rightleftharpoons AMP + P_i + 7.3 \text{ kcal mol}^{-1}$

17. (b)

18. (b) : Lactic acid fermentation occurs in lactic acid bacteria (*e.g., Lactobacillus*), some fungi and muscles. In lactic acid fermentation, pyruvic acid produced in glycolysis is directly reduced by NADH to form lactic acid. No CO_2 is produced. The enzyme is lactate dehydrogenase which requires FMN and Zn^{2+}.

$$\text{Pyruvic Acid} + \text{NADH} \xrightarrow[FMN,\ Zn^{2+}]{\text{Lactate dehydrogenase}} \text{Lactic Acid} + NAD^+$$

19. (c) : 3 ATPs are formed for every pair of electrons that enters by way of NADH and 2 ATPs are formed for every pair electrons that enters by way of $FADH_2$.

20. (b)

21. (a) : Anaerobic respiration takes place in the absence of oxygen. It leads to incomplete degradation of substrate into alcohol and CO_2 releasing some energy (2ATP). Aerobic respiration occurs in the presence of oxygen. It results in complete oxidation of substrate into CO_2, water and energy (38 ATP).

22. (d) : During glycolysis, fructose-1, 6-biphosphate splits up in the presence of aldolase enzyme to form one molecule each of 3-carbon compounds, 3-phospho-glyceraldehyde, PGAL (or glyceraldehyde-3-phosphate) and dihydroxy acetone-3-phosphate (DHAP).

$$\text{Fructose-1, 6-bisphosphate} \xrightarrow{\text{Aldolase}} \text{3-phosphoglyceraldehyde} + \text{Dihydroxyacetone-3- phosphate.}$$

23. (c) : Pyruvic acid (end product of glycolysis) gets converted to acetyl CoA and then enters Krebs' cycle which takes place in mitochondrial matrix. End products of respiratory pathway are - $CO_2 + H_2O + ATP$.

24. (b)

25. (d) : Acetyl CoA (2-carbon compound) combines with oxalo-acetate (4-carbon compound) in the presence of condensing enzyme citrate synthase to form a tricarboxylic 6-carbon compound called citric acid or citrate. It is the first product of Krebs' cycle. CoA is liberated.

$$\text{Acetyl CoA + Oxaloacetic acid + } H_2O \xrightarrow{\text{Citrate synthase}} \text{Citrate + CoA}$$

Citrate undergoes reorganisation in the presence of iron containing enzyme aconitase first forming *cis* aconitate and releasing water.

$$\text{Citrate} \underset{Fe^{+2}}{\overset{\text{Aconitase}}{\rightleftharpoons}} cis - \text{aconitate} + H_2O$$

26. (c) : Dough kept overnight in warm weather become soft and spongy due to fermentation. In this process CO_2 is produced which makes the dough soft and spongy.

27. (d) : Glucose is phosphorylated to glucose-6-phosphate by ATP in the presence of enzyme hexokinase or glucokinase and Mg^{2+}.

28. (d)

29. (d) : One glucose molecule forms - 2 NADH and 2 ATP during glycolysis and 8 NADH, 2 FADH and 2 ATP or 2GTP are forms during Kreb's cycle.

30. (c) : Cytochromes are iron containing pigments found in all cells, in which aerobic respiration takes place.

31. (b) : During glycolysis, partial oxidation of one molecule of glucose into two molecules of pyruvic acid through a series of ten enzyme mediated reaction.

32. (a) : Succinate undergoes dehydrogenation (removal of hydrogen) to form furmarate with the help of membrane based enzyme succinate dehydrogenase.

33. (d) : In Glycolysis, each NADH is equivalent to 3ATP, so that the net gain of ATP in glycolysis is 8, *i.e.*, 2NADH + 2ATP = 8 ATP.

34. (b) : Pyruvate undergoes oxidative decarboxylation to produce acetyl CoA in presence of enzyme pyruvate dehydrogenase.

35. (b) : Respiration is an energy releasing enzymatically controlled catabolic process which involves a breakdown of polymers into smaller and manageable products. Since it produces energy, it is an exergonic reaction.

36. (b) **37. (d)**

38. (a) : Fermentation is the incomplete oxidation of glucose under anaerobic conditions by sets of reactions where pyruvic acid is converted to CO_2 and ethanol (alcoholic fermentation) or lactic acid (lactic acid fermentation). In fermentation, there is a net gain of only 2 ATP molecules for each molecule of glucose degraded to pyruvic acid.

39. (c)

40. (a) : Various electron carriers are arranged in ETS in the order of their decreasing energy level, NAD being the first and oxygen the last. Thus, NAD has the highest energy while oxygen has the lowest energy.

41. (d) **42. (d)**

43. (b) : In ETS, electron passes from one carrier to another *via* complex I to IV in the electron transport chain, they are coupled to ATP synthase (complex V) for the production of ATP from ADP and inorganic phosphate.

44. (d) : NADH and $FADH_2$ carries high energy electrons and deposit them into the electron transport chain. After providing electron and hydrogen ion in ETS, NAD^+ and FAD will be available for the next cycle. Surplus of hydrogen ions (protons) in the intermembrane space used to power ATP synthase as these hydrogen ions are allowed to flow back through a channel in ATP synthase.

45. (b) : Ubiquinone is a coenzyme, a non-protein part of enzyme which is necessary for the functioning of enzyme,

46. (c)

47. (c) : In lactic acid fermentation, pyruvic acid is directly reduced by NADH in the presence of enzyme lactic dehydrogenase, coenzyme FMN and Zn^{2+} as cofactor.

48. (a) : I and IV

49. (d) : $$\text{Pyruvate} \xrightarrow[\text{TPP. } Mg^{2+}]{\text{Pyruvate decarboxylase}} \text{Acetaldehyde} + CO_2 (\uparrow)$$

$$\text{Acetaldehyde + NADH} \xrightarrow{\text{Alcohol decarboxylase}} C_2H_5OH + NAD^+$$

50. (a) : In fermentation not much energy is released, less than seven percent of energy in glucose is released and not all of it is trapped as high energy bonds of ATP.

51. (a) : The term amphibolic is given to a biochemical pathway that involves both catabolism, *i.e.*, breakdown of some substances and anabolism *i.e.*, synthesis of some substances. In cellular respiration, both anabolism and catabolism occur during oxidation of respiratory substrate to release energy.

52. (b) : One of the two phosphates of diphosphoglycerate is linked by high energy bond. It can synthesize ATP and form 3-phosphoglycerate. The enzyme is phsophoglycerate kinase. The direct synthesis of ATP from metabolites is called substrate level phosphorylation.

The formation of pyruvate from PEP helps in the production of ATP by substrate level phosphorylation. The enzyme used is pyruvate kinase.

53. (c) : Many cells possess, in addition to the tricarboxylic acid, another pathway of glucose degradation whose first reaction is the oxidation of glucose 6-phosphate to 6 - phosphogluconate. The phosphogluconate pathway, also known as the pentose phosphate pathway or the hexose monophosphate shunt, is not a mainline pathway for the oxidation of glucose. Its primary purpose in most cells is to generate reducing power in the extramitochondrial cytoplasm in the form of NADPH.

54. (b) : Oxidative phosphorylation is the synthesis of energy rich ATP molecules with the help of energy liberated

during oxidation of reduced co-enzymes ($NADH_2$, $FADH_2$) produced in respiration. The process occurs in mitochondria. The enzymes which synthesize ATP is called ATP synthase.

55. (b) : ETC is a set of electron-carriers present in a specific sequence along inner mitochondrial membrane. These electron-carriers function in a specific sequence and are - nicotinamide adenine dinucleotide (NAD), flavin mononucleotide (FMN), Coenzyme-Q, cytochrome-*b*, cytochrome–c_1, cytochrome-*c*, cytochrome-*a* and cytochrome-a_3.

It is also called cytochrome-system (CS), as five out of these carriers are cytochromes. Transport of electrons on these electron-carriers is a down-hill journey or a descending stairway. During electron transfer, the electron donor gets oxidised, while electron-acceptor gets reduced so these transfers involve redox-reactions and are catalysed by enzymes, called reductases. Oxidation and reduction are complimentary. This oxidation-reduction reaction over the ETC is called biological oxidation.

56. (d) : Glycolysis produce 2 pyruvate molecules which after link reaction produce two acetyl CoA. As two molecules of acetyl-CoA are formed from one glucose molecule, Krebs' cycle must rotate twice for each molecule to respire. Therefore net gain of Krebs' cycle is :

$2\text{Acetyl-CoA} + 8H_2O + 6\text{NAD}+ + 2\text{FAD} + 2\text{GDP} + 2\text{Pi} \rightarrow$

$4CO_2 + 2H_2O + 6\text{NADH} + 6\text{H}+ + 2FADH_2 + 2\text{GTP} + 2$ Coenzyme-A

So, Krebs' cycle is also a low energy producing (like glycolysis) process as only 2GTP molecules are formed. $NADH_2$ and $FADH_2$ are reduced coenzymes and can release their energy only in electron transport chain (ETC). The 6 $NADH_2$ and 2 $FADH_2$ formed in Krebs' cycle, provide about 22 molecules of ATP in the electron transport chain.

57. (c) : Respiratory quotient (RQ) is the ratio of the volume of carbon dioxide released to the volume of oxygen taken in during respiration in the given period of time at a standard temperature and pressure. Its value varies with the respiratory substrates and their oxidation. In case of carbohydrate, RQ is equal to one or unity. In fat and protein due to poor oxygen content in respiratory substrate, O_2 absorption is more and CO_2 liberation is less so, RQ is less than unity. Thus, RQ of germinating seeds of those plant which contain starch (cereals) as the main reserve food is equal to unity but those which contain fat (poorer in O_2) will be less than unity.

58. (b) : Aerobic respiration occurs inside the mitochondria in the presence of molecular oxygen in most of plants and animals, called aerobes. It is divided into 3phases–

(i) Glycolysis (ii) Krebs' or TCA cycle and (iii) Electron transport system.

59. (d) : Glycolysis is a process of breakdown of glucose or similar hexose sugar into two molecules of pyruvic acid through a series of enzyme mediated reactions, releasing energy (ATP) and reducing power ($NADH_2$). It is the first step of respiration, which occurs inside the cytoplasm and is independent of O_2. In glycolysis, two molecules of ATP are consumed and four molecules of ATP are produced. Whereas, two molecules of $NADH_2$ are formed during oxidative process. Since, each NADH is equivalent to 3 ATP, so net gain in glycolysis is 8 ATP.

60. (c) : Terminal oxidation is the name of oxidation found in aerobic respiration that occurs towards the end of catabolic process and involves the passage of both electrons and protons of reduced coenzymes to oxygen. For aerobic organisms it is essential that the enzymes and reduction products of the Krebs' cycle be associated with the electron transport system. Through this association, the reduced pyrimidine nucleotide NADH, FADH and NADPH are reoxidised. The energy released from these oxidations is utilized in the synthesis of ATP.

SUBJECTIVE TYPE QUESTIONS

1. $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$

2. It happens due to incomplete oxidation of the substrate.

3. $3NADH_2$ molecules are produced from one molecule of acetyl Co-A in TCA cycle.

4. Instance where lactic acid is formed by fermentation are

(i) During fermentation by lactic acid bacteria.

(ii) During strenuous exercise, in the striated muscles in humans.

5. The hydrogen atoms accepted by $NADH_2$ during glycolysis are introduced to route I of ETS. In this route 3 ATP molecules are produced.

6. If the respiratory substrate is fat, then RQ of the respiring cells will be less than one because the volume of CO_2 evolved is quite less in comparison to the volume of O_2 being consumed.

7. Oxysomes, or $F_0 - F_1$ particles are present on inner mitochondrial membrane.

8. Ethyl alcohol and CO_2 are the end products of alcoholic fermentation.

9. Gylcolysis, which involves breaking down of sugar to pyruvic acid is the first step in cellular respiration.

10. Two pairs of protons (*i.e.*, 4) passes through complex V for the synthesis of two molecules of ATP.

11. The aerobic respiration is a high energy yielding process. During the process of aerobic respiration as many as 36 molecules of ATP are produced for every molecule of glucose that is utilized. This shows that aerobic respiration produces much more energy than anaerobic respiration, which produces only 2 ATP molecules.

12. The organic substances, which are catabolised in the living cells to release energy are called as respiratory substrates. Though any food stuff-carbohydrate, fat or protein may act as a respiratory substrate, the most common respiratory substrate is glucose.

13. The conversion of BPGA to 3-phosphoglyceric acid (PGA), is an energy yielding process; this energy is trapped by the formation of an ATP. Another ATP is synthesised during the conversion of PEP to pyruvic acid.

14. (i) End product of glycolysis is pyruvic acid

$$\text{Glucose} + 2\text{ADP} + 2\text{P}_i + 2\text{NAD} \rightarrow 2 \text{ Pyruvic acid} + 2\text{ATP} + 2\text{NaDH}_2$$

It occurs in cytoplasm, *i.e.*, outside the mitochondria.

(ii) Fermentation in plant cells occurs in absence of oxygen.

15. The main steps in aerobic respiration are as follows

(i) Glycolytic breakdown of glucose into pyruvic acid.

(ii) Oxidative decarboxylation of pyruvic acid to acetyl CO-A (acetyl coenzyme-A). (Link reaction)

(iii) Oxidative and cyclic degradation of activated acetate derived from pyruvate to produce energy (Kreb's cycle). Glycolysis takes place in cytoplasm whereas Link reaction and Kreb's cycle takes place in matrix of mitochondria.

16. The RQ will be infinity (∞) during anaerobic respiration. In anaerobic respiration, CO_2 is evolved but oxygen is not used. Therefore, RQ, in such a case, will be infinite.

e.g., $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 + \text{energy}$

$$\text{RQ} = \frac{2\text{CO}_2}{\text{O}_2} = \text{Infinity.}$$

17. (i) On the inner membrane of mitochondria.

(ii) Oxygen.

18. Anaerobic respiration is an exclusive mode of respiration that occurs in prokaryotes, unicellular eukaryotes, moulds and some parasitic worms.

19. Amino acids enter Krebs' cycle directly as glutamate that forms α-ketoglutarate and aspartate that forms oxaloacetate after their deamintion.

20. 6 ATP (Since oxidation of 2 pyruvate yields 2NADH and each NADH molecule is equivalent to almost 3 ATP molecules, hence $3 \times 2 = 6$ ATP).

21. The three phases of respiration are :

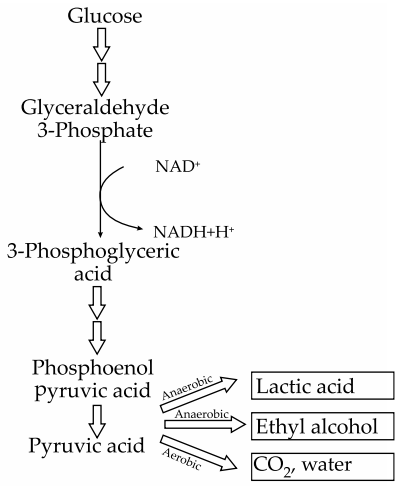
(i) External respiration : It is a physical process that involves exchange of oxygen of environment (air or water) and carbon-dioxide of the blood at the respiratory organ.

(ii) Internal (tissue) respiration : It is also a physical process that involves exchange or oxygen of blood and carbon-dioxide of the cell at the cellular level.

Both the exchange of gases occur on the principle of diffusion.

(iii) Cell respiration : It is an enzymatically- controlled stepped chemical process in which glucose is oxidised inside the mitochondria to produce energy-rich ATP molecules with high-energy bonds. So respiration is a biochemical process.

22.



23. In lactic acid fermentation, no CO_2 is released. The enzyme required for this reaction is lactic dehydrogenase.

$$\text{Pyruvic acid} + \text{NADH} \xrightarrow[\text{FMN, } Zn^{2+}]{\text{Lactic dehydrogenase}} \text{Lactic acid} + \text{NAD}^+$$

24. The electron transport chain is comprised of four complexes and two mobile electron carriers *i.e.,* coenzyme *Q*, a non–protein part of the chain (except this all the members of the chain are proteins) and cytochrome *c*.

Complex I consists of flavoproteins of NADH dehydrogenase of which FMN is the prosthetic group. Combined with the flavoprotein is non-heme iron of NADH dehydrogenase. This complex spans inner mitochondrial membrane and is able to translocate protons across it from matrix side to outer side.

Complex II consists of flavoprotein of succinate dehydrogenase, of which FAD is the prosthetic group. Combined with the flavoprotein is non-heme iron of succinate dehydrogenase.

Between complexes II and III is the mobile carrier – coenzyme Q (CoQ) or ubiquinone (UQ).

Complex III consists of cytochrome *b* and cytochrome c_1. Associated with cytochrome *b* is non-heme iron of complex III. Between complexes III and IV is the mobile carrier cytochrome *c*.

Complex IV consists of cytochrome a and cytochrome a_3 and bound copper that are required for this complex reaction to occur. This cytochrome also called cytochrome oxidase, is the only electron carrier in which the heme iron has a free ligand that can react directly with molecular oxygen.

The electrons either follow the pathway of complexes I, III and IV or II, III and IV depending upon the substrates from Krebs' cycle.

25. Complete aerobic breakdown of one molecule of hexose result in the release of ATP molecule. The number of ATP molecule released during :

– Glycolysis : Two molecules of NADPH are released during glycolysis. The glycolysis also yields 4 ATP molecules

out of which 2 ATP molecules are consumed. Thus, the glycolysis contributes a total of 2 + 4 = 6 ATP molecule.

– Oxidative decarboxylation : Two molecules of NADH are released during the oxidative decarboxylation and synthesis of acetyl CoA from pyruvic acid. Thus, number of ATP molecules will be $2 \times 3 = 6$.

– Krebs' cycle : This cycle releases 6 molecules of NADPH and 2 molecules of $FADH_2$. The Krebs' cycle also releases 2 ATP molecules thus total number of ATP molecules produced during Krebs' cycle are

$2 + 2 \times 2 + 6 \times 3 = 24$ molecules

Net production of ATP molecules is 36 or 38.

26. The various intermediates of Krebs' cycle are utilised to synthesise other compounds through anabolic reactions / pathway such as :

(i) Acetyl CoA provides 2-carbon compounds for the synthesis of fatty acids, cutin, aromatic compounds and isoprenoids for forming phytol chain of chlorophyll, carotenoids, steroids, terpenes, gibberellins, etc.

(ii) α-ketoglutarate of Krebs' cycle produces an important amino acid called glutamate.

(iii) Succinyl CoA takes part in synthesis of pyrrole compounds of chlorophyll, cytochrome and phytochrome.

(iv) Oxaloacetate produces another important amino acid called aspartate. It also forms pyrimidines and alkaloids.

(v) It forms GTP which is an important component of signal-transduction system.

27. Three aerobic conditions where RQ is more than unity is as follows:

(i) $\underset{\text{Oxalic acid}}{2(COOH)_2} + O_2 \rightarrow 4CO_2 + 2H_2O$ RQ = 4 CO_2/1 O_2 = 4.0

(ii) $\underset{\text{Malic acid}}{C_4H_6O_5} + 3\ O_2 \rightarrow 4CO_2 + 3H_2O$ RQ = $4CO_2/3O_2$ or 1.3

(iii) $\underset{\text{Succinic acid}}{2C_4H_6O_4} + 7O_2 \rightarrow 8CO_2 + 6H_2O$ RQ = $8CO_2/7O_2$ or 1.14

28. The pyruvate dehydrogenase complex is a multimolecular aggregate of three enzymes: pyruvate decarboxylase whose prosthetic group is coenzyme thiamine pyrophosphate (TPP); dihydrolipoyl transacetylase (prosthetic group is lipoic acid) and dihydrolipoyl dehydrogenase (prosthetic group is flavin adenine dinucleotide FAD) and it also requires Mg^{2+}. It carries out the given decarboxylation reaction that acts as a gateway step as it links glycolysis with Krebs' cycle :

$$\text{Pyruvate} + NAD^+ + CoA \xrightarrow[\text{dehydrogenase}]{\text{Pyruvate}} \text{Acetyl CoA} + NADH + H^+ + CO_2$$

29. (a) ETS complex IV comprises of cytochrome *c* oxidase that contains cytochrome a and cytochrome a_3. The latter possesses two copper centres that help in transfer of electrons to oxygen.

(b) The three inhibitors that block electron transport by acting on NADH dehydrogenase are :

(i) Rotenone - a toxic plant substance

(ii) Amytal - a barbiturate drug

(iii) Piercidin - an antibiotic resembling ubiquinone

30. The direct synthesis of ATP from metabolites is called substrate level phosphorylation.

(i) In glycolysis, ATP is synthesised from 1, 3-biphosphoglycerate. The reaction is as follows :

$$\text{1, 3 biphosphoglycerate} + ADP \underset{Mg^{2+}}{\overset{\text{Phosphoglycerate kinase}}{\rightleftharpoons}} \text{3-phosphoglycerate} + ATP$$

(ii) Another step at which substrate level phosphorylation occurs in glycolysis is during formation of pyruvate from phosphoenol pyruvate (PEP).

$$PEP + ADP \xrightarrow[Mg^{2+},\ K^+]{\text{Pyruvate kinase}} \text{Pyruvate} + ATP$$

31. Anaerobic respiration produces very little energy because :

(i) There is incomplete breakdown of respiratory substrate.

(ii) At least one of the products of anaerobic respiration is organic. It can be further oxidised to release energy.

(iii) NADH produced during glycolysis is often used up.

(iv) ATP formation does not occur during regeneration of NAD^+.

(v) Electron transport chain is absent.

(vi) Oxygen is not used for receiving electrons and protons.

32. Differences between glycolysis and fermentation are as follows:

	Glycolysis	Fermentation
(i)	It is the first step of respiration which occurs without 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.

33. a = Glyceraldehyde 3-phosphate
b = Phosphoenol pyruvic acid
c = Ethanol
d = Lactic acid

The given metabolic pathway in figure is anaerobic respiration or fermentation.

Anaerobic respiration is an enzyme mediated energy liberating catabolic process of step-wise but incomplete breakdown of organic substrate without using oxygen as an oxidant. Energy is liberated during breaking of bonds between various types of atoms. The common products of anaerobic respiration are CO_2, ethyl alcohol and lactic acid.

$$C_6H_{12}O_6 \xrightarrow{\text{Enzymes}} 2CO_2 + \underset{\text{Ethyl alcohol}}{2C_2H_5OH} + 59 \text{ kcal}$$

$$C_6H_{12}O_6 \xrightarrow{\text{Enzymes}} \underset{\text{Lactic acid}}{2C_3H_6O_3} + 36 \text{ kcal}$$

It is of two types:

(i) Alcoholic fermentation : It takes place in two steps:

(a) Pyruvate $\xrightarrow[\text{decarboxylase, TPP, } Mg^{2+}]{\text{Pyruvate}}$ Acetaldehyde + $CO_2(\uparrow)$

(b) Acetaldehyde + NADH $\xrightarrow[\text{dehydrogenase}]{\text{Alcohol}}$ $C_2H_5OH + NAD^+$

It produces alcohol from pyruvic acid and releases carbon dioxide.

(ii) Lactic acid fermentation : It takes place in a single step

Pyruvic acid + NADH $\xrightarrow[\text{FMN, } Zn^{2+}]{\text{Lactic dehydrogenase}}$ Lactic acid + NAD^+

It produces lactic acid from pyruvate and does not release carbon dioxide.

Applications of anaerobic respiration are as follows :

(i) It has important role in brewing (Saccharomyces cerevisiae), baking, vinegar and milk industries (*Streptococcus lactis*). Vinegar is produced by fermentation of sugars in the presence of acetic acid bacteria (*Acetobacter aceti*).

(ii) Production of industrial alcohols and organic acids like citric acid and malic acid.

34. The amphibolic nature of TCA cycle can be explained by the following reasons :

Amphibolic pathway is the one which is used for both breakdown (catabolism) and build-up (anabolism) reactions. Respiratory pathway 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.

(i) Acetyl CoA is helpful not only is using fatty acids in Krebs' cycle but is also raw material for synthesis of fatty acids, steroids, terpenes, aromatic compounds and carotenoids.

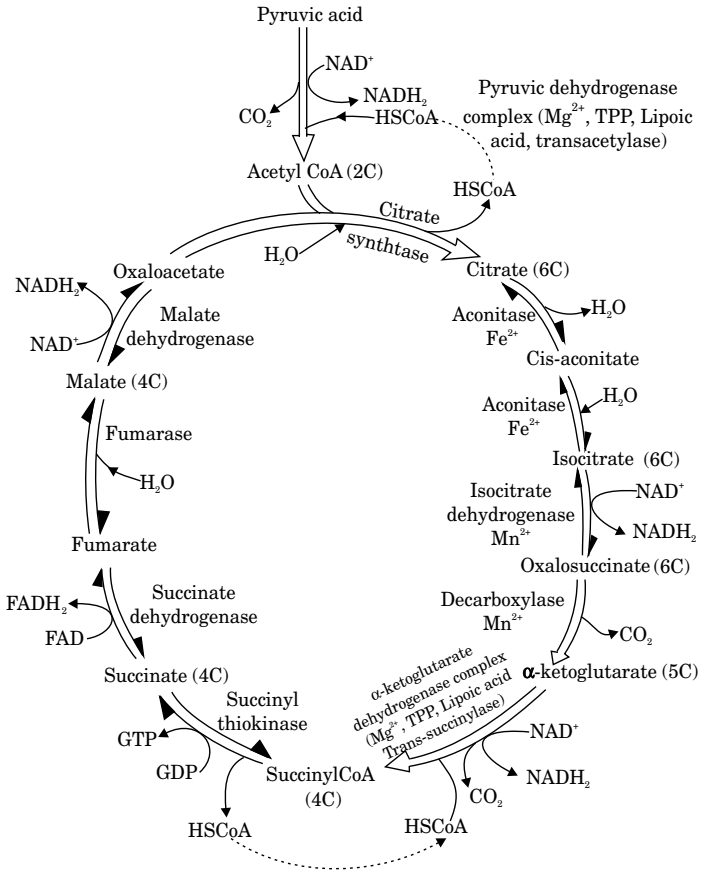
(ii) α-ketoglutarate is organic acid which forms glutamate (an important amino acid) on amination.

(iii) Oxaloacetate on amination produces aspartate (another important amino acid).

(iv) Both aspartate and glutamate are components of proteins. Pyrimidines and alkaloids are other products.

(v) Succinyl CoA forms cytochromes and chlorophyll.

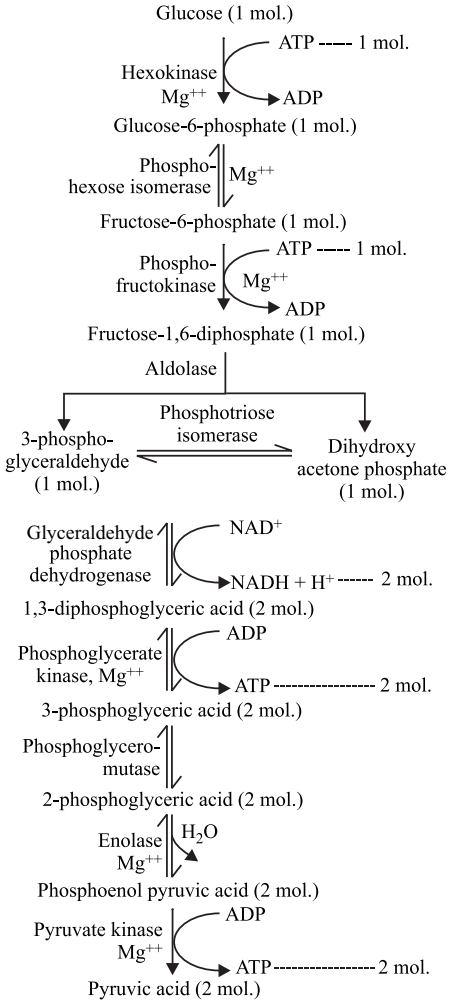
35. A schematic representation of citric acid cycle (Krebs' cycle) is given below :



36. Glycolysis : Glycolysis means "the splitting of sugar". A glucose molecule is converted into 2 molecules of pyruvic acid during glycolysis. It occurs in cytosol or cytoplasm of the cell.

Sequence of reactions in glycolysis :

The series of reactions occurring in glycolysis is as follows:



37. The total ATP production from the complete oxidation of a glucose molecule to CO_2 and H_2O under aerobic conditions are.

(i) Glycolysis provides 2 ATP molecules and $2NADH + 2H^+$.

(ii) Pyruvate oxidation yields 2 $NADH + 2H^+$ only.

(iii) Krebs' cycle gives 2 GTP molecules, $6 NADH + 6H^+$ and $2FADH_2$. Generally no distinction is made between ATP and GTP because GTP is changed into ATP in the cytoplasm by an enzyme nucleoside diphosphate kinase. Therefore, GTP is regarded ATP in the concerned calculations.

(iv) ETS produces 32 or 34 ATP molecules, and is the major source of energy for a cell. Its yield is as under :

- 2 NADH molecules from glycolysis give 4 ATP molecules if their electrons are introduced into route 2 of ETC by the less efficient shuttle, or 6 ATP molecules if their electrons are passed by the more efficient shuttle into route 1 to ETC.
- 2 NADH molecules from pyruvate oxidation yield 6 ATP molecules in route 1 of ETC.
- 6 NADH molecules from Krebs' cycle yield 18 ATP molecules in route 1 of ETC.
- 2 $FADH_2$ molecules from Krebs' cycle yield 4 ATP molecules in route 2 of ETC.

32 or 34 ATP from electron transfers, when added to 4 ATP from glycolysis and Krebs' cycle, give a grand total of 36 or 38 ATP for each glucose molecule fully oxidised to CO_2 and H_2O.

The shuttle system seems to vary with the species. Thus, a glucose molecule on complete oxidation produces 36 ATP in most eukaryotic cells, but also forms 38 ATP in some species. In aerobic prokaryotes, heart, liver and kidneys, 38 ATP molecules are produced per glucose molecule oxidised.

$Glucose + 36/38\ Pi + 6O_2 \rightarrow 6CO_2 + 42/44\ H_2O + 36/38\ ATP + Heat$

The 42/44 H_2O molecules shown in the products above include $6H_2O$ molecules produced in the last step of ETS by combination of hydrogen and oxygen, and 36/38 H_2O molecules released as by products of the synthesis of ATP.

$36/38\ ADP + 36/38\ Pi \longrightarrow 36/38\ ATP + 36/38\ H_2O$

In the prokaryotic cells, aerobic cell respiration of a glucose molecule always provides 38 ATP molecules because NADH molecules formed during glycolysis are not to enter the mitochondria.