SENIOR FIVE TERM 3

TOPIC 4: Respiration

Competency: The learner appreciates how living organisms generate cellular energy, by analysing respiratory processes and the chemical breakdown of food within cells, to make informed decisions that promote good health and wellbeing.

Contents

Respiration

This is the oxidation of organic substance to liberate energy in the body. **Aerobic respiration** requires oxygen whereas **anaerobic respiration** does not require oxygen.

Organic molecules (usually carbohydrate or fat) are broken down bond by bond, by a series of enzyme - controlled reactions. Each bond broken releases a small amount of energy converted to **adenosine triphosphate (ATP).** ATP is the immediate source of energy for cellular reactions.

Uses of ATP

1. Provide energy to build up macromolecules such as proteins from amino acids, polysaccharides form monosaccharides and DNA synthesis.
2. Provide energy for movement of materials such as active transport.
3. Provides energy for secretion of materials.
4. Provide energy for muscle contraction, spindle formation in cell division and ciliary action
5. Provide energy for activation of molecules before they are used in the body.

Cell respiration

Cell respiration involves oxidation of a substrate to yield chemical energy (ATP). Organic compounds which are used as substrates in respiration are carbohydrates, fats and proteins.

Carbohydrates

These are usually the first choice of most cells. In fact, brain cells of mammals cannot use anything but glucose. Polysaccharides are hydrolyzed to monosaccharides before they enter the respiratory pathway i.e. starch in plant and glycogen in animals are first converted to glucose.

Fats/lipids

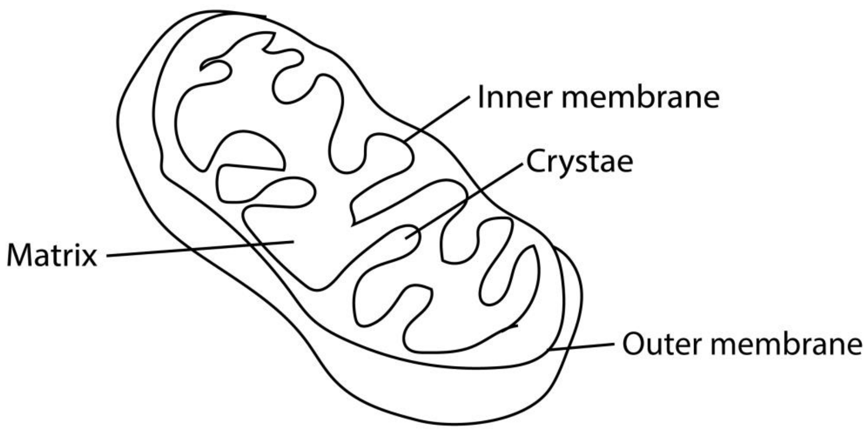
They form the “first” reserve and are mainly used when carbohydrate reserves have been exhausted. However, in skeleton muscle cells, if glucose and fatly acids are available, these cells respire the acids in preference to glucose.

Lipids are better energy source than carbohydrates because they have a higher proportion of hydrogen and an almost insignificant proportion of oxygen compared with carbohydrates. Thus a given mass of lipids yields more energy on oxidation than an equal mass of carbohydrate.

Proteins

Since proteins have other essential functions they are only used when all carbohydrate and fat reserves have been used up, as during prolonged starvation.

Mitochondrion



Function

Production of cellular energy, ATP

Adaptations of mitochondria

- Membranes are permeable to enable the mitochondrion acquire oxygen and metabolites and also to release carbon dioxide and its products.
- Has extensive folding of inner membrane to create a high surface area for enzymes that produce ATP.
- The inner membrane is highly impermeable to most ions and small molecules. This property is critical for maintaining the proton gradient needed for chemiosmosis and ATP synthesis
- The inter-membrane space is narrow, allowing protons pumped by the ETC to accumulate quickly and create a steep electrochemical gradient.
- have a small amount of mitochondrial DNA, allowing them to create mitochondrial proteins quicker than from nucleic genes.
- Have necessary enzymes for production of energy

The break of glucose in respiration

When glucose is the substrate of respiration, its oxidation can be divided into three phases, glycolysis, oxidative de-carboxylation (Krebs or citric acid cycle or TCA, tri-carboxylic acid cycle); oxidative phosphorylation. Glycolysis is common to anaerobic and aerobic respiration, but the other two phases only occur only in presence of oxygen.

Stages of glycolysis in the cytoplasm of the cell

1. Glucose (6C sugar)

   (ATP → ADP)

   The glucose molecule is phosphorylated to make it more reactive. The phosphate molecule comes from conversion of ATP to ADP

2. Glucose phosphate(6C)

   Glucose is reorganized into its isomer fructose phosphate

3. Fructose

   (ATP → ADP)

   Further phosphorylation takes place by the addition of another phosphate group from ATP make the sugar more active

4. Fructose bisphosphate

   Sugar splits into two 3 carbon sugars

5. Gkyceraldehyde-3-phosphate (2molecules)

   (Inorganic Phosphate → ; → 2 x2H)

   Further phosphorylation takes place by the addition of another phosphate group from inorganic sources but not ATP. 2pairs of hydrogen removed

6. Glycerate-1,3-bisphosphate (2molecules)

   (2ADP → 2ATP)

   A phosphate molecule is lost from each glycerate-1,3-bisphosphate molecule yielding two ATP molecules from two ADP molecules.

7. Glycerate-3-phosphate (2molecules)

   A phosphate is removed from the each glycerate-3-phosphate to form a pair of ATP

8. Pyruvate (3C) (2molecules)

Glycolysis represents a series of reactions in which a glucose molecule is broken down into two molecules of pyruvate. Glycolysis occurs in the **cytoplasm of cells**, not in the mitochondria, and does not require the presence of oxygen. The process may be subdivided into two steps, first the conversion of glucose into fructose 1,6 - di-phosphate, and secondly the splitting of fructose -1,6- di-phosphate into 3C sugars which are later converted into pyruvate. Two ATP molecules are used up for phosphorylation reaction in the first step whilst four ATP molecules are produced in the second step. Four hydrogen atoms are also release. These are oxidized to water by molecular oxygen with accompanying phosphorylation of ADP to ATP molecules during oxidative. Each pair of hydrogen atom is oxidized to form 2 ATP

The ultimate fate of pyruvate depends on the availability of oxygen in the cell. If it is present, pyruvate will enter a mitochondrion and be completely oxidized into carbon dioxide and water **aerobic respiration.** If oxygen is unavailable pyruvate will be converted into ethanol or lactate (**anaerobic respiration).**

Summary

source	Number of ATP
From stages 6 and 7	4ATP
ATP from NADH2	4ATP
Total	8ATP

Aerobic respiration.

There are two phases involved in aerobic respiration, first, if sufficient oxygen is available, each pyruvate molecule enters a mitochondrion where it is converted into a 2-carbon compound **acetyl co-enzyme A** (acetyl CoA for short). In this reaction carbon dioxide is given off, and the pyruvate loses a pair of hydrogen atoms which again results in the synthesis of ATP.

Acetyl CoA is a very important intermediate in respiration. It links glycolysis, oxidation of fats and proteins with the **Krebs cycle.**

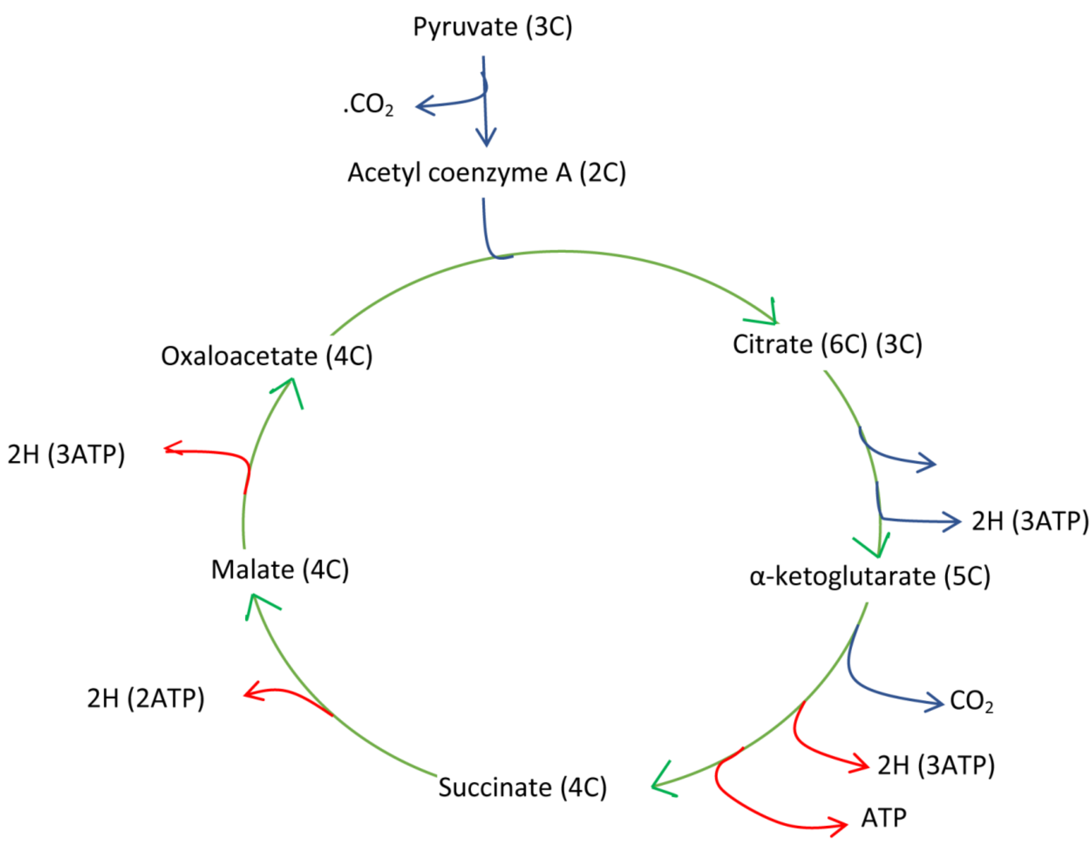
The Krebs cycle, tricarboxylic cycles or citric cycle

1. Before pyruvate enters the Krebs cycle it combines with a compound called **coenzyme A** to form Acetyl coenzyme A. in the process, a molecule of carbon dioxide and a pair of hydrogen atoms are removed.
2. The 2-carbon acetyl coenzyme A enters the Krebs cycle by combining with a 4-carbon **oxaloacetate (oxaloacetic acid** to give a 6-carbon **citrate (citric acid).** This reaction requires energy which is provided at the expense of the energy-rich bond of acetyl group CoA.
3. The citrate is degraded to a 5-carbon **α-ketoglutarate (α-ketoglutaric acid)** and then the 4-carbon oxaloacetate by progressive loss of two carbon dioxide thus completing the cycle.
4. For each turn of the cycle, a total of four pairs of hydrogen atoms are also formed.

5. Of these, 3 pairs of hydrogen atoms are combined with hydrogen carrier, nicotinamide adenine dinucleotide (NAD) and yield three ATP for each pair of hydrogen atoms. The remaining pair of hydrogen atoms combine with a different hydrogen carrier, **Flavine adenine dinucleotide (FAD)**. And yield 2 ATP.

6. It must be remembered that all these products are formed from a single pyruvate molecule of which two are produced from each glucose molecule.

Krebs Cycle in the matrix of the mitochondria



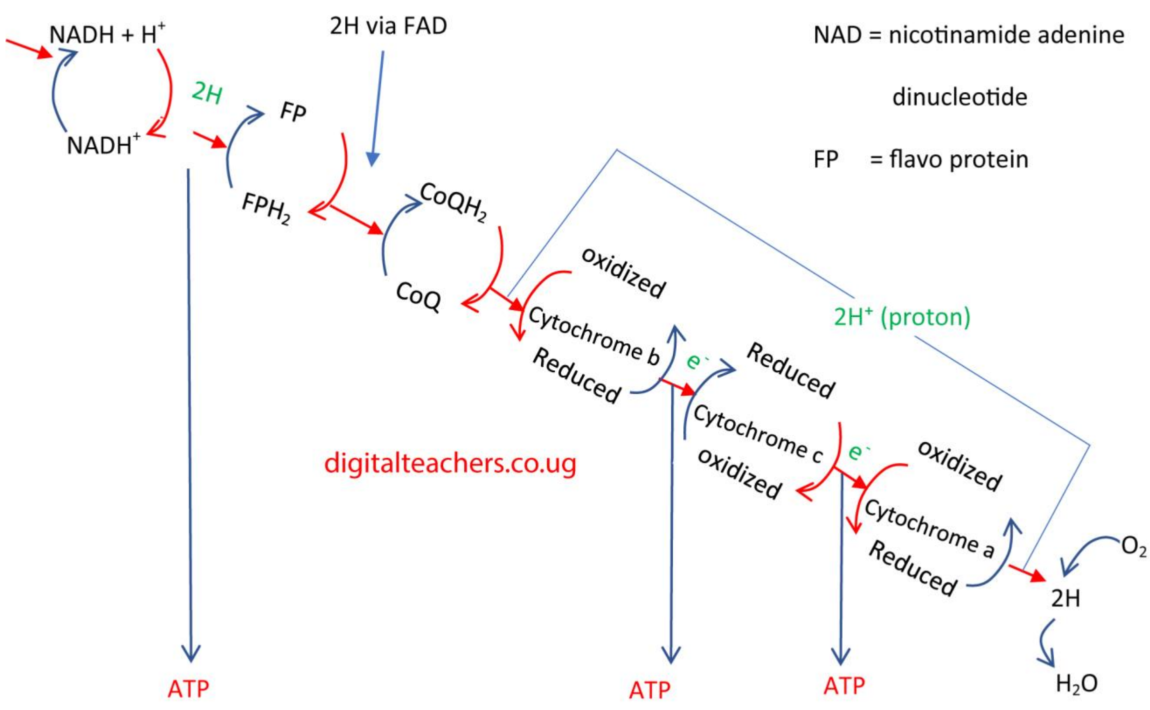
Summary

Source of ATP	Number of ATP	Total number
3 pairs if H with NAD	9ATP	9ATP x 2
1 pair of H with FAD	2ATP	2ATP x 2
Energy of the cycle	1ATP	1ATP x 2
Glycolysis process	8ATP	8ATP x 1
Pyruvate to Acetyl Co A	3ATP	3ATP x 2
Total		38 ATP

Electron transport in the stalked membrane of the mitochondria

It occurs in the **inner** membranes of the mitochondria. It is the means in by which the energy, in the form of hydrogen atom, from Krebs cycle, is converted to ATP. The hydrogen atoms attached to a hydrogen carriers NAD and FAD are transferred to a chain of other carriers at progressively lower energy levels. As the hydrogens pass from one carrier to the next, the energy released is used to produce ATP. The series of carrier is called **respiration chain**. The carriers in the chain include **NAD, Flavo protein, coenzyme Q** and iron-containing protein called **cytochromes**. Initially hydrogen atoms are passed along the chain, but latter split into their proton and electron and only the electron pass from carrier to carrier. For this reason, the pathway can be called electron or hydrogen transport system. At the end of the chain the protons and electrons recombine, and the hydrogen atoms create a link with oxygen to form water. This formation of ATP through the oxidation of the hydrogen atoms is called **oxidative phosphorylation**. The role of oxygen is to act as the final electron acceptor.

Summary of the electron transport system



How ATP production changes during various exercise intensities

During exercise, the demand for ATP (adenosine triphosphate) can increase more than 100-fold compared to resting levels. The body meets this increasing demand by activating and transitioning between its three main energy systems: the phosphagen system, the glycolytic system, and the oxidative system. The contribution of each system changes according to the intensity and duration of the exercise.

Extreme-intensity exercise (0–10 seconds)

For very short, explosive movements, ATP is produced at a maximum rate using the fastest and most immediate energy sources.

- **Phosphagen system dominates:** This system uses the small stores of ATP and phosphocreatine (PCr) already present in the muscles.
- **How it works:** When a muscle contracts, it breaks down ATP. The enzyme creatine kinase then immediately uses the energy released from the breakdown of PCr to resynthesize ATP.
- **ATP production:** The phosphagen system produces a limited amount of ATP but at the highest possible rate. This pathway does not require oxygen, so it is anaerobic.

  Examples: Powerlifting, a 100-meter dash, or a single max-effort jump.

High-intensity exercise (10 seconds–2 minutes)

Once the phosphagen system is depleted, the body shifts to a rapid, but less efficient, anaerobic process to continue producing ATP.

- **Glycolytic system takes over:** This system breaks down glucose, obtained from glycogen stores in the muscles and liver, to produce ATP.
- **How it works:** In a process called glycolysis, glucose is broken down into pyruvate. Because oxygen is limited during high-intensity exercise, pyruvate is converted to lactate, allowing ATP production to continue.
- **ATP production:** Glycolysis produces a moderate amount of ATP at a high rate but is not sustainable due to the buildup of lactate and hydrogen ions, which contributes to muscle fatigue.

Examples: A 400-meter sprint, high-intensity interval training (HIIT), and repeated heavy lifts.

Moderate-intensity exercise (2–30+ minutes)

For sustained exercise, the body transitions to the more efficient oxidative system as oxygen delivery to the muscles increases.

- **Oxidative system dominates:** Also known as aerobic metabolism, this system uses oxygen to generate large quantities of ATP for longer durations.

- **How it works:** The oxidative system uses a wider range of fuel sources, including carbohydrates (glucose) and, increasingly, fats. Pyruvate from glycolysis enters the mitochondria for the Krebs cycle and electron transport chain, which yield a much higher ATP output.

- **ATP production:** This process is slower than anaerobic systems but is significantly more efficient and produces enough ATP to sustain activity for prolonged periods.

  Examples: Long-distance running, jogging, or cycling.

Low-intensity exercise (longer than 30 minutes)

During extended, low-intensity exercise, the body relies almost exclusively on the highly efficient oxidative system.

- **Fat becomes the primary fuel:** At lower intensities, the oxidative system relies predominantly on fat (fatty acids) as its fuel source. The vast energy reserves from fat stores allow for the longest possible duration of exercise.

- **ATP production:** Though the rate of ATP production is the slowest of the three systems, the total capacity is practically limitless, as even lean individuals have large stores of fat.

Examples: Walking, gentle swimming, or slow hiking.

Effect of cyanide on respiration

Cyanide affects respiration by poisoning the mitochondrial electron transport chain, specifically by binding to a key enzyme called cytochrome c oxidase (Complex IV). This action prevents the body's cells from using oxygen, which is essential for aerobic respiration and the production of ATP.

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Anaerobic respiration

A variety of microorganism (anaerobes) employ anaerobic respiration as their major ATP yielding process. Organism that survive only in absence of oxygen are termed **obligate anaerobes** e.g. C. Brotulium and C. tetani). Obligate anaerobe find oxygen poisonous.

Other organisms such as yeast and alimentary canal parasites (such as tape worms), can exist whether oxygen is available or not. These are called **facultative anaerobe.** Also, some cells that are temporarily deprived of with **no oxygen available to accept the hydrogen** oxygen (such as muscle cells) are able to respire anaerobically.

Pyruvate serves as an electron/hydrogen acceptor in absence of oxygen to accept the hydrogen atoms released during glycolysis; and depending on the metabolic pathways within the organisms' cells, the end-product of anaerobic respiration will either be ethanol and carbon dioxide (e.g. fermentation as in yeast) or lactate, for example **lactate fermentation** in muscle cells:

In Alcoholic fermentation the glucose is converted to ethanol and carbon dioxide

$$C_6H_{12}O_6 \xrightarrow{\text{fermentation}} 2CH_3CH_2OH + 2CO_2$$

Alcoholic fermentation is the basis of brewing in which ethanol is an important product and baking industry in which carbon dioxide expands the dough.

Lactic fermentation occurs occasionally in animal cells during strenuous exercise and oxygen is insufficient. It allows animal to survive periods of insufficient oxygen. When oxygen is latter availed, lactic acid is oxidized to carbon dioxide and water or can be turned into carbohydrates. The amount of oxygen required to oxidize lactic acid accumulated in muscles is called the **oxygen debt**.

Differences in aerobic and anaerobic respiration

	Aerobic Respiration	Anaerobic Respiration
Definition	Aerobic respiration uses oxygen.	Anaerobic respiration is respiration without oxygen; the process uses a respiratory electron transport chain but does not use oxygen as the electron acceptors.
Cells that use it	Aerobic respiration occurs in most cells.	Anaerobic respiration occurs mostly in prokaryotes
Amount of energy released	High (36-38 ATP molecules)	Lower (Between 36-2 ATP molecules)
Stages	Glycolysis, Krebs cycle, Electron Transport Chain	Glycolysis, Krebs cycle, Electron Transport Chain
Products	Carbon dioxide, water, ATP	Carbon dixoide, reduced species, ATP
Site of reactions	Cytoplasm and mitochondria	Cytoplasm and mitochondria
Reactants	glucose, oxygen	glucose, electron acceptor (not oxygen)
combustion	complete	incomplete
Production of Ethanol or Lactic Acid	Does not produce ethanol or lactic acid	Produce ethanol or lactic acid

Alternative respiratory substances

1. **Fats** are oxidized after hydrolysis to glycerol and fatty acids. Glycerol is phosphorylated, and converted into glycealdehyde-3-phosphate which is incorporated into the glycolysis pathway. Fats produce more hydrogens than glucose/carbohydrates and hence produce more energy.

2. **Proteins** are used only in cases of starvation. They are hydrolyzed to constituent amino acids which are deaminated to form carbohydrates before converted to pyruvate.

Respiratory Quotients

The respiratory quotient (RQ) is the measure of the ratio of carbon dioxide evolved by an organism to the oxygen consumed, over a certain period.

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

For hexose sugar like glucose, the equation for its complete oxidation is

$$C_6H1_2O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

$$RQ = \frac{6CO_2}{6O_2} = 1.0$$

Importance:

(i) Knowledge of respiratory quotient helps in determining respiratory substrate.

(ii) It helps in knowing the type of respiration being performed,

(iii) It provides some information about major transformation of food materials.

In fats and proteins, the ratio of carbon dioxide evolved to oxygen consumed is far smaller than in carbohydrates. A fat and proteins, therefore requires more oxygen for its complete oxidation than carbohydrates. The respiratory quotient of fats is 0.7 whereas that of proteins is 0.9. Organisms rarely respire one substance at a time, thus the respiratory quotients of an animal is between 0.8 and 0.9.

Low respiratory quotient may also indicate that carbon dioxide produce is used elsewhere for example;

(i) at compensation point during photosynthesis carbon dioxide produced used is in photosynthesis

(ii) during egg formation carbon dioxide produced is used for shell formation. Carbon dioxide is the source of carbonate ions for formation of $CaCO_3$ in egg shells

(iii) RQ is less than one when respiration is aerobic but the respiratory substrate is either fat or protein. RQ is about 0.7 for most of the common fats. It occurs during germination of fatty seeds.

$C_{57}H_{104}O_6 + 80\ O_2 \rightarrow 57CO_2 + 52H_2O$
(triolein)
$RQ = \frac{57CO_2}{80O_2} = 0.71$
$2(C_{51}H_{98}O_6) + 145O_2 \rightarrow 102CO_2 + 98H_2O$
(tripalmitin)
$RQ = \frac{102CO_2}{145O_2} = = 0.7$

RQ is about 0.9 in case of proteins, peptones, etc.

(iv) **RQ Zero:**
Succulents do not evolve carbon dioxide during night (when their stomata are open) as the same is used in carbon fixation. They also change carbohydrates to organic acids which utilise oxygen but do not evolve carbon dioxide.

$$2C_6H_{12}O_6 + 3O_2 \rightarrow 3C_4H_6O_5 + 3H_2O \quad RQ = \text{Zero } CO_2/3O_2 = \text{Zero}$$

High respiratory quotients occur

(i) When carbohydrates are converted into fat e.g. when an animal is preparing to hibernate and in fattening livestock since during conversion of carbohydrates to fat carbon dioxide is liberated when pyruvate is converted Acetyl CoA. Acetyl CoA is then converted to fats without using oxygen

(ii) During anaerobic respiration because carbon dioxide is given out but no oxygen used.

$$C_6H_{12}O_6 \xrightarrow{\text{zymase}} 2CO_2 + 2C_2H_5OH \qquad RQ = 2\ CO_2/\ \text{Zero } O_2 \text{ or infinity}$$

Basal metabolic rate

Is the minimal rate of energy expenditure per unit time by endothermic animals at rest.

Factors affecting the BMR

1. **Body size**: Metabolic rate increases as weight, height, and surface area increase.
2. **Body composition:** Fat tissue has a lower metabolic activity than muscle tissue. As lean muscle mass increases, metabolic rate increases.
3. **Gender:** The basal metabolic rate (BMR) averages 5 to 10 percent lower in women than in men. This is largely because women generally possess more body fat and less muscle mass than men of similar size.
4. **Age:** A decrease in lean muscle mass during adulthood results in a slow, steady decline of roughly 0 3 percent per year in BMR after the age of about 30. This can be largely avoided by strength training throughout adulthood.
5. **Climate and body temperature:** The BMR of people in tropical climates is generally 5 to 20 percent higher than their counterparts living in more temperate areas because it takes energy to keep the body cool. Exercise performed in hot weather also imposes an additional metabolic load. Body fat content and effectiveness of clothing determine the magnitude of increase in energy metabolism in cold environments; it takes energy to keep the body warm if you work or exercise in very cold weather.

6. **Hormonal levels:** Thyroxine (T4), the key hormone released by the thyroid glands has a significant effect upon metabolic rate. Hypothyroidism is relatively common, especially in women near or after menopause. Everyone with a weight problem should have their thyroid function checked by their doctor and treated appropriately if it turns out to be low.
7. **Health:** Fever, illness, or injury may increase resting metabolic rate two-fold

Revision Exercise

Objective questions

1. Lactic acid accumulation in muscles of an athletic during action is due to B
   A. Oxygen debt
   B. Anaerobic respiration
   C. Panting
   D. High rate of respiration
2. The end product of glycolysis D
   A. Glucose diphosphate
   B. Lactic acid
   C. Citric acid
   D. Pyruvic acid
3. The following process does not require respiratory energy? C
   A. Synthesis of cellulose
   B. Meiosis
   C. Loss of water from the stomata
   D. Mineral absorption
4. Which of the following are formed during anaerobic respiration in yeast cell? C
   A. Lactic acid and ATP
   B. Lactic acid and ADP
   C. Ethanol and ATP
   D. Ethanol and ADP
5. How many kilojoules of energy are released if 1 gram of sugar burned in oxygen raises the temperature of 500g of water by 7.5^{0}C, (4.18J raise the temperature of 1 gram of water by 1^{0}C) A
   A. 15.7kJ
   B. 156kJ
   C. 1.56kJ
   D. 1560kJ

* Heat liberated = mcθ = 500 x 4.18 x 7.5 = 15,675J = 15.7kJ

6. What happens to most of the reduced NADH2 molecules metabolism? B
   A. Direct use in the synthesis of starch to glucose
   B. Oxidation in mitochondria resulting in ATP formation
   C. Oxidation in Calvin cycle
   D. Combination with sulphuric acid as part of Krebs cycle
7. Which of the following will speed of phosphorylation of the Hexose sugar? C
   A. Decrease of ADP concentration
   B. A decrease in the concentration of ATP
   C. An increase in the concentration of the phosphate
   D. An increase in the concentration of phosphorylated hexose

* Phosphate is a reactant, increasing the concentration of reactant speeds reaction

8. An athletic had just finished a race; the phrase “oxygen debt” refers to D
   A. The amount of oxygen originally present in the muscle of an athlete before the race
   B. The total amount of oxygen an athlete requires to restore the breathing rate to normal
   C. The amount of oxygen taken in after the race and used for complete combustion of lactic acid
   D. The amount of oxygen after the race to convert excess lactic acid to glycogen in the liver.

* "Oxygen debt" (or the modern term, excess post-exercise oxygen consumption, EPOC) refers to the extra oxygen consumed by the body after strenuous exercise to restore all systems to their normal pre-exercise state.

A key part of this recovery process is the removal of accumulated lactic acid, a byproduct of anaerobic respiration during intense activity when the oxygen supply is insufficient. The lactic acid is transported by the blood to the liver, where the extra oxygen is used to convert most of it back into glucose, which is then often stored as glycogen.

9. Which of the following biological processes does not utilize respiratory energy? A
   A. Loss of water from stoma
   B. Mineral salt absorption
   C. Synthesis of cellulose
   D. Meiosis

10. Which one of the following compounds act as hydrogen acceptor during anaerobic respiration in animals? D
   A. NAD
   B. NADP
   C. Lactic acid
   D. Pyruvic acid

* **Anaerobic respiration in animals is lactic acid fermentation.** When there is a lack of oxygen, such as during intense exercise, animal cells perform anaerobic respiration, converting glucose to lactic acid to generate energy.

Pyruvic acid accepts hydrogen from NADH. During this process, pyruvic acid, which is the end product of glycolysis, acts as the hydrogen acceptor. It takes hydrogen from NADH to become reduced to lactic acid. This reaction, catalyzed by the enzyme lactate dehydrogenase, regenerates NAD^+ so that glycolysis can continue to produce a small amount of ATP in the absence of oxygen.

11. Which one of the following is not a method of measuring the rate of respiration in an organism? A

   A. Estimating the amount of food taken in by the organism per day
   B. Measuring the heat produced by the organism in a given time
   C. Measuring the amount of CO_2 produced by an organism in a given time
   D. Estimating the amount of oxygen consumed by the body in a given time

* **Respiration is the process of energy release.** The rate of respiration refers to how quickly an organism breaks down food to release energy. Measuring food intake only tells you how much potential energy the organism is taking in, not how fast it is being used.

12. The substance that supplies phosphate at the beginning of glycolysis is B

   A. Adenosine diphosphate (ADP)
   B. Adenosine triphosphate (ATP)
   C. Adenosine monophosphate (AMP)
   D. Nicotinamide adenine dinucleotide phosphate (NADP)

13. The following are physiological conditions in living cells C

   1. High concentration of ADP and Pi
   2. High concentration ATP
   3. High concentration of hydrogenase
   4. High concentration of ATPase

   Which of them will increase the rate of sugar down

   A. 1 and 2
   B. 2 and 3
   C. 1 only
   D. 4 only

* The rate of sugar breakdown (cellular respiration/glycolysis) is highly regulated by the cell's energy needs.

1. High concentration of ADP and Pi: ADP (adenosine diphosphate) and Pi (inorganic phosphate) are the products of ATP hydrolysis, meaning the cell has low energy reserves. High levels of ADP and Pi allosterically activate key regulatory enzymes in glycolysis and the Krebs cycle, such as phosphofructokinase-1 (PFK-1), thereby increasing the rate of sugar breakdown to produce more ATP.

2. High concentration of ATP: A high concentration of ATP signals that the cell has sufficient energy. ATP acts as an allosteric inhibitor of key glycolytic enzymes (like PFK-1 and pyruvate kinase), which slows down sugar breakdown to conserve the glucose supply when energy is not needed.

3. High concentration of hydrogenase: Hydrogenases are enzymes that catalyze the reversible reaction between hydrogen gas and protons/electrons. They are not directly involved in the main pathways of sugar breakdown in typical animal or plant cells.

4. High concentration of ATPase: ATPases are enzymes that break down ATP into ADP and Pi, releasing energy for cellular work. While they increase the concentration of ADP and Pi (which in turn promotes sugar breakdown), the presence of more ATPase itself represents an *increased demand* for ATP consumption, rather than a direct *increase in the rate of sugar breakdown* as a primary regulatory condition. The low ATP/high ADP condition is the actual signal.

14. A rat requires more energy per unit body weight than required by human because the rat D
    - A. Has a large surface area
    - B. Is more active
    - C. Has higher body temperature
    - D. Has a higher metabolic rate

* To meet high rate of heat loss due to its large surface area to volume ratio

15. In which of the following does anaerobic respiratory not occurs? D
    - A. Skeletal muscle
    - B. Yeast cell
    - C. Bacterial
    - D. Smooth muscle

* **Anaerobic respiration is for short, intense energy bursts.** This process, also known as fermentation, provides a quick but inefficient way to produce ATP without oxygen. It occurs in cells that experience periods of oxygen shortage due to high energy demand.

Smooth muscle has a steady, low-energy demand. Smooth muscle, which is found in the walls of internal organs and blood vessels, performs sustained, involuntary contractions rather than rapid, powerful movements. Its metabolic needs are typically met by aerobic respiration, which is far more efficient in producing ATP.

16. The life process which releases most energy is C

A. The light reaction of photosynthesis
B. Fermentation of glucose
C. Aerobic cellular respiration of glucose
D. The oxidation of lactic in mammalian of muscle cells

* **Aerobic respiration yields the most ATP.** Cellular respiration is the process of breaking down glucose to release energy in the form of ATP. Aerobic respiration, which uses oxygen, completely breaks down one glucose molecule to yield a high amount of ATP, typically **30 to 38 ATP** molecules.

Other processes are less efficient. Fermentation (anaerobic respiration) and other partial breakdowns of glucose release significantly less energy. For example, fermentation of a single glucose molecule produces only **2 ATP**.

17. The respiration of the fat tri olein can be summarized as the follows by the equation C

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

Which of the following resents the respiratory quotient (RQ) for this fat?

A. 1.5
B. 1.4
C. 0.71
D. 0.65

* RQ = $\frac{Vol\ of\ CO_2 used}{Vol\ of\ O_2 used} = \frac{52}{80} = 0.71$

18. Which biological process takes place in the mitochondrion? C

A. Glycolysis
B. Formation of lactic acid
C. Tricarboxylic cycle
D. Alcoholic fermentation

19. Which of the following conversion takes place in human under conditions of starvation? B

A. Fatty acids to carbohydrate
B. Proteins to carbohydrates
C. Glucose to lipids
D. Lipids to lipoproteins

20. During which one of the following is the respiratory quotient most likely to be high D

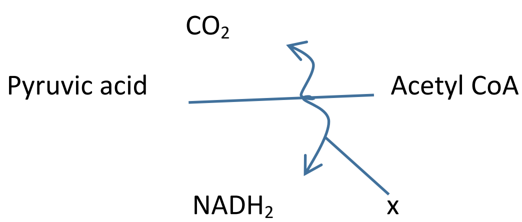
A. In plants during bright light
B. In animals during laying down of fats
C. During egg laying in birds
D. During lactic acid formation

*
- **Lactic acid formation** is a form of anaerobic respiration in which oxygen

consumption is significantly reduced.

- During intense exercise, the accumulation of lactic acid leads the body to expel more carbon dioxide to buffer the acidity, causing the respiratory exchange ratio (a measure equivalent to RQ during exercise) to rise and potentially exceed 1.0, sometimes even reaching values above 2. This combination of high $CO2$ output and low oxygen use results in a very high RQ.

21. The figure below shows some reactions in the respiratory pathway A



The enzyme which catalyzes the reaction marked X is

A. Pyruvate dehydrogenase
B. Acetyl CoA dehydrogenase
C. Pyruvate decarboxylase
D. Acetyl CoA decarboxylase

22. During strenuous activity, the pyruvic acid in the muscle may accept hydrogen from reduced NADH to become B

A. Acetyl CoA
B. Lactic acid
C. Ethanol
D. Citric acid

23. The equation for complete oxidation of a substance is A

$2C_{18}H_{34}O_2 + 51O_2 \longrightarrow 36CO_2 + 34H_2O$

The respiratory quotient for oxidation is

A. 0.70
B. 1.4
C. 0.9
D. 1.0

* RQ = $\frac{Vol\ of\ CO_2 used}{Vol\ of\ O_2 used} = \frac{36}{50} = 0.72$

24. Which of the following is liberated during both aerobic and anaerobic respiration? A

A. Carbon dioxide and energy
B. Ethanol and water
C. Water and carbon dioxide
D. Carbon dioxide and ethanol

* **Aerobic respiration:** This process uses oxygen to completely break down glucose, yielding a large amount of energy (ATP). The waste products are carbon dioxide and

water.

Anaerobic respiration: This process occurs without oxygen and produces much less energy. In organisms like yeast, the products are ethanol and carbon dioxide. In animals, the product is lactic acid, but this process still releases a small amount of energy.

Therefore, carbon dioxide and energy are liberated in both aerobic and some forms of anaerobic respiration, such as in yeast

25. In endergonic reaction, the products of the reaction contain C
    A. More energy than the reactants and energy is released
    B. Less energy than the reactants and energy is absorbed
    C. More energy than the reactants and energy is supplied
    D. Less energy than the reactants and energy is released

* **Endergonic reaction defined:** An endergonic reaction is a chemical reaction that requires an input of energy from its surroundings to proceed.

Energy storage: Because energy is absorbed (supplied) during the reaction, this energy is stored within the chemical bonds of the products.

Result: Consequently, the products of an endergonic reaction contain more potential chemical energy than the original reactants.

26. Which of the following is the ultimate hydrogen acceptor during anaerobic respiration? C
    A. Lactic acid
    B. NAD
    C. Pyruvic acid
    D. Acetaldehyde

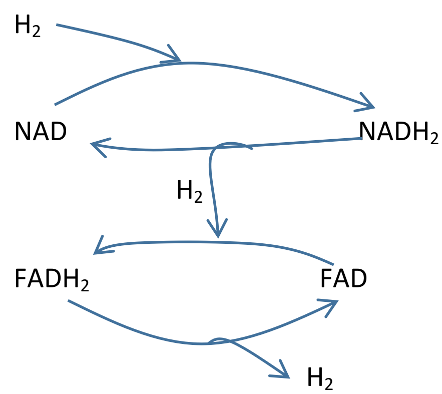
27. Which one of the following is unlikely to be found in the body of obligate anaerobes? C
    A. Glycolytic enzymes
    B. ATP
    C. Mitochondria
    D. Acetaldehyde

* **Mitochondria are the "powerhouses" of the cell** that perform aerobic respiration. This process requires oxygen as the final electron acceptor to produce a large amount of ATP.

Obligate anaerobes cannot survive in the presence of oxygen and therefore rely on anaerobic respiration or fermentation for energy.

Since mitochondria are the sites of aerobic respiration, they are not found in prokaryotic obligate anaerobes (like bacteria). Even in some anaerobic eukaryotes, typical mitochondria are replaced by other organelles like hydrogenosomes or mitosomes that perform anaerobic metabolism.

28. The figure shows that B



A. NAD is oxidized to $NADH_2$
B. $NADH_2$ is reduces FAD to $FADH_2$
C. $FADH_2$ is reduced is reduced to FAD
D. $NADH_2 + H_2 \rightarrow NAD$

* Reduction is addition of hydrogen to a compound

29. Anaerobes thrive better than aerobic organism in water experiencing thermal pollution because C
    A. High temperatures kill aerobic organisms
    B. Anaerobes possess enzymes that work best at high temperatures
    C. High temperatures reduce solubility of oxygen
    D. High temperatures encourage multiplication of aerobes predators.

30. A major difference between respiration and burning is that D
    A. no heat is produced during respiration
    B. burning is a faster process
    C. burning is a chemical process
    D. chemical energy is stored in respiration

31. Compared to carbohydrates, fats have high energy value because fats B
    A. have long chains of fatty acids
    B. have a higher proportional of hydrogen
    C. are more compact in structure
    D. have a high proportion of oxygen

32. The compound which acts as oxidizing agent during anaerobic respiration in plants B

A. NAD and pyruvate
B. Ethanal and NAD^+
C. NAD and FAD
D. NADP and pyruvic acid

* The compound which acts as an oxidizing agent (accepts hydrogen/electrons) during anaerobic respiration in plants is **ethanal and NAD+**

33. Which of the following increases the rate phosphorylation of hexose sugar during the normal respiration process? A

A. An increase in ADP concentration
B. An increase in ATP concentration
C. An increase in concentration of hexose sugar
D. A decrease in concentration of phosphorylated sugar

* **ADP indicates low energy.** An increase in the concentration of adenosine diphosphate (ADP) signifies that the cell has low levels of available energy (ATP).

Metabolic regulation: The cell's metabolism is regulated to meet its energy demands. High concentrations of ADP act as a signal to activate key regulatory enzymes in glycolysis, the pathway for sugar breakdown.

Driving glycolysis forward: By activating these enzymes, a high ADP concentration increases the overall rate of glycolysis, including the initial phosphorylation of the hexose sugar, in order to produce more ATP and restore the cell's energy balance.

34. Which one of the following activities in living organisms can result in a respiratory quotient of less than 1.0? B

A. When carbohydrates are respired
B. During extensive laying, down of fat in livestock
C. At compensation point, during photosynthesis
D. When the rate of exhalation equals that of inhalation.

35. A rat requires more energy per unit body weight than that required by a human because a rat D

A. Has a larger surface area
B. Is more active
C. Has higher body temperature
D. Has a higher metabolic rate

36. Lipids are better energy sources than carbohydrates is that D

A. Are insoluble
B. Do not form hydrogen bonds with water

C. Are more compact
D. Have a higher proportion of hydrogen

37 Which one of the following changes occur in mammalian body at the onset of an exercise? C
A. Increase in the pH of blood
B. Decrease in the rate of contraction of the diaphragm muscles
C. Increase in the rate of tissue respiration
D. Decrease in the amounts of water vapor in the breath

38 Fats yield more energy per unit mass than carbohydrates because fats possess B
A. More carbon atoms
B. More hydrogen atoms
C. Few carbon atoms
D. Fewer oxygen atoms

39 Which one of the following best describes basal metabolic rate? D
A. Average amount of energy produced by the body
B. Average amount of energy produced when at rest
C. Amount of energy produced by an average body
D. Amount of energy produced when all voluntary movement have ceased.

* **Basal Metabolic Rate (BMR) is the energy expenditure at a state of complete rest**. It is the minimum amount of energy the body needs to perform essential, life-sustaining functions such as breathing, blood circulation, and cell production.

40 Lactic acid accumulation in the muscle of an athlete during action is due to B
A. Oxygen debt
B. Anaerobic respiration
C. Panting
D. High rate of respiration

41 In which one of the following parts of the cell does most production of ATP occurs? B
A. Matrix of mitochondria
B. Cristae of the mitochondria
C. Cytoplasm of the cell
D. Outer membrane of the mitochondria

42 Which one of the following is not a method of measuring the rate of respiration in an organism? A
A. Estimating the amount of food taken in by the organism per day
B. Measuring the heat produced by the organism in a given time
C. Measuring the amount of carbon dioxide produced by an organism in a given time
D. Estimating the amount of oxygen consumed in a given time

43 In an individual whose energy intake is 50000kJ per day, loses 1dm^3 of sweat in a day during manual work. Given that the latent heat of vaporization of sweat is 2.45kJcm^{-3}, the percentage of energy lost by the individual during the work is C
A. 4.22

B. 5.0
C. 4.9
D. 7.65

* $1dm^3 = 1000cm^3$
Heat lost through sweating = $2.45kJcm^{-3} \times 1000cm^3 = 2450kJ$
Percentage energy lost = $\frac{2450}{50000} x\ 100 = 4.9\%$

44. The latent heat of evaporation of sweat is $3.15kJcm^{-3}$. What is the percentage of energy lost by sweating from a manual worker who loses $2dm^3$ per day of sweat and has a daily energy intake of 40,000kJ? D
A. 6.30
B. 7.88
C. 8.25
D. 15.75

* $1dm^3 = 1000cm^3$
Heat lost through sweating = $3.15kJcm^{-3} \times 2000cm^3 = 6300kJ$
Percentage energy lost = $\frac{6300}{40000} x\ 100 = 15.75\%$

45 In which of the following does anaerobic respiration not occur D
A. Skeletal muscles
B. Yeast cell
C. Bacteria
D. Smooth muscle

46 Which one of the following food materials has the highest amount of potential energy per unit weight? D
A. Proteins
B. Vitamins
C. Monosaccharide
D. Fats

47 Which one of these activities would result into a low respiratory quotient? D
A. Respiration in muscles during heavy exercise
B. Formation of calcareous shells
C. Fattening livestock
D. Preparation for hibernation in a mammal.

* A low respiratory quotient (RQ) indicates that an organism is primarily metabolizing fats as its energy source. The RQ for fat metabolism is approximately 0.7, while for carbohydrates it is 1.0.

- **Preparation for hibernation:** Mammals preparing for hibernation need to store large amounts of energy to survive the long, dormant period. They do this by eating and storing significant amounts of fat. Just before and during the early stages of hibernation, they primarily rely on the breakdown of these stored fats for energy. This fat metabolism, which requires a high amount of oxygen for every molecule of carbon dioxide produced, results in a low RQ.

Why other options are incorrect

- **A. Respiration in muscles during heavy exercise:** During heavy exercise, muscles often switch to anaerobic respiration, producing a high amount of carbon dioxide (to buffer lactic acid) with limited oxygen consumption. This leads to a high RQ, often greater than 1.0.

- **B. Formation of calcareous shells:** The formation of calcareous shells in aquatic organisms involves the removal of carbon dioxide from the surrounding water, which is a process separate from the primary metabolic respiration that determines the RQ. This process is not directly related to a low RQ.

- **C. Fattening livestock:** This process, also known as lipogenesis, involves converting excess carbohydrates into fat for storage. This conversion produces carbon dioxide without a corresponding increase in oxygen consumption, which can lead to an RQ greater than 1.0.

48 The equation for respiration of a substrate is A

$2C_{51}H_{98}O_6 + 145O_2\ (g) \rightarrow 102CO_2\ (g) + 98H_2O(l)$

What is the respiratory quotient of substrate?

A. 0.70
B. 0.80
C. 0.90
D. 1.0

* RQ = $\frac{Vol\ of\ CO_2 used}{Vol\ of\ O_2 used} = \frac{102}{15} = 0.70$

49 During respiration in the absence of oxygen, pyruvic acid is converted B

A. lactic acid and water
B. ethanol and carbon dioxide in plants
C. lactic acid and carbon dioxide in plants
D. ethanol and water in plants

Structured questions

50. Fill in the missing using appropriate words (s) so as to complete the account of cellular respiration

'the initials stage in cellular respiration is glycolysis which occurs with occur in the ……………………… of the cell. A monosaccharide such as …………………… is first ………………………. Then converted into a 3-carbon intermediate product called ………………

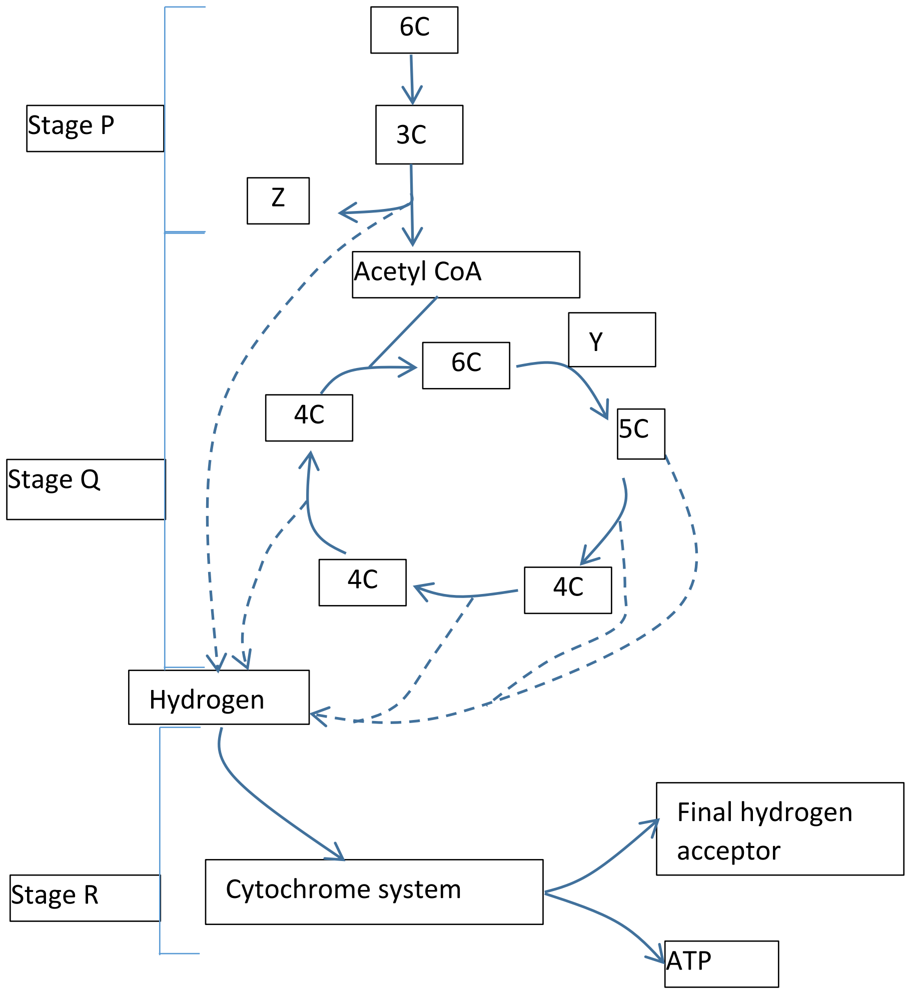
In the absence of oxygen this product may enter another metabolic pathway giving rise to …………………………… in animals and …………………… in plants. The end product of glycolysis is ……………… which is decarboxylated and enter the …………………. Cycle. This cycle links other pathways which enables organism acid such as ………………………………. and ………………………… To be regarded and small organic molecules in the cycle provides …………………… uses into the reduction of ………………………… during cycle a total of …………….. molecules are formed from complete oxidation per molecule of a 6-carbon sugar

Answer

The initial stage in cellular respiration is glycolysis which occurs in the **cytoplasm** of the cell. A monosaccharide such as **glucose** is first **phosphorylated** (or activated) then converted into a 3-carbon intermediate product called **pyruvic acid** (or pyruvate).

In the absence of oxygen this product may enter another metabolic pathway giving rise to **lactic acid** in animals and **ethanol** (and carbon dioxide) in plants. The end product of glycolysis is **pyruvic acid** which is decarboxylated and enters the **Krebs** (or Citric Acid) cycle. This cycle links other pathways which enables organic acids such as **fats** (lipids) and **proteins** (amino acids) to be degraded, and small organic molecules in the cycle provide **acetyl CoA** (uses into the reduction - *this phrase is unclear in the original prompt*) to the cycle. During the cycle a total of **38** (or 30-32) molecules of **ATP** are formed from complete oxidation per molecule of a 6-carbon sugar.

51.



(a) Where exactly do reactions P, Q and R occur?
P- glycolysis in cytoplasm

Q – Kreb's cycle in matrix of mitochondria

R- electron transport system in **cristae**, the folds of the inner mitochondrial membrane.

(b) What is substance Z?
CO_2

(c) What is the 6C intermediate compound from the reaction between acetyl CoA and the 4C compound
Citrate

(d) Name the enzyme controlling reaction Y
decarboxylase

(e) Name the final hydrogen acceptor in the cytochromes system indicated in the diagram
Oxygen

(f) (i) Define the term respiratory Quotient (RQ)

The **Respiratory Quotient (RQ)** is a dimensionless number defined as the **ratio of the volume of carbon dioxide (CO_2) produced to the volume of oxygen (O_2) consumed** during respiration

(ii) Glucose has a formula $C_6H_{12}O_6$ and tripalmitin has the formula

$C_{51}H_{99}O_6$. The two substances when completely oxidized have the following overall equation.

$C_6H1_2O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$

$C_{51}H_{99}O_6 + 145/2O_2 \longrightarrow 51CO_2 + 49H_2O$

Using the above equations calculate RQ values for aerobic respiration of tripalmitin

RQ = $\frac{Vol\ of\ CO_2 used}{Vol\ of\ O_2 used} = \frac{51}{72.5} = 0.70$

(iii) State the RQ value of glucose in anaerobic respiration. Explain your answer.

In plants RQ is infinite because CO2 is produced with no oxygen consumed

In animals RQ = 0, no oxygen used and no carbon dioxide produced

52. (a) Differentiate between respiratory quotient (RQ) and basal metabolic rate (BMR)

The **Respiratory Quotient (RQ)** is a dimensionless number defined as the **ratio of the volume of carbon dioxide ($CO2$) produced to the volume of oxygen ($O2$) consumed** during respiration

Basal Metabolic Rate (BMR) is the minimum amount of energy (calories/kilojoules) the body requires to maintain essential, life-sustaining functions while at complete physical, mental, and digestive rest.

(b) The table below shows the respiratory quotient in germinating seeds under difeerent treatment

	Treatment	RQ
(i)	4hrs soaking in water	6.0
(ii)	4hr soaking then 4 hour exposure to air	1.8
(iii)	4hour soaking the 24hrs exposure to air	1.0

Explain the difference respiratory quotients of the germinating seeds under the different treatment. (06 marks)

When the seeds are not exposed to air, there is inadequate oxygen supply and absorption. The seeds respire an aerobically to produce carbon dioxide.

The volume of carbon dioxide released by the seeds in respiration far exceeds that of oxygen consumed and the RQ is greater than 1.0.

When exposed to air for 4hrs, the volume of oxygen absorbed by the seeds increases. Then, here is a combination of aerobic and anaerobic respiration occurring. However, the volume of carbon dioxide produced exceeds that of oxygen consumed and the RQ is still above 1.0 but less than in (i) above.

When exposed to air for air 24hrs, the volume of oxygen absorbed is adequate for the plant of rely solely on aerobic respiration for its energy needs.

Since carbohydrate is the main energy substrate in the need, complete respiration consumers the same volume oxygen as the volume of carbon dioxide produced and so the RQ is 1.0.

(c) Explain why the BMR varies with age of individual (02marks)
Basal Metabolic Rate (BMR) varies with age due to significant changes in **body composition**, **hormonal levels**, and the energy required for **growth**.

54. (a) Name the organelle most imortant in photosynnthesis and respiration

(i) Photosynthesis: chloroplast
(ii) Respiration: Mitochondrion

(a) Give four differences and five similarities between the two organelles
(i) Differences

Differences between chloroplast and mitochondria

	Chloroplast	Mitochondria
1	They are usually found in plants	They are found in plants and animal cell
2.	They convert light energy into chemical energy (sugar)	Breakdown chemical energy (sugar) into another form of chemical energy (ATP)

3.	Contain chlorophyll	Lack chlorophyll
4.	Inner membrane is thylakoid	Inner membrane is cristae

(ii) Similarities

- Both produce energy
- Each has its own DNA
- Each is enclosed by two membranes
- Both have extensive membrane systems inside
- Both have matrix

55. (a) Give an account of glycolysis

Ref. page 4

(b) Explain what happened to the pyruvate under aerobic conditions.

Under aerobic conditions (in the presence of sufficient oxygen), the pyruvate molecules produced during glycolysis in the cytoplasm are transported into the mitochondria to undergo further oxidation, primarily through the Krebs cycle and the electron transport chain.

1. **Transport into the Mitochondrion**: The two molecules of pyruvate (a 3-carbon compound) produced from one molecule of glucose in the cytoplasm are actively transported across the outer and inner mitochondrial membranes into the **mitochondrial matrix**.

2. **The Link Reaction (Oxidative Decarboxylation):** Once in the matrix, each pyruvate molecule undergoes a critical transformation known as the **link reaction** (or pyruvate dehydrogenase complex reaction):

- **Decarboxylation:** A carbon atom is removed from pyruvate in the form of a molecule of **carbon dioxide** (CO_2). This is the first CO_2 produced during aerobic respiration.
- **Oxidation and NAD$^+$ Reduction:** The remaining 2-carbon unit is oxidized. The energy from this oxidation is used to reduce a molecule of NAD+ to **NADH**, which is a high-energy electron carrier.
- **Formation of Acetyl CoA:** The 2-carbon unit is then attached to a coenzyme called Coenzyme A (CoA) to form **acetyl CoA** (acetyl coenzyme A).

The net result for the two pyruvate molecules is two molecules of acetyl CoA, two molecules of $CO2$, and two molecules of NADH.

3. **The Krebs Cycle (Citric Acid Cycle):** The acetyl CoA molecules then enter the Krebs cycle, which also takes place in the mitochondrial matrix:

- **Entry:** Each acetyl CoA (2C) combines with a 4-carbon compound called oxaloacetate to form a 6-carbon compound called **citrate**.
- **Cycle of Reactions:** The citrate molecule goes through a series of reactions that generate energy carriers and produce waste products:
  - It is gradually oxidized and converted back to oxaloacetate, continuing the cycle.
  - CO_2 is released.
  - More **NADH** and **$FADH_2$** (another high-energy electron carrier) are produced.
  - A small amount of **ATP** is produced directly (substrate-level phosphorylation).

4. **Electron Transport Chain and Oxidative Phosphorylation**:The NADH and $FADH_2$ generated during the link reaction and the Krebs cycle carry high-energy electrons to the inner mitochondrial membrane (cristae).

- **Electron Flow:** The electrons are passed down a series of protein complexes (the electron transport chain or cytochromes system).
- **ATP Production:** The energy released from the movement of these electrons is used to pump protons across the membrane, creating a gradient that drives the production of large amounts of **ATP** via ATP synthase (oxidative phosphorylation).
- **Final Acceptor:** At the end of the chain, **oxygen** acts as the final electron acceptor, combining with hydrogen ions to form **water** (H_2O).

56. (a) Distinguish between aerobic respiration and anaerobic respiration

(b) Outline the major steps involved in the process of glycolysis in a cell.

(c) How is energy produced in glycolysis?

57. (a) Differentiate between aerobic and anaerobic respiration. (05marks)

Feature	Aerobic Respiration	Anaerobic Respiration
Oxygen Requirement	Requires oxygen (O_2)	Occurs in the absence of oxygen

Oxidation of Glucose	Complete breakdown of glucose	Incomplete breakdown of glucose
Energy Produced (ATP)	High yield (approx. 36–38 ATP per glucose)	Low yield (approx. 2 ATP per glucose)
End Products	Carbon dioxide (CO_2) and water ($H2O$)	Lactic acid (in animals) or ethanol and CO_2 (in plants/yeast)
Location in Cell	Cytoplasm and mitochondria	Cytoplasm only
Rate of Reaction	Slower, sustained process	Faster, for quick bursts of energy
Final Electron Acceptor	Oxygen ($O2$)	An inorganic molecule other than oxygen (e.g., nitrate, sulfate) or an organic molecule (e.g., pyruvate, acetaldehyde)
Organisms	Most higher organisms (plants, animals, humans)	Lower organisms (bacteria, yeast) and muscle cells during intense exercise

(b) Describe what happens to the end product of glycolysis in absence of oxygen (10marks)

In the absence of oxygen, the end product of glycolysis, **pyruvic acid (pyruvate)**, enters a metabolic pathway called **fermentation**. The specific end products of fermentation vary depending on the type of cell:

In Animal Cells (Lactic Acid Fermentation)

In animal cells, such as muscle cells during strenuous exercise when oxygen is limited, pyruvate is converted to **lactic acid (lactate)**.

- **Process:** Pyruvate acts as the hydrogen acceptor and is reduced by NADH (a high-energy carrier molecule produced during glycolysis).
- **Purpose:** This reaction is catalyzed by the enzyme lactate dehydrogenase. Crucially, this process regenerates **NAD^+** from NADH.
- **Outcome:** The regeneration of NAD^+ allows glycolysis to continue producing a small amount of ATP in the absence of oxygen, providing short-term energy to the muscle cells. Lactic acid is later transported to the liver and converted back into glucose when oxygen is available (clearing the oxygen debt).

In Plant Cells and Yeast (Alcoholic Fermentation)

In most plant cells and in yeast cells, pyruvate is converted to **ethanol (alcohol)** and **carbon dioxide**.

- **Process:** This is a two-step process:

- Pyruvate is first decarboxylated (loses a carbon dioxide molecule) to form **acetaldehyde**.
- Acetaldehyde is then reduced by NADH to form **ethanol**.

- **Purpose:** Similar to lactic acid fermentation, this process regenerates **NAD^+** from NADH, allowing glycolysis to continue and produce ATP.
- **Outcome:** Ethanol and carbon dioxide are the waste products of this process, which is used commercially to produce alcoholic beverages and bread (where CO_2 causes the dough to rise).

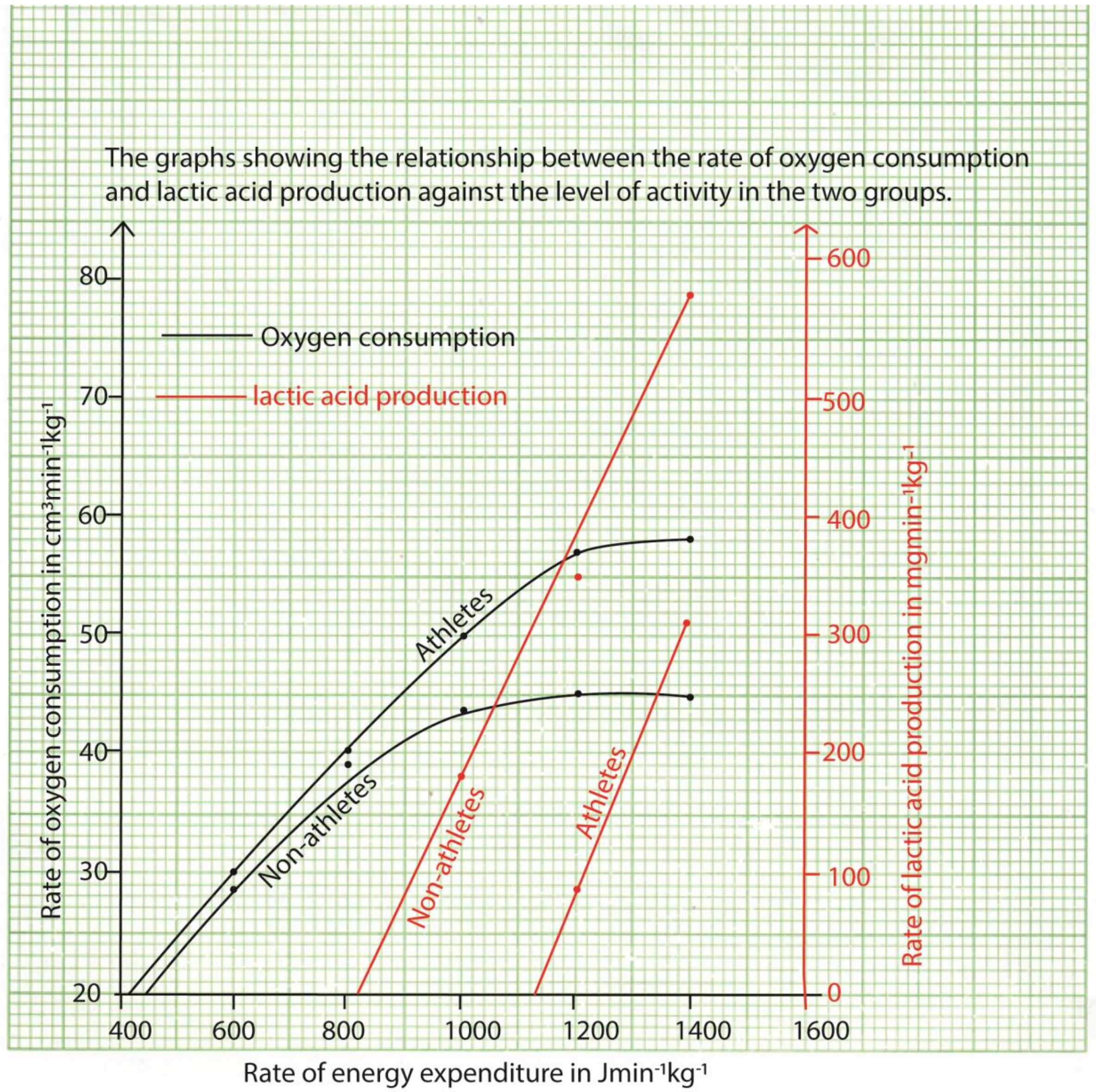
(c) Why is it important to produce ATP during cellular respiration? (05marks)

ATP provides energy for all the biological processes such breathing, heartbeat, locomotion, growth etc.

58. An investigation was carried out into the effects of athlete training on respiration in human muscle. A group of athlete and non-athlete exercised at different levels. The level of exercise was expressed as rates of energy expenditure $Jmin^{-1}kg^{-1}$ of body mass. At each level, rates of oxygen consumption and lactic acid production were measured, the results are shown in the table below. Figures in the table are the means of the measurements made for each group.

Rate of energy Expenditure in $Jmin^{-1}kg^{-1}$	Rate of oxygen consumption in $cm^3min^{-1}kg^{-1}$		Rate of lactic acid production in $mgmin^{-1}kg^{-1}$	
	Athletes	Non-athletes	Athletes	Non-athletes
600	30	29	0	0
800	40	39	0	0
1000	50	44	0	185
1200	57	45	85	350
1400	58	45	305	590

(a) Plot graphs to show the relationship between the rate of oxygen consumption and lactic acid production against the level of activity in the two groups.



Or the different categories of graphs can be drawn separately

(b) Using your graphs in (a) describe the effect of increasing the level of exercise on the rates of oxygen consumption and lactic acid accumulation in

(i) Athletes

- An increase in the level of activity leads to steady/gradual/uniform rise in the rate of oxygen consumption up to the level of 1000 after which the rate of increase is slower and tend to level off.
- Lactic acid accumulation increases exponentially after energy consumption goes beyond 1000JMin^{-1}kg^{-1}.

(ii) Non-athletes

- An increase in the level of activity leads to steady/gradual/uniform rise in the rate of oxygen consumption up to the level of 1000 after which the rate of increase is slower and tends to level off.
- Lactic acid accumulation increases exponentially after energy consumption goes beyond 800JMin^{-1}kg^{-1}.

(c) How do the two groups of people compare in their abilities to consume oxygen and accumulate lactic acid during the exercise?

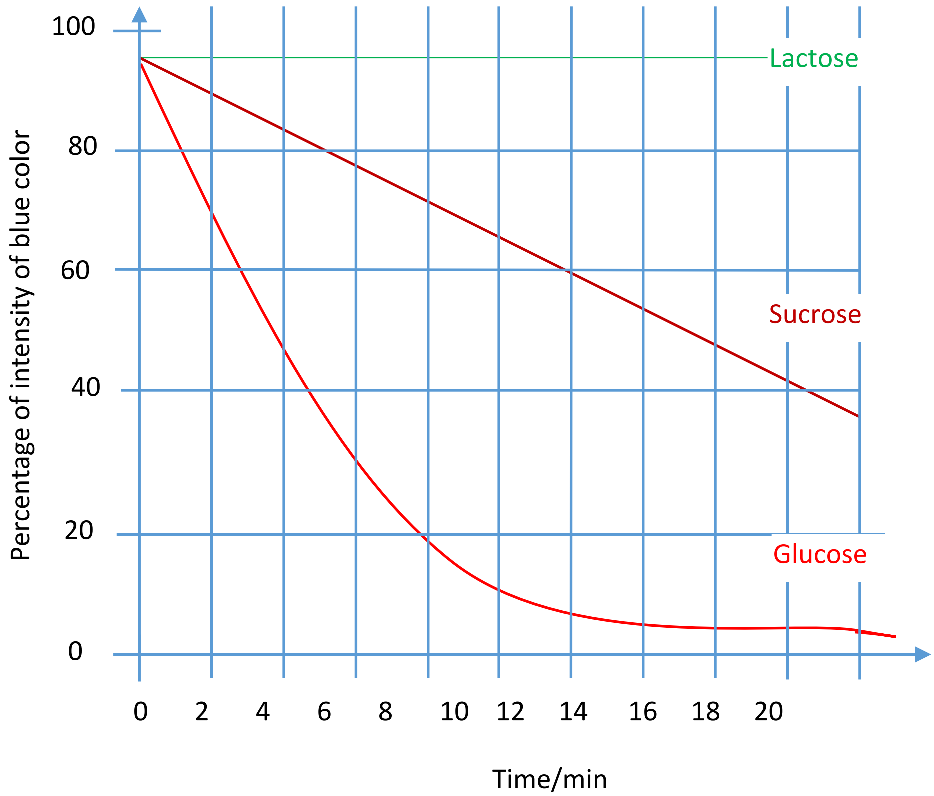
- Athletes consume oxygen at a higher rate than non-athletes
- Non-athlete produce more lactic acid than athletes
- Non athlete starts to produce lactic acid at lower rate of energy consumption.

(d) Using the data provided, suggest any advantage an athlete has over a non-athletes.

Athletes consume more oxygen leading to complete respiration producing more energy then non-athlete. They thus produce less lactic acid.

59. An experiment was carried out to investigate the rate of respiration of yeast calls mixed with three different carbohydrates (glucose, sucrose and lactose), using methylene blue as an indicator (methylene blue is blue in alkaline condition and colorless in acidic condition).

1cm^3 of 0.1M methylene blue was added to a mixture of 5cm^3 of a suspension of yeast in 10cm^3 of 0.5% glucose solution in boiling tube. The boiling tube was placed in a water bath at 30^{0}C for 20 minutes. The rate of respiration was measured as a percentage of the intensity of the blue color at the beginning of the experiment, at interval of 2minutes. The experiment was repeated using 5% sucrose and lactose. The results are shown in the figure below. Study the figure and answer the questions that follow.



(a) Calculate the average rate of respiration of yeast in glucose solution during the first four minutes in terms percentage intensity of blue color. (3minutes)

Rate of respiration = $\frac{\text{change in percentage intensity of blue colour}}{\text{time taken}}$

$= \frac{100-52}{4}$

$= \frac{48}{4}$

Rate of respiration = 12%per minute

Hence the average rate of respiration of yeast in glucose solution during the first four minutes is 12% per minute

(b) Describe the change in the intensity of blue color with time, for each carbohydrate. (05marks)

- Initially, the percentage intensity of blue colour is 100% for all carbohydrates.
- **Lactose:**The percentage intensity of blue colour remains the same throughout the

time of the experiment.

- **Sucrose:** The percentage intensity of blue decreases gradually and linearly with time
- **Glucose:**The percentage intensity of blue colour decreases rapidly up to the 8th minute. It then decreases gradually up to the 18th minute after which it remains more or less constant up to the end of the experiment.

(c) Explain the relationship described in (b) for each carbohydrate,

(i) Lactose (03marks)

Lactose is not a substrate of yeast metabolism and therefore is not utilized throughout the experiment. This may be as a result of lack of enzyme, lactase, in the yeast cells to hydrolyze lactose into glucose and galactose.

Hence, As a result, the pH of the contents of the reaction medium remains the same throughout the experiment.

(ii) Sucrose

Sucrose is readily hydrolyzed into glucose and fructose by the enzyme, invertase, present in yeast. Glucose then undergoes anaerobic respiration to produce alcohol and carbon dioxide is an acidic gas and therefore lowers the pH of the contents of the boiling tube and so reduces the percentage of the intensity of the blue colour.

Sucrose acts as a ready stock of glucose which is increasingly broken down to provide glucose for respiration of the yeast cells. As a result, increasingly more carbon dioxide is produced, thereby progressively increasing the acidity of the medium and therefore reducing the percentage intensity of the blue colour continually.

(iii) glucose

Initially, the concentration of glucose is high. This is utilized directly by the yeast cells, respiring anaerobically to produce carbon dioxide and alcohol. Since the glucose is readily available, the rate of production of carbon dioxide is higher for glucose than sucrose and therefore reduces the percentage intensity of the blue colour more rapidly with time.

Decreasing rate of reduction in percentage intensity of the blue colour occurs because;

- The amount of glucose remaining in the boiling tube has greatly reduced.
- The yeast cells have started to be inhibited/ killed by the accumulation of ethanol in the reaction medium.

  As a result, the rate of respiration decreases progressively at a decreasing rate until equilibrium is attained and it remains constant.

(d) Suggest what would happen to the color for glucose and sucrose if the experiment continued for 10 more minutes. Give an explanation in each case (10marks)

The colour for glucose would remain the same throughout the extra 10 minutes.

- This is because the yeast cells are inhibited by the accumulation of ethanol so that further respiration of the available glucose, if any, does not continue. Therefore, the pH of the medium remains the same for the entire extra 10

The colour for sucrose would eventually reduce in intensity at a decreasing rate until it becomes constant.

- This is because sucrose would continue to decrease in the medium until it is depleted
- Also, the accumulation of alcohol in the medium would eventually inhibit the action of the enzymes of the yeast cells.

(e) Explain why the boiling tubes were

(i) Kept covered during the experiment. (03marks)

- to prevent the escape of the carbon dioxide produced during process of yeast reparation.
- To prevent entry of oxygen into the reaction medium. This would lead to rapid aerobic breakdown of the food substrates

(ii) Placed in a water bath at 30^0C. (3marks)

- – to maintain the temperature at a value optimum for the functioning of the yeast enzymes. This is important in order to ensure that only the investigated variables are investigated.

Thanks

Dr. Bbosa Science