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VCE Biology $\frac{3}{4}$
Cellular Respiration & Anaerobic Fermentation [2.2]
Workbook

Outline:



Aerobic Cellular Respiration

Pg 3-13

- Glycolysis
- Link Reaction
- Krebs's Cycle
- Electron Transport Chain

Anaerobic Fermentation

Pg 14-18

- Lactic Acid Fermentation
- Alcoholic Fermentation

Factors Affecting the Rate of Cellular Respiration

Pg 19-20

Biofuel Production

Pg 21-24

Study Design Key Knowledge:



Study Design: Cellular Respiration and Anaerobic Fermentation

The main inputs, outputs, and locations of glycolysis, Krebs's Cycle and electron transport chain including ATP yield (details of biochemical pathway mechanisms are not required).

The location, inputs, and the difference in the output of anaerobic fermentation in animals and yeasts.

The factors that affect the rate of cellular respiration: temperature, glucose availability, and oxygen concentration.

Uses and applications of anaerobic fermentation of biomass for biofuel production.

Learning Objectives:



- ❑ BI34 [2.2.1] - Recall the inputs, outputs & locations of all stages of aerobic cellular respiration.
- ❑ BI34 [2.2.2] - Recall the inputs, outputs & locations of all stages of anaerobic cellular respiration, including lactic acid & alcoholic fermentation.
- ❑ BI34 [2.2.3] - Describe the significance of the mitochondria as the necessary location for aerobic respiration.
- ❑ BI34 [2.2.4] - Identify & describe factors - such as temperature, glucose availability, & oxygen concentration - on the rate of cellular respiration.
- ❑ BI34 [2.2.5] - Identify & explain the role of enzymes & coenzymes in cellular respiration, including both aerobic & anaerobic.
- ❑ BI34 [2.2.6] - Apply experimental design principles to create methodologies to test factors that affect cellular respiration.
- ❑ BI34 [2.2.7] - Describe the importance of breaking down biomass into simple sugars for biofuel production.
- ❑ BI34 [2.2.8] - Explain how yeast can be used to produce bioethanol from biomass.


Section A: Aerobic Cellular Respiration

What is the significance of cellular respiration?



Overview



- Cellular respiration is the process by which organisms are able to actually garner energy from the food that they eat in a usable form.
-  Why can't our cells just use a chocolate doughnut as energy?
- This usually involves the breakdown of glucose into _____.
- Equation - $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + ATP$

What is meant by 'aerobic' cellular respiration?



Active Recall: What is the purpose of ATP?





Misconception

"Cellular Respiration must be the reverse of photosynthesis!"

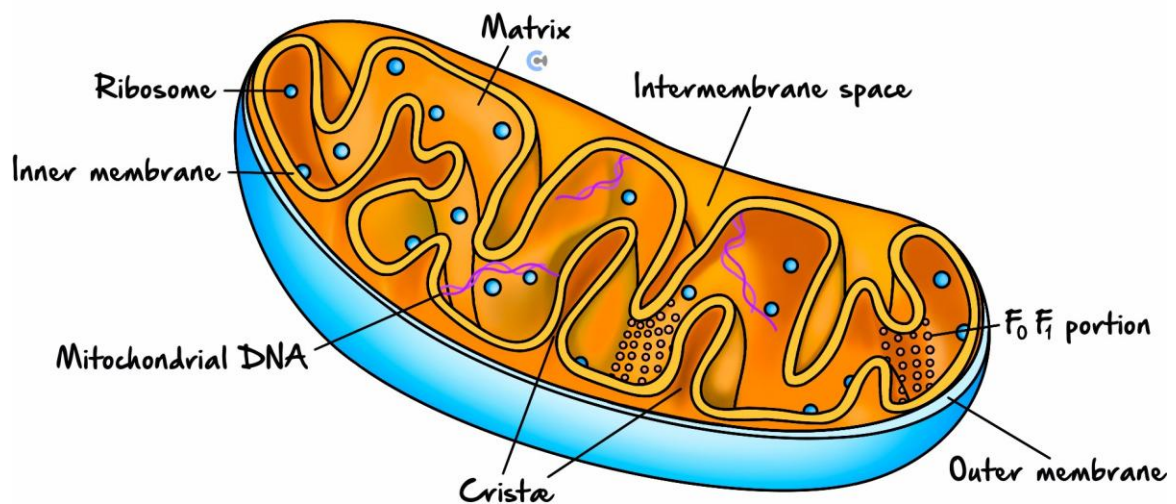
Although the equations may be the reverse, they are completely different biochemical pathways!



The Powerhouse of the Cell

- If you can't answer this - do you really study biology?
- THE MITOCHONDRIA!

Mitochondrion



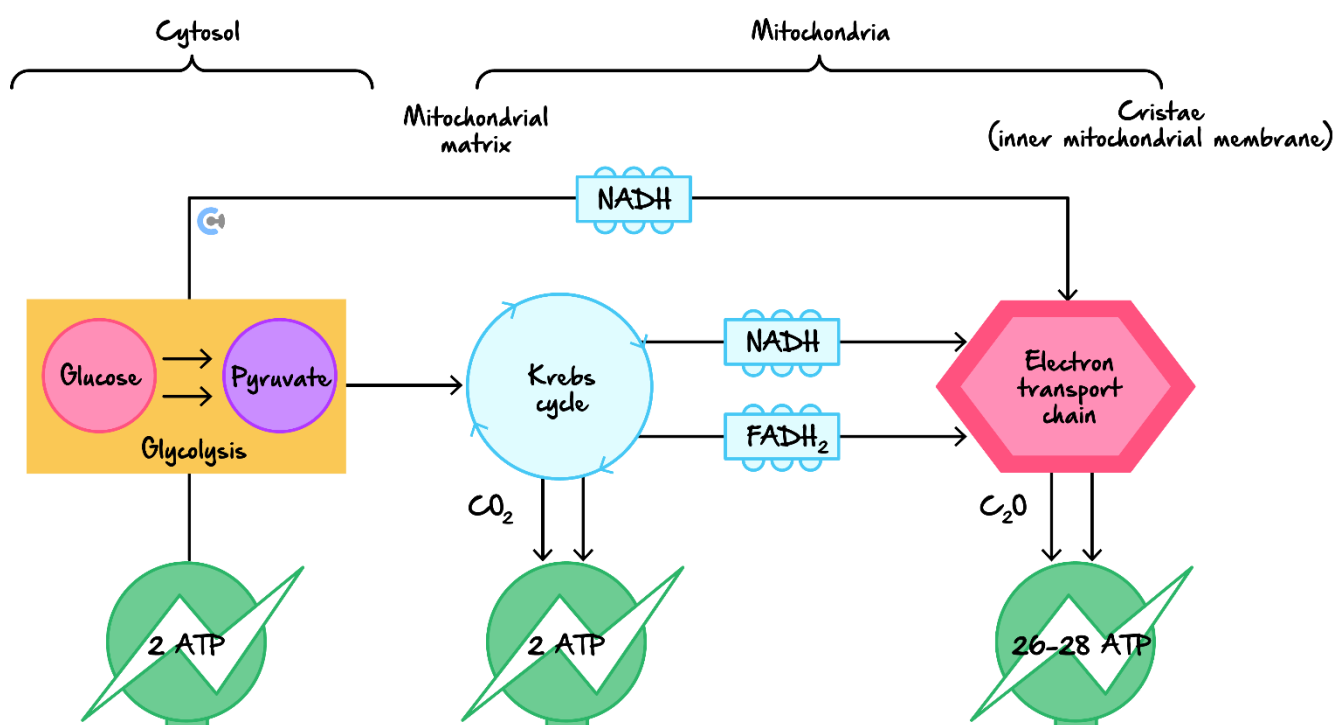
- 🔗 The _____ is where the Krebs Cycle takes place.
- 🔗 _____ are the folded membranes where the electron transport chain takes place.

Exploration: Where do the mitochondria come from?





Stage	Inputs	Outputs	Location
Glycolysis	Glucose, 2ADP + Pi, 2NAD ⁺	2 Pyruvate, 2NADH, 2ATP	
Link Reaction	2 Pyruvate, 2NAD ⁺	2 Acetyl CoA, 2 CO ₂ , 2NADH	
Kreb's Cycle	2 Acetyl CoA, 2ADP + Pi, NAD ⁺ , FAD	4CO ₂ , 2ATP, 6NADH, FADH ₂	
Electron Transport Chain	$\frac{26}{28}$ ADP + Pi, NADH, FADH ₂ , O ₂	$\frac{26}{28}$ ATP, NAD ⁺ , FAD, H ₂ O	



TIP: This table is pretty much all that is required knowledge for VCE - but it is really important to still have an understanding of the processes as they help with application!



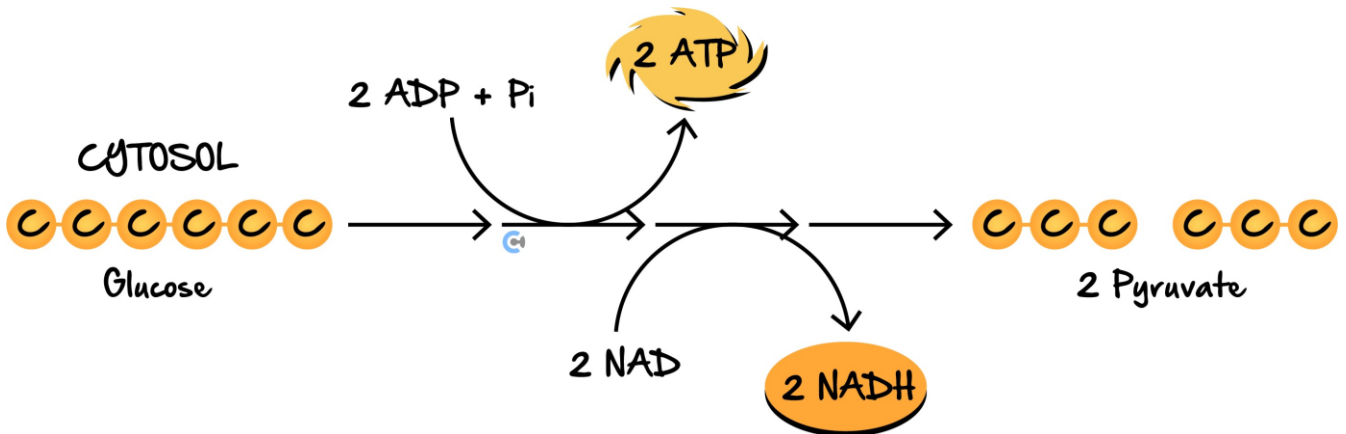
NOTE: The link reaction is technically considered not required by VCAA, but knowing it happens makes it easier to understand the relationship between the outputs for glycolysis and inputs for Kreb's Cycle.



Sub-Section: Glycolysis

Glycolysis

- The FIRST step of the process, is actually a series of reactions.
- Main goal is to break the glucose into 2-3 carbon _____ molecules.
- ⚙ Also produces the loaded _____ and _____, from the energy released by the breakdown of glucose.
- ⚙ _____ does not participate further in respiration and is used as an energy source, whereas the _____ is used in the Electron Transport Chain.



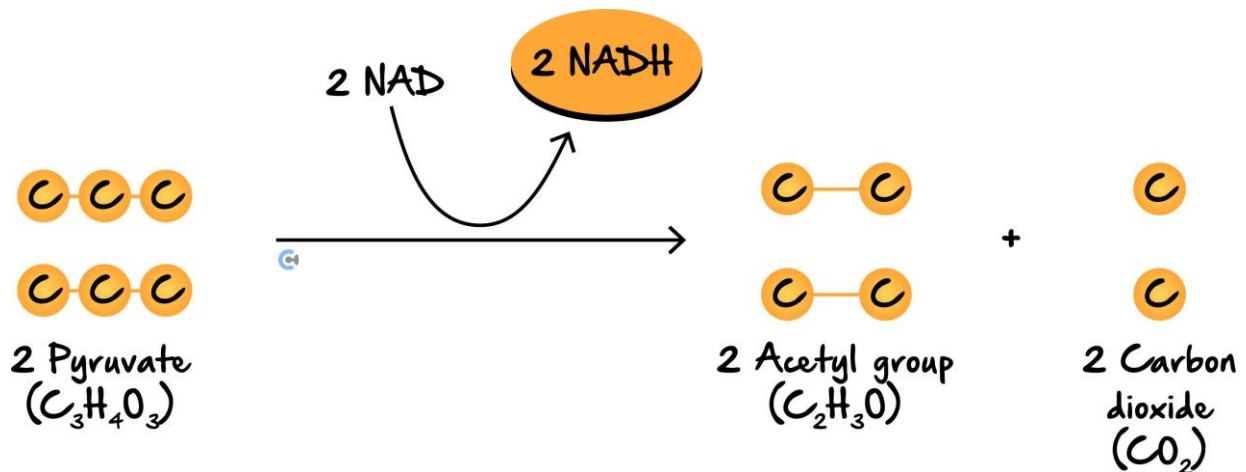
Inputs	Outputs	Location
Glucose ($C_6H_{12}O_6$)	2 pyruvate	
2ADP + Pi	2ATP	
2NAD ⁺	2NADH	

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Sub-Section: Link Reaction

Link Reaction

- ▶ Although not directly assessed by VCAA, the link reaction is necessary to remember the inputs of the Krebs's Cycle.
- ▶ The pyruvate from glycolysis is transported to the mitochondria's matrix, where the link reaction takes place - pyruvate is converted into Acetyl-CoA.
- ▶ Produces 2CO_2 as waste (1 per pyruvate).
- ▶ Produces 2NADH .



Inputs	Outputs	Location
	2 Acetyl CoA	Mitochondrial Matrix
2NAD^+	2NADH	

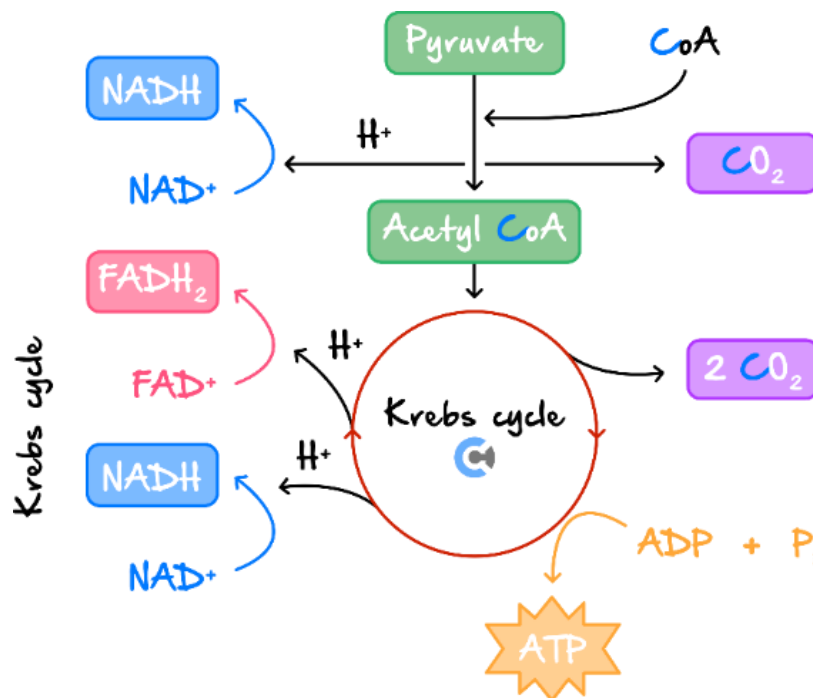
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Why is the link reaction necessary?

Sub-Section: Krebs's Cycle

Krebs's Cycle

- The Krebs's cycle serves to break down the Acetyl-CoA to CO_2 through a series of reactions which aim to produce charged _____ for the _____.
- ⚙ Produces a small amount of energy in the form of ATP which can be used for cellular reactions.
- ⚙ Modulated by several key enzymes (details are not required knowledge).



Space for Personal Notes



<u>Inputs</u>	<u>Outputs</u>	<u>Location</u>
	4CO ₂	
2ADP + Pi	2ATP	
	6 NADH	
2FAD + 4H ⁺		

Active Recall: What do NADH and FADH₂ do?

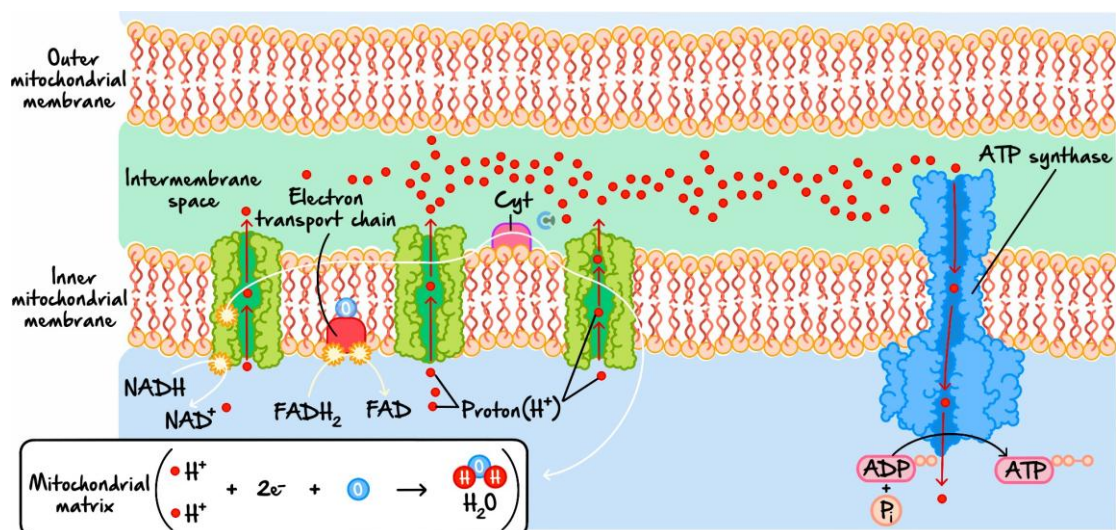


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Sub-Section: Electron Transport Chain

Electron Transport Chain

- This is the critical step of the process - which produces the majority of the ATP in this process.
- ⚙ Essentially involves cycling the protons that have been collected across the mitochondrial membrane to drive ATP production via _____.
- The Process:
 - ⚙ All the electron and proton carriers that have been loaded, arrive at the _____ of the mitochondria.
 - ⚙ There are protein complexes embedded in the membrane, and they collect the electrons and protons by unloading the carriers NADH and FADH₂.
 - ⚙ The energy of these _____ is used to pump the H⁺ ions (protons) into the intermembrane space, building up the concentration of them there.
 - ⚙ To move down the _____ they pass through an enzyme called ATP Synthase, which utilises their kinetic energy to then make ATP.
 - ⚙ This will produce lots of ATP, given the large number of carriers that have been generated previously, leaving free protons and electrons once this has been accomplished.
 - ⚙ They can be dangerous for a cell if left free, so are collected by _____.





Exploration: What is the significance of the cristae of the mitochondria?



Exploration: To what other biochemical pathway does this step bear similarities?



Exploration: Why would free protons and electrons be dangerous to the cell?



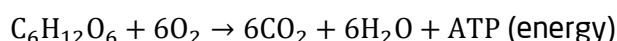
<u>Inputs</u>	<u>Outputs</u>	<u>Location</u>
O ₂	H ₂ O	
26/28 ADP + Pi		
	10 NAD ⁺	
2 FADH ₂	2 FAD	



Key Takeaways

✓ Overview:

- ⚙ Cellular respiration is the process of converting chemical energy in glucose into ATP, the main energy currency for cellular activities.
- ⚙ Organisms cannot use food directly (e.g., a doughnut) as energy because it must first be broken down into a usable form through biochemical reactions.
- ⚙ General equation:



- ⚙ ATP provides energy for critical functions like muscle contractions, active transport, and synthesis of macromolecules.

✓ The Powerhouse of the Cell:

- ⚙ Mitochondria are the key site of aerobic respiration, with specialised structures:
 - ✓ **Matrix:** Location of the Krebs cycle.
 - ✓ **Cristae:** Folded inner membranes that house the ETC, maximising surface area for ATP production.
- ⚙ Endosymbiotic theory explains the origin of mitochondria as once-independent prokaryotes.
- ⚙ Explains the presence of their own ribosomes and mitochondrial DNA.

✓ Key Stages:

⚙ Glycolysis:

- ✓ Location: Cytoplasm.
- ✓ Inputs: Glucose, NAD⁺, ADP.
- ✓ Outputs: 2 Pyruvate, 2 NADH, 2 ATP (net).
- ✓ Main purpose: Splitting one glucose molecule into two 3-carbon molecules (pyruvate) while generating small amounts of ATP and NADH.




Link Reaction:

- ✓ Location: Mitochondrial matrix.
- ✓ Inputs: Pyruvate.
- ✓ Outputs: Acetyl-CoA, CO₂ (waste), NADH.
- ✓ Pyruvate is decarboxylated and combined with Coenzyme A to form Acetyl-CoA.



Krebs Cycle:

- ✓ Location: Mitochondrial matrix.
- ✓ Inputs: Acetyl-CoA, NAD⁺, FAD, ADP.
- ✓ Outputs: CO₂, NADH, FADH₂, ATP.
- ✓ A series of reactions that produce electron carriers (NADH, FADH₂) for the ETC.
- ✓ Generates a small amount of ATP.

Electron Transport Chain (ETC):

- ✓ Location: Cristae.
- ✓ Inputs: NADH, FADH₂, O₂.
- ✓ Outputs: ATP, H₂O.
- ✓ Mechanism:
 -  Electrons from NADH and FADH₂ pass through protein complexes, driving proton pumps.
 -  A proton gradient forms in the intermembrane space, and protons flow back through ATP synthase, generating ATP.
 -  O₂ serves as the final electron acceptor, forming water.

✓ Significance:

-  The ETC generates the bulk of ATP (approximately 32-34 ATP per glucose molecule).
-  Cristae structure optimises energy production.

Section B: Anaerobic Fermentation

What happens when there is no oxygen in a cell?




How will cells get their energy?




No Oxygen?!



- When there is no oxygen, aerobic respiration cannot take place, and for most organisms, this is the primary and most efficient source of ATP.
 -  What happens now?
- The Krebs's Cycle and Electron Transport Chain will not take place, why?
- Glycolysis can still occur to produce some ATP, but this cannot occur indefinitely without another biochemical pathway occurring.

REMINDER: Glycolysis occurs in the cytoplasm and is the only stage of cellular respiration that doesn't require oxygen. This is why it's crucial in both aerobic and anaerobic conditions."



Exploration: Obligate vs Facultative Anaerobes



Discussion: Why can't glycolysis go on forever?



Sub-Section: Lactic Acid Fermentation



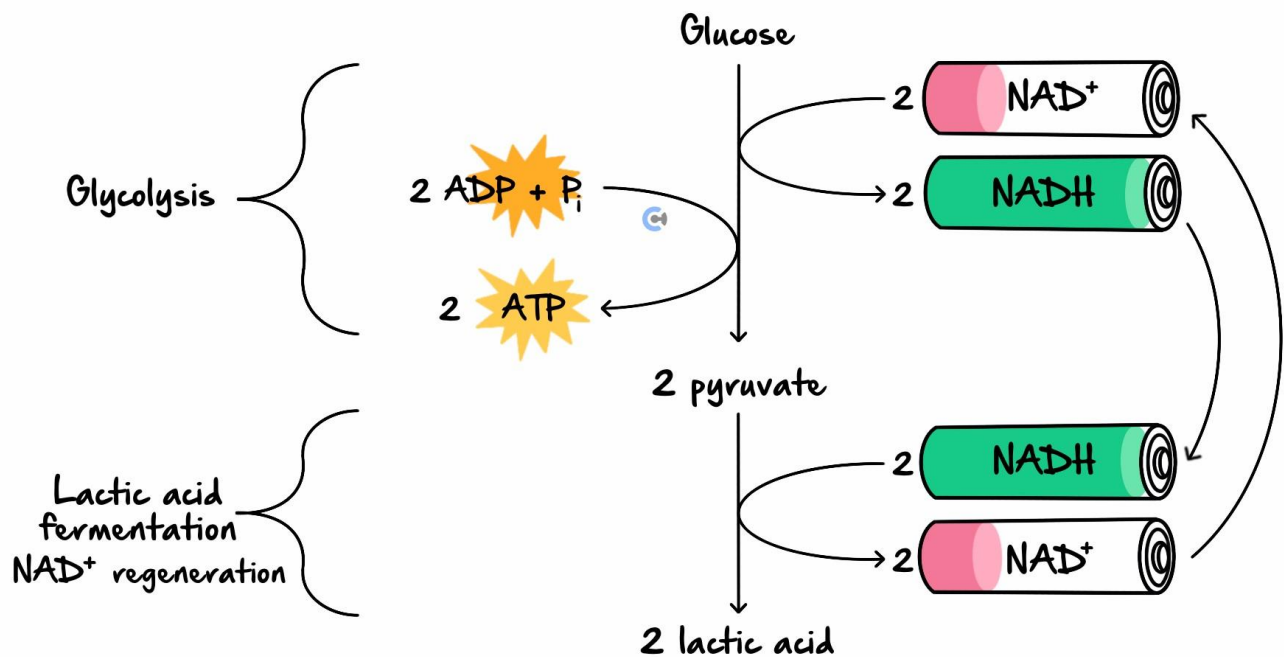
Anaerobic Fermentation in Animals

- As discussed above, glycolysis will still occur and this step will provide the net 2 ATP which is the energy output of this pathway in animals.
- However, a method of _____ is required to allow glycolysis to continue, and this is different in animals and yeast.
- 🔄 In animals, pyruvate is converted to _____ which involves a conversion of 2 NADH into 2NAD⁺.

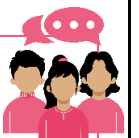
Lactic acid fermentation in animals

Location: cytosol

Word equation: glucose → 2 lactic acid + 2 ATP



Discussion: Can this continue forever?



Sub-Section: Alcoholic Fermentation

How does this work?

Anaerobic Fermentation in Yeast

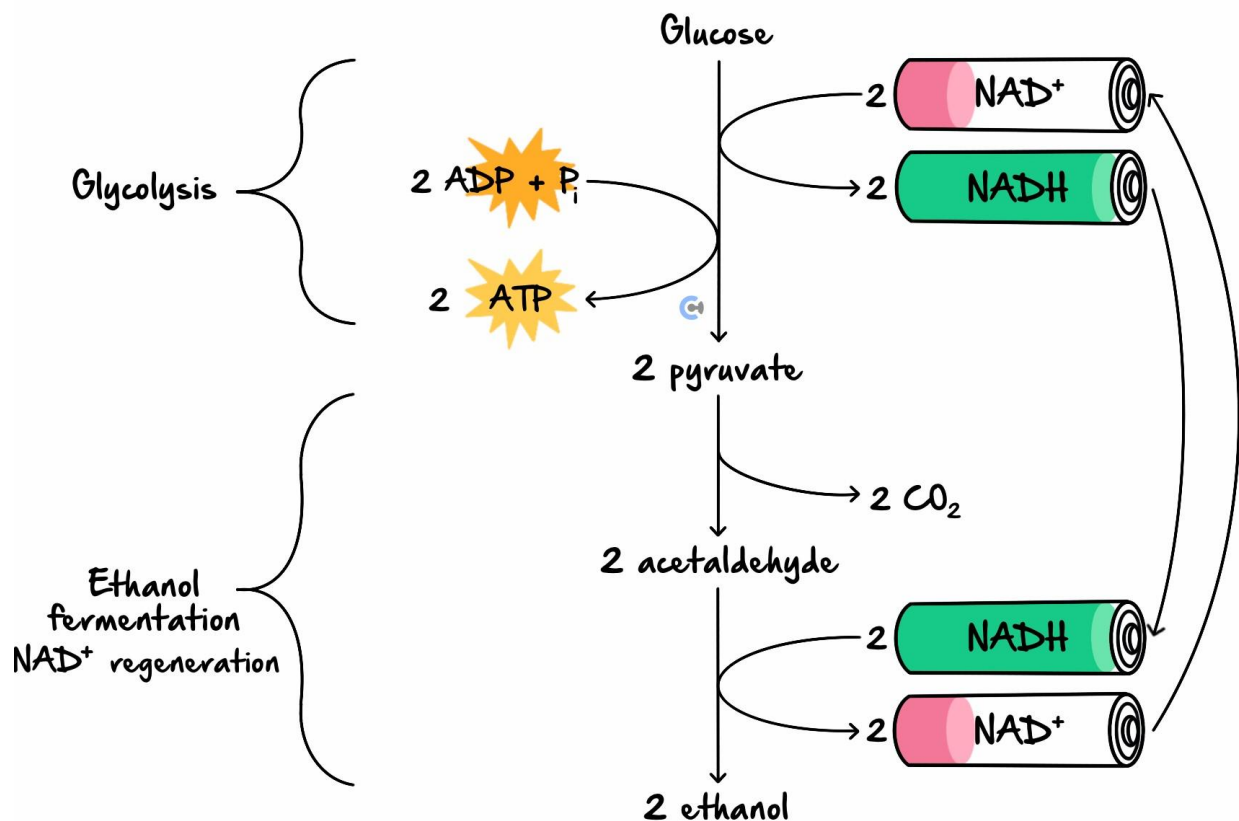
➤ As discussed above, glycolysis will still occur and this step will provide the net 2 ATP which is the energy output of this pathway in yeast.

🔄 In yeast, pyruvate is converted to _____ and CO_2 , which involves the conversion of 2 NADH into 2NAD^+ .

Ethanol fermentation in yeasts

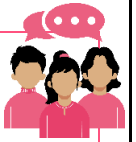
Location: cytosol

Word equation: $\text{glucose} \rightarrow 2 \text{ ethanol} + 2 \text{ CO}_2 + 2 \text{ ATP}$



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Discussion: Can this continue forever?



Discussion: Let's compare these pathways!





- How does the glucose usage of both pathways compare? Which one uses glucose faster?

Key Takeaways







1. Overview:




-  When oxygen is unavailable, cells rely on anaerobic pathways to produce ATP.
-  Glycolysis continues to provide ATP, but its products (pyruvate and NADH) must be processed differently to regenerate NAD⁺.

2. Pathways:




In Animals:

-  Pyruvate → Lactic acid.
-  This conversion regenerates NAD⁺, allowing glycolysis to continue.
-  Common during vigorous exercise when oxygen demand exceeds supply.
-  Limited by lactic acid accumulation, which lowers pH and causes fatigue.



 **In Yeast:**

-  Pyruvate → Ethanol + CO₂.
-  Process involves decarboxylation of pyruvate and reduction of acetaldehyde.
-  Important in brewing and baking industries.

3. Efficiency:

-  Anaerobic fermentation produces only 2 ATP per glucose molecule compared to 36-38 ATP in aerobic respiration.
-  Hence, there is an increase in glucose consumption.
-  Glycolysis alone cannot sustain high energy demands indefinitely.

4. Biological Significance:

-  Facultative anaerobes (e.g., yeast) can switch between aerobic and anaerobic pathways depending on oxygen availability.
-  Obligate anaerobes survive only in oxygen-free environments.

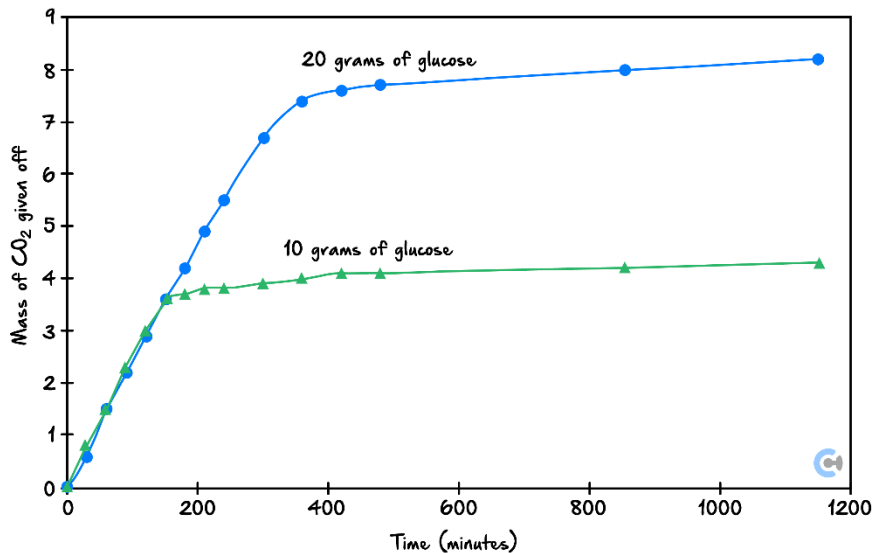
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Section C: Factors Affecting the Rate of Cellular Respiration



Factors

- Glucose availability - it will increase the rate until it reaches a saturation point where it will then start to plateau. Can also be due to limiting factors.



- Oxygen - increasing the rate as above until other factors become limiting.
- Temperature - have a go at drawing the graph yourself!
- pH - have a go at drawing the graph yourself!





Exploration: How would these factors affect the rate of anaerobic fermentation?



Key Takeaways






✓ Glucose Availability:

-  Determines the initial substrate concentration.
-  Respiration rate increases with glucose until saturation or another factor becomes limiting.

✓ Oxygen Availability:

-  Essential for aerobic stages (Krebs cycle and ETC).
-  Absence halts these stages, forcing cells to rely on anaerobic fermentation.

✓ Temperature:


-  Enzymes involved in respiration have an optimal temperature range.
-  Too low: Reduced enzyme activity.
-  Too high: Denaturation and loss of function.

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Section D: Biofuel Production



What are biofuels?

- Biofuels are fuels that are created from organic biomass, which includes plants, animal byproducts, and biological waste.
-  Fuels are _____.
- Biofuels are considered to be better for the environment because they are _____ and _____ to a certain extent.

Exploration: What is meant by 'renewable', 'carbon neutral', and 'sustainable'?



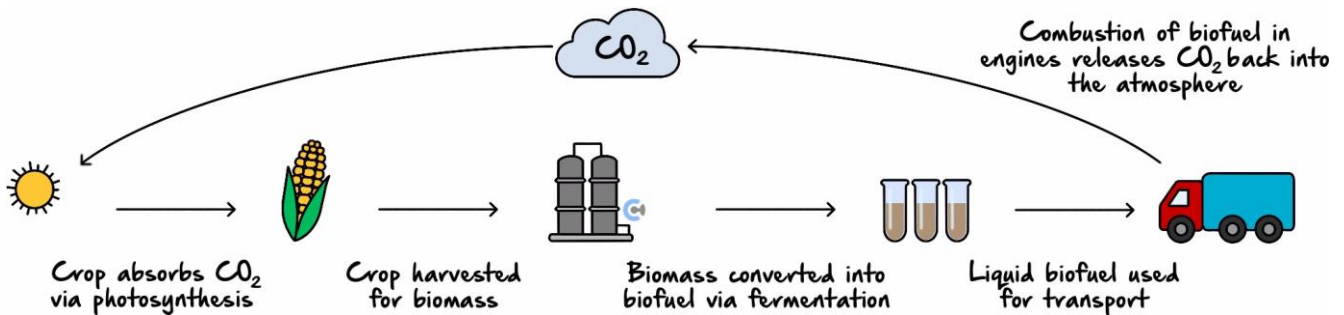
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How are they made?

➤ Crops are harvested for their biomass, and this biomass is then fermented.

🔄 Yeast undergoes _____ to make the ethanol.



1. **Enzymatic Hydrolysis:** Break down plant materials (e.g., sugarcane, corn) into simple sugars using enzymes.
2. **Fermentation:** Add yeast to the sugar solution, where it converts sugars into ethanol and carbon dioxide in an oxygen-free environment.
3. **Distillation:** Separate ethanol from the mixture using heat to concentrate it to ~95% purity.
4. **Dehydration:** Remove remaining water to produce high-purity ethanol for use as biofuel.

Exploration: Biodiesel



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Exploration: What are some of the implications of the use of biofuels?



Key Takeaways

✓ What Are Biofuels?:

⚙️ Fuels derived from biomass (organic material like crops, animal waste, or biological byproducts).

⚙️ Examples:

✓ Ethanol: Produced through fermentation by yeast.

✓ Biodiesel: Created from plant oils or animal fats.

✓ Production Process:

⚙️ Enzymatic Hydrolysis: Breaking complex carbohydrates (e.g., cellulose) into simple sugars.

⚙️ Fermentation: Yeast converts sugars into ethanol and CO₂ under anaerobic conditions.

⚙️ Distillation: Purifies ethanol to ~95%.

⚙️ Dehydration: Removes water to produce high-purity ethanol for fuel.

✓ Environmental and Economic Considerations:

⚙️ Strengths:

✓ Renewable and potentially carbon-neutral.

✓ Reduces reliance on fossil fuels.

✓ Promotes localised energy production.

⚙️ Weaknesses:

✓ Food vs fuel dilemma: Cropland used for biofuels may compete with food production.

✓ High production costs and limited compatibility with existing energy systems.

✓ Environmental impacts: Deforestation, reduced biodiversity, and secondary pollutants like nitrous oxide.

✓ Future Implications:

⚙️ Biofuels represent a step toward sustainable energy but require careful balance between environmental and societal needs.



Contour Check

Learning Objective: [2.2.1] - Recall the inputs, outputs & locations of all stages of aerobic cellular respiration

Study Design

The main inputs, outputs and locations of glycolysis, Kreb's Cycle and electron transport chain including ATP yield (details of biochemical pathway mechanisms are not required)

Key Takeaways

☐ Key Stages:

☐ Glycolysis:

☐ Location:

☐ Inputs:

☐ Outputs:

☐ Main purpose:

☐ Link Reaction:

☐ Location:

☐ Inputs:

☐ Outputs:

☐

- **Krebs Cycle:**

- ☐ Location:
- ☐ Inputs:
- ☐ Outputs:
- ☐ A series of reactions that produce electron carriers (_____) for the ETC.
- ☐ Generates a small amount of _____.

- **Electron Transport Chain (ETC):**

- ☐ Location:
- ☐ Inputs:
- ☐ Outputs:
- ☐ Mechanism:

-

-

-

- ☐ **Significance:**

- The ETC generates the bulk of ATP (approximately 32-34 ATP per glucose molecule).
 - Cristae structure optimises energy production.

Learning Objective: [2.2.2] - Recall the inputs, outputs & locations of all stages of anaerobic cellular respiration, including lactic acid & alcoholic fermentation

Study Design

The location, inputs and the difference in the output of anaerobic fermentation in animals and yeasts

Key Takeaways

☐ Pathways:

☐ In Animals:



☐ This conversion regenerates NAD^+ , allowing glycolysis to continue.

☐ Common during vigorous exercise when oxygen demand exceeds supply.

☐ Limited by lactic acid accumulation, which lowers pH and causes fatigue.

☐ In Yeast:



☐ Process involves decarboxylation of pyruvate and reduction of acetaldehyde.

☐ Important in brewing and baking industries.

Learning Objective: [2.1.3] - Describe the significance of the mitochondria as the necessary location for aerobic respiration

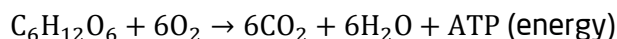
Study Design

The main inputs, outputs and locations of glycolysis, Krebs's Cycle and electron transport chain including ATP yield (details of biochemical pathway mechanisms are not required)

Key Takeaways

□ Overview:

- Cellular respiration is the process of converting chemical energy in glucose into ATP, the main energy currency for cellular activities.
- Organisms cannot use food directly (e.g., a doughnut) as energy because it must first be broken down into a usable form through biochemical reactions.
- General equation:



- ATP provides energy for critical functions like muscle contractions, active transport, and synthesis of macromolecules

□ The Powerhouse of the Cell:

- Mitochondria are the key site of aerobic respiration, with specialised structures:
 - **Matrix:**
 - **Cristae:**
- Endosymbiotic theory explains the origin of mitochondria as once-independent prokaryotes.
- Explains the presence of their own ribosomes and mitochondrial DNA.

Learning Objective: [2.2.4] - Identify & describe factors - such as temperature, glucose availability, & oxygen concentration - on the rate of cellular respiration

Study Design

The factors that affect the rate of cellular respiration: temperature, glucose availability and oxygen concentration

Key Takeaways

☐ Glucose Availability:



☐ Oxygen Availability:



☐ Temperature:



Learning Objective: [2.2.5] - Identify & explain the role of enzymes & coenzymes in cellular respiration, including both aerobic & anaerobic

Study Design
graph

Key Takeaways

☐ **Enzymes:**

- ☐ _____ each step in glycolysis, Krebs cycle, and ETC (e.g., dehydrogenases).
- ☐ ATP synthase in the ETC synthesises ATP from ADP and inorganic phosphate using the proton gradient.

☐ **Coenzymes:**

- ☐ _____ and _____ act as electron carriers, transferring electrons and protons to the ETC.
- ☐ Coenzyme A (in Link Reaction) facilitates the conversion of pyruvate to Acetyl-CoA.

Learning Objective: [2.2.6] - Apply experimental design principles to create methodologies to test factors that affect cellular respiration

Study Design
graph

Key Takeaways

- ☐ No specific content from the workbook fits this section. However, experimental designs might involve:
- ☐ Measuring oxygen consumption or CO₂ production.
 - ☐ Altering glucose concentration, oxygen levels, or temperature.
 - ☐ Using indicators (e.g., methylene blue) to track metabolic activity.

Learning Objective: [2.2.7] - Describe the importance of breaking down biomass into simple sugars for biofuel production

Study Design

Uses and applications of anaerobic fermentation of biomass for biofuel production

Key Takeaways

☐ **What Are Biofuels?:**

- ☐ Fuels derived from biomass (organic material like crops, animal waste, or biological byproducts).
- ☐ Examples:
 - ☐ Ethanol: Produced through fermentation by yeast.
 - ☐ Biodiesel: Created from plant oils or animal fats.

☐ **Environmental and Economic Considerations:**

☐ **Strengths:**

☐ **Weaknesses:**

☐ **Future Implications:**

- ☐ Biofuels represent a step toward sustainable energy but require careful balance between environmental and societal needs.

Learning Objective: [2.2.8] - Explain how yeast can be used to produce bioethanol from biomass

Study Design

Uses and applications of anaerobic fermentation of biomass for biofuel production

Key Takeaways

- ❑ Biomass (e.g., sugarcane, corn) contains complex carbohydrates like cellulose.
- ❑ **Enzymatic Hydrolysis:**
 - Enzymes break down complex carbohydrates into simple sugars (e.g., glucose).
- ❑ Simple sugars serve as the substrate for fermentation, allowing efficient conversion into biofuels like ethanol.
- ❑ **Fermentation:** Yeast converts sugars into ethanol and CO₂ under anaerobic conditions.
 - **Distillation:** Purifies ethanol to ~95%.
 - **Dehydration:** Removes water to produce high-purity ethanol for fuel.



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