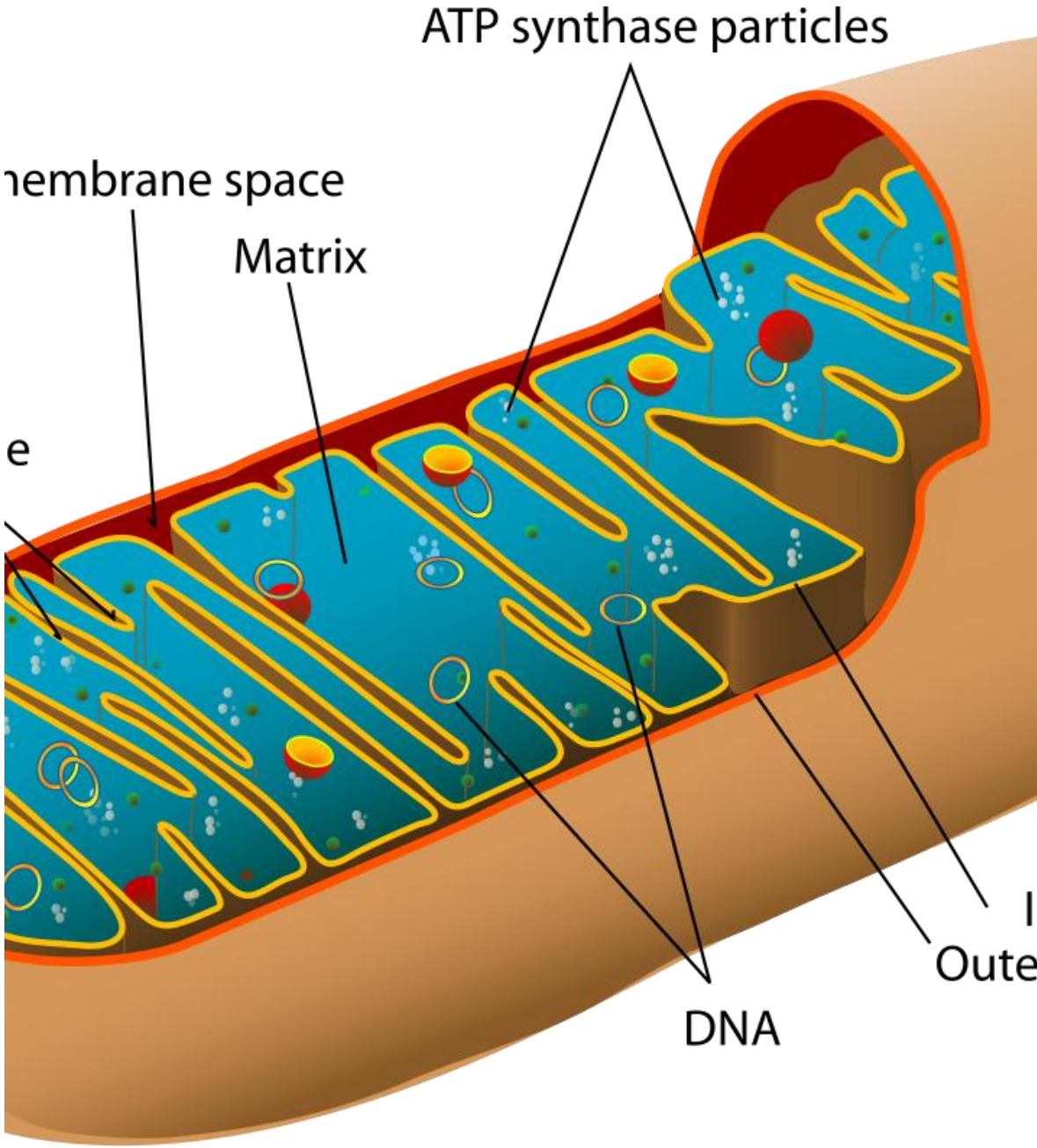
DP Biology – C1.2 (HL extension)

Inside cell respiration

- What do hydrogen and oxygen contribute to releasing energy in cells?
- How is energy shared out and used within cells?



HL statements C1.2.7–17. Textbook pp. 412–424.
Image: a mitochondrion. Mariana Ruiz Villarreal, public domain.

Objectives for each class

Class	Statements	By the end of the class, you can...
1	C1.2.7–8	Explain oxidation as removal of hydrogen, the role of NAD, and the stages of glycolysis
2	C1.2.9–10	Explain how anaerobic respiration regenerates NAD in humans and in yeast, and its uses in baking and brewing
3	C1.2.11–12	Explain the link reaction and the Krebs cycle
4	C1.2.13–14	Explain how reduced NAD passes energy to the electron transport chain, which builds a proton gradient
5	C1.2.15–16	Explain chemiosmosis, ATP synthase and the role of oxygen
6	C1.2.17	Compare fats and sugars as fuels for respiration, and review the whole process

Oxidation, reduction and NAD

	Oxidation	Reduction
Electrons	Lost	Gained
Hydrogen	Removed	Added
Oxygen	Added	Removed

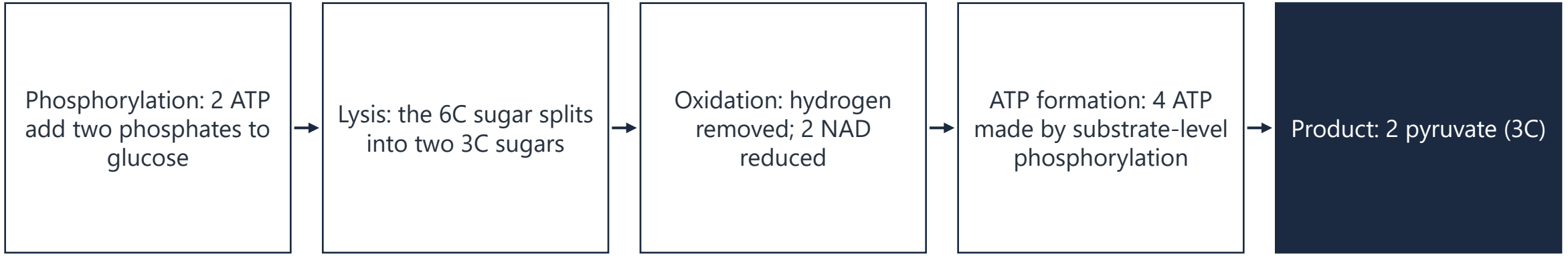
- Respiration oxidizes glucose by removing hydrogen (**dehydrogenation**)
- **NAD** accepts the hydrogen and is reduced
- NAD+ + 2H → NADH + H+ (reduced NAD)
- Oxidation and reduction always happen together: **redox**

Key idea

A hydrogen atom is a proton plus an electron. Removing hydrogen therefore removes electrons, which is oxidation. NAD carries the hydrogen, and its energy, to the electron transport chain.

Glycolysis: glucose to pyruvate

C1.2.8



Per glucose	Amount
ATP used	2
ATP made	4
Net ATP	2
Reduced NAD	2

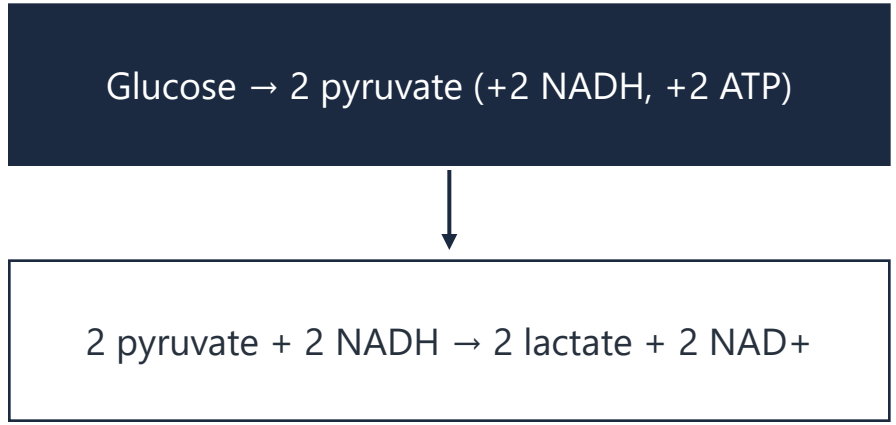
Where and how

In the cytoplasm, with no oxygen needed. Each of the ten or so steps has its own enzyme. Phosphorylation makes glucose less stable, so it can be split.

Regenerating NAD without oxygen

C1.2.9

- Glycolysis needs a supply of NAD+
- Without oxygen, reduced NAD cannot pass its hydrogen to the electron transport chain
- So in humans, pyruvate accepts the hydrogen and becomes **lactate**
- This regenerates NAD+, so glycolysis can continue
- Net yield: only 2 ATP per glucose

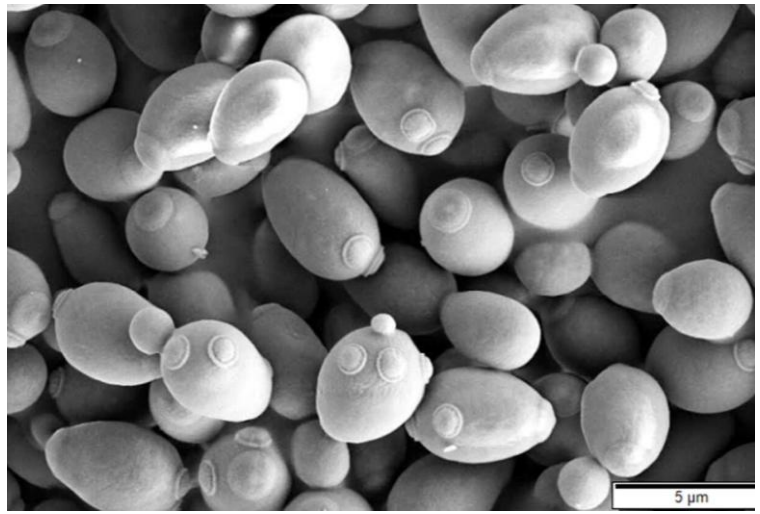


In muscle

In intense exercise, muscles cannot get oxygen fast enough and make lactate. This gives ATP quickly but little of it. Lactate is later taken to the liver and converted back, using oxygen.

Anaerobic respiration in yeast

C1.2.10



Yeast cells (SEM). M. D. Murtey and P. Ramasamy, CC BY 3.0.



Bread dough rising in baskets. Wald1siedel, CC BY-SA 4.0.

	Humans	Yeast
Same	Glycolysis	Glycolysis
Hydrogen acceptor	Pyruvate	Ethanal (from pyruvate)
Products	Lactate	Ethanol and carbon dioxide

Use	Product that matters
Baking	Carbon dioxide makes dough rise; ethanol evaporates in the oven
Brewing	Ethanol; carbon dioxide gives fizz

The link reaction

C1.2.11

Pyruvate (3C) enters the matrix → Decarboxylation: CO_2 removed → Oxidation: hydrogen removed, NAD reduced → Acetyl group (2C) joins coenzyme A → Acetyl-CoA enters the Krebs cycle

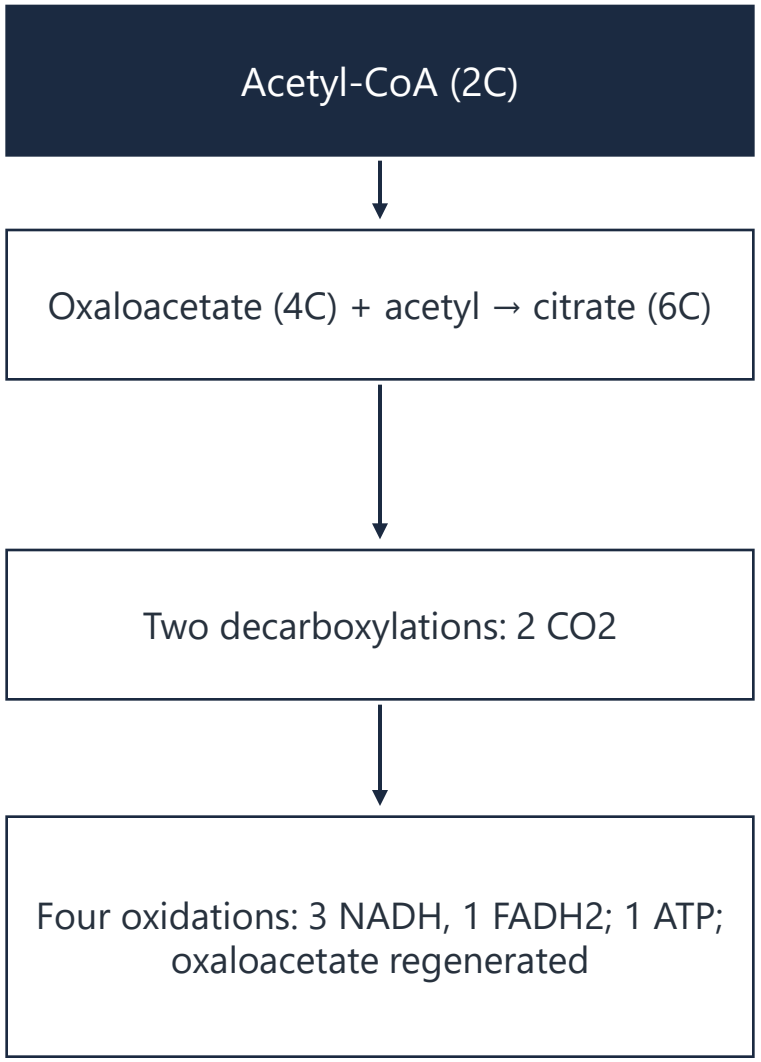
Other fuels

Fatty acids from lipids are cut into 2C acetyl groups, which also join coenzyme A. So acetyl-CoA is the common entry point to the Krebs cycle for both carbohydrates and lipids.

Per glucose (2 pyruvate)	Yield
CO_2	2
Reduced NAD	2

The Krebs cycle

- In the mitochondrial matrix
- Only citrate and oxaloacetate need to be named
- The oxidations are dehydrogenations
- It turns twice per glucose



Per turn	Yield
CO2	2
Reduced NAD	3
Reduced FAD	1
ATP	1

Where the hydrogen goes

C1.2.8–12

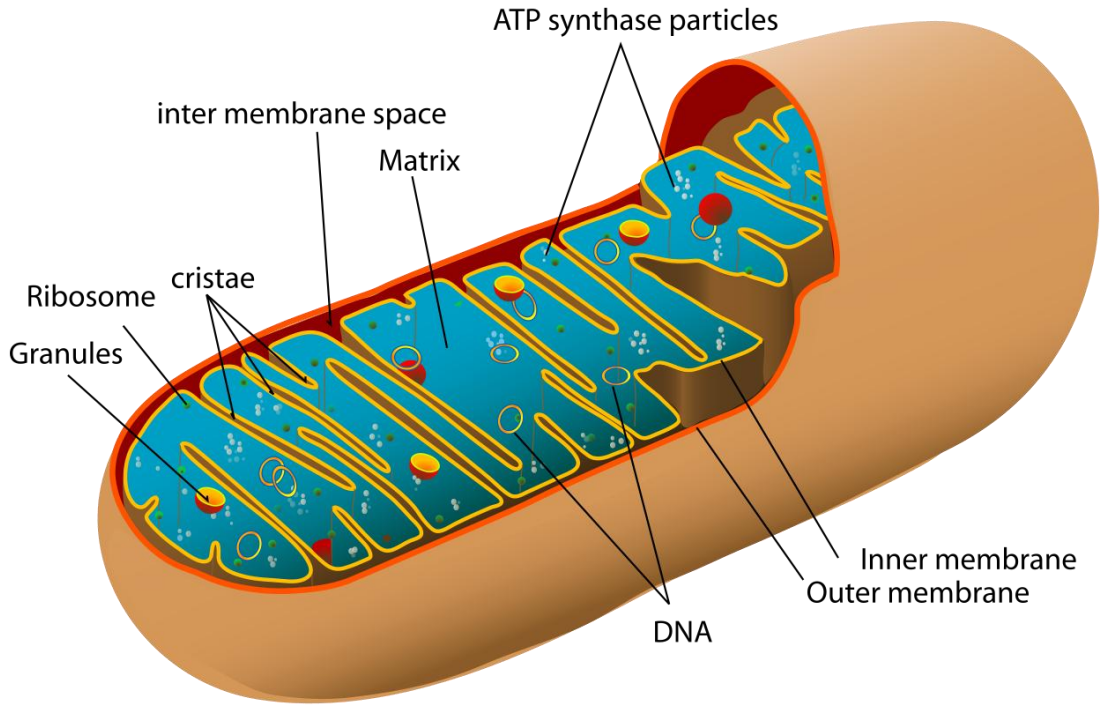
Stage, per glucose	ATP	Reduced NAD	Reduced FAD	CO2
Glycolysis	2 (net)	2	0	0
Link reaction	0	2	0	2
Krebs cycle (two turns)	2	6	2	4
Total so far	4	10	2	6

Activity

Complete this table from memory, then explain why most of the energy of glucose is still not in ATP at this stage. Where is it?

Reduced NAD delivers to the chain

C1.2.13

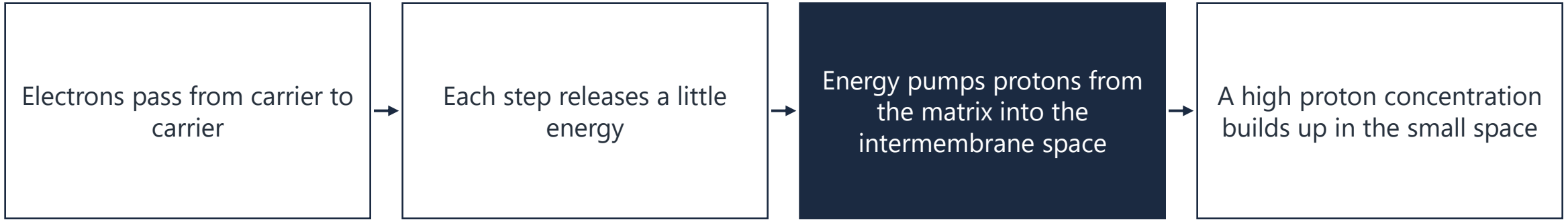


Mitochondrion: the chain is in the inner membrane (cristae). Public domain.

- Reduced NAD from glycolysis, the link reaction and the Krebs cycle passes a pair of electrons to the first carrier
- This oxidizes it back to NAD+, ready to be reused
- Reduced FAD passes its electrons to a later carrier, so it releases less energy
- The carriers are proteins in the inner membrane

Building a proton gradient

C1.2.14



Why in small steps?

Releasing all the energy at once would be lost as heat. Passing electrons along a chain of carriers lets the energy be used bit by bit to pump protons. The inner membrane is impermeable to protons, so they can only return through ATP synthase.

Chemiosmosis and ATP synthase

C1.2.15

- Protons diffuse back into the matrix down their gradient
- The only route is through **ATP synthase**
- The flow turns part of the enzyme, changing its shape
- This energy joins ADP and phosphate to make ATP: **oxidative phosphorylation**
- About 30 to 32 ATP per glucose are made in total

Mitchell's idea

Peter Mitchell proposed chemiosmosis in 1961. At first many biochemists rejected it. Experiments showing that a proton gradient alone could drive ATP synthesis convinced them. He received a Nobel Prize in 1978.

Common mistake

Protons are not used up in making ATP. Their movement down the gradient provides the energy.

Oxygen: the final acceptor

At the end of the chain: 2 electrons + 2 H+ (from the matrix) + 1/2 O2 → H2O

- Oxygen accepts the electrons from the last carrier
- It also takes protons from the matrix, forming **metabolic water**
- Removing electrons keeps them flowing along the chain
- Without oxygen, the chain backs up, reduced NAD cannot be recycled, and only glycolysis can continue

Cyanide

Cyanide blocks the last carrier, so electrons cannot reach oxygen. The chain stops, ATP production collapses, and cells die even though oxygen is present.

Lipids or carbohydrates?

C1.2.17

	Carbohydrate	Lipid
Energy per gram	About 17 kJ	About 37 kJ
Why	More oxygen already in the molecule	Less oxygen, more hydrogen and carbon to oxidize
Entry to respiration	Glycolysis, then link reaction	Fatty acids cut into acetyl groups, enter as acetyl-CoA
Anaerobic use	Yes, via glycolysis	No: fatty acids do not go through glycolysis

So

Lipids are a compact store of energy, but they can only be respired aerobically. Sprinters rely on carbohydrate; long endurance events use more fat.

Check that you can explain

1. Oxidation as removal of hydrogen, and NAD as a carrier
2. The four stages of glycolysis and its net yield
3. How lactate and ethanol formation regenerate NAD
4. How yeast is used in baking and brewing
5. The link reaction and the Krebs cycle
6. How the electron transport chain builds a proton gradient
7. How ATP synthase makes ATP by chemiosmosis
8. Why oxygen is needed, and why lipids yield more energy

Exit activity: 5 minutes

On your own and without notes. Hand this in as you leave.

1. How many ATP and reduced NAD does glycolysis give, per glucose, after costs?
2. Explain why anaerobic respiration must convert pyruvate to lactate.
3. Explain the role of oxygen in aerobic respiration.

Image credits

Animal mitochondrion diagram en.svg – Mariana Ruiz Villarreal LadyofHats – Public domain

Saccharomyces cerevisiae SEM.jpg – Mogana Das Murtey and Patchamuthu Ramasamy – CC BY 3.0

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