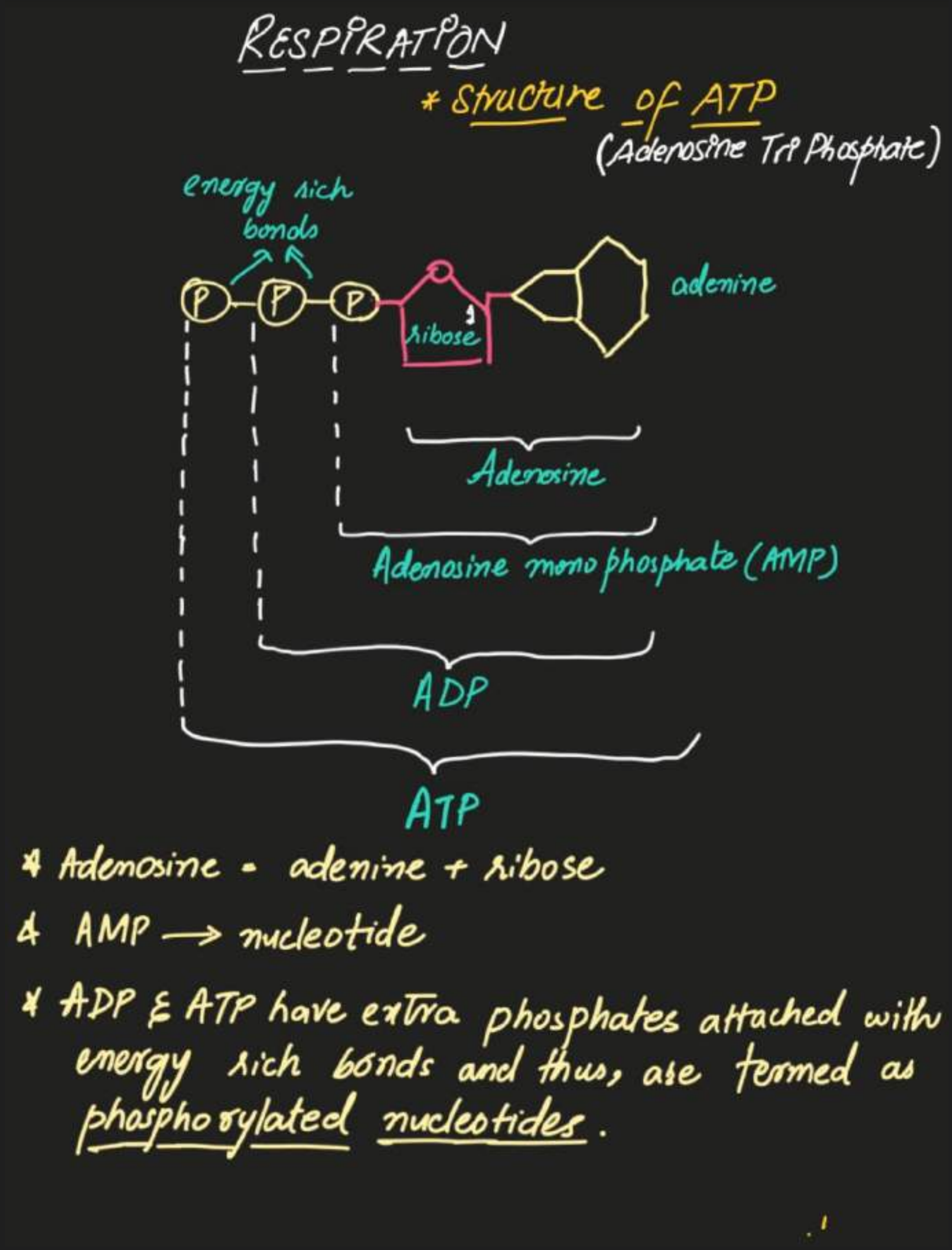
HEUSER

Energy & Respiration



RESPIRATION

* Structure of ATP
(Adenosine Tri Phosphate)

* Adenosine = adenine + ribose

* AMP → nucleotide

* ADP & ATP have extra phosphates attached with energy rich bonds and thus, are termed as phosphorylated nucleotides.

With

Mohammad Hussham Arshad, MD

ADVANCED LEVEL BIOLOGY 9700

UNIT 12: ENERGY AND RESPIRATION

Learning Objectives:

- Structure of ATP
- Propertise of ATP
- Uses of Energy

Video Lecture 1 Slides
Mohammad Hussham Arshad, MD
Biology Department

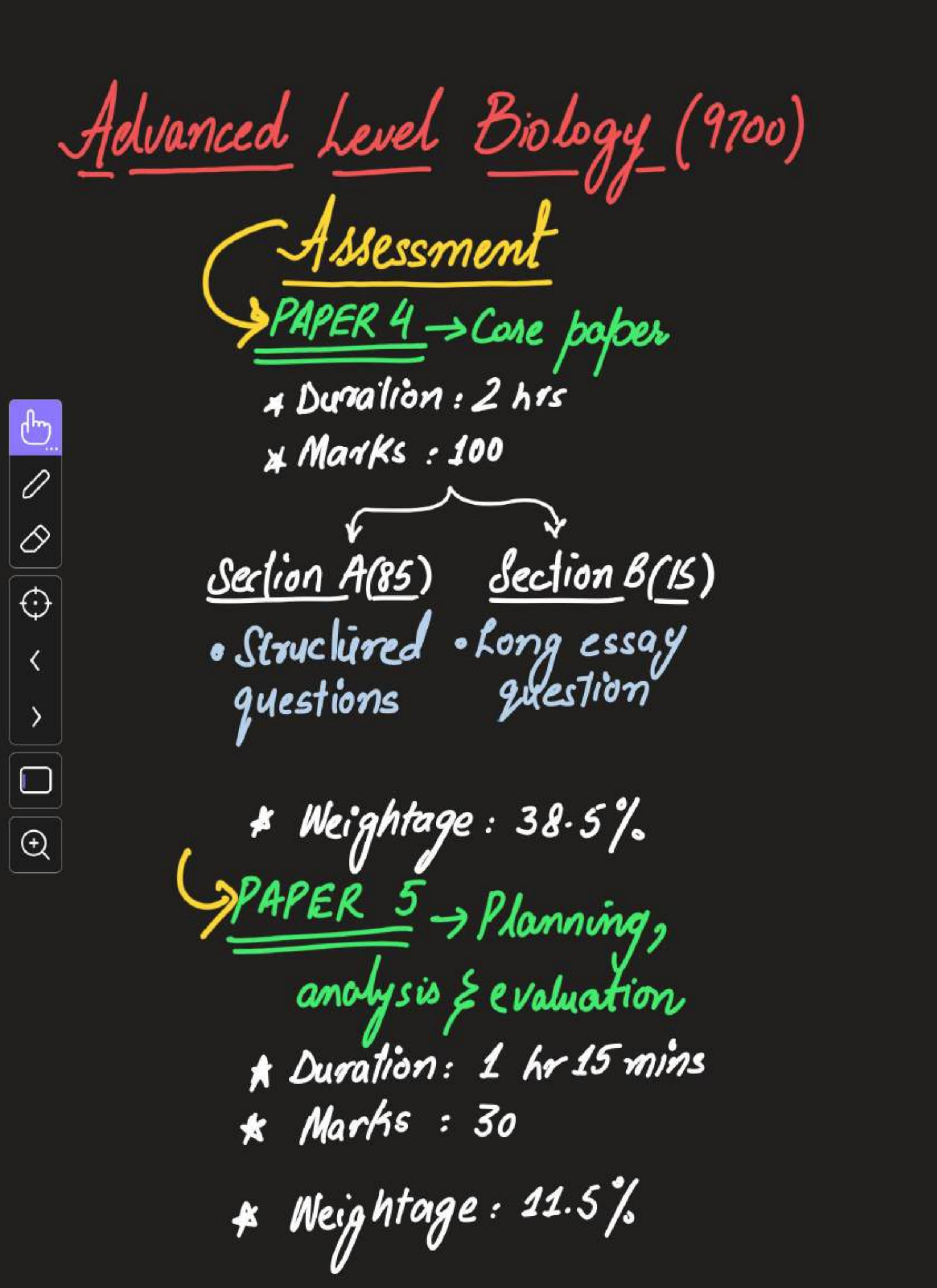
Advanced Level Biology (9700)

Syllabus Outlines

1) Respiration
2) Photosynthesis
3) Homeostatis
4) Control & Coordination
5) Inherited change
6) Genetic technology
7) Biodiversity, classification & conservation
8) Selection & evolution

AND

* the entire AS course



Advanced Level Biology (9700)

Assessment

PAPER 4 → Core paper

- Duration : 2 hrs
- Marks : 100

Section A (85)
- Structured questions

Section B (15)
- Long essay question

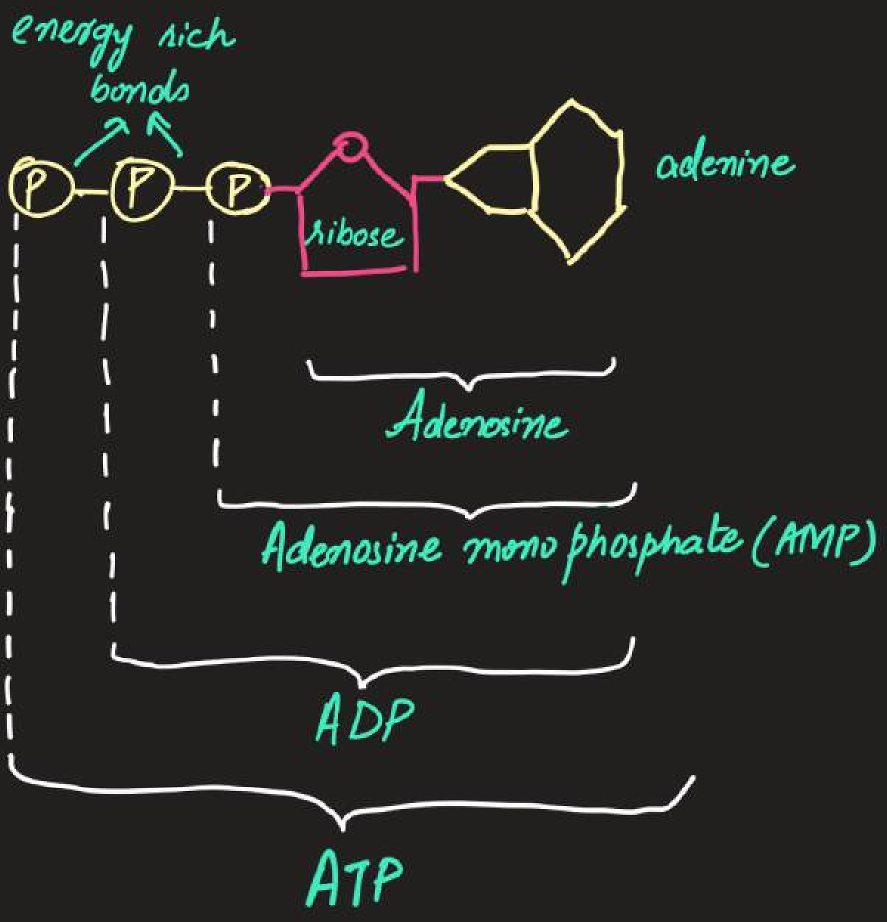
- Weightage : 38.5%

PAPER 5 → Planning, analysis & evaluation

- Duration : 1 hr 15 mins
- Marks : 30
- Weightage : 11.5%

RESPIRATION

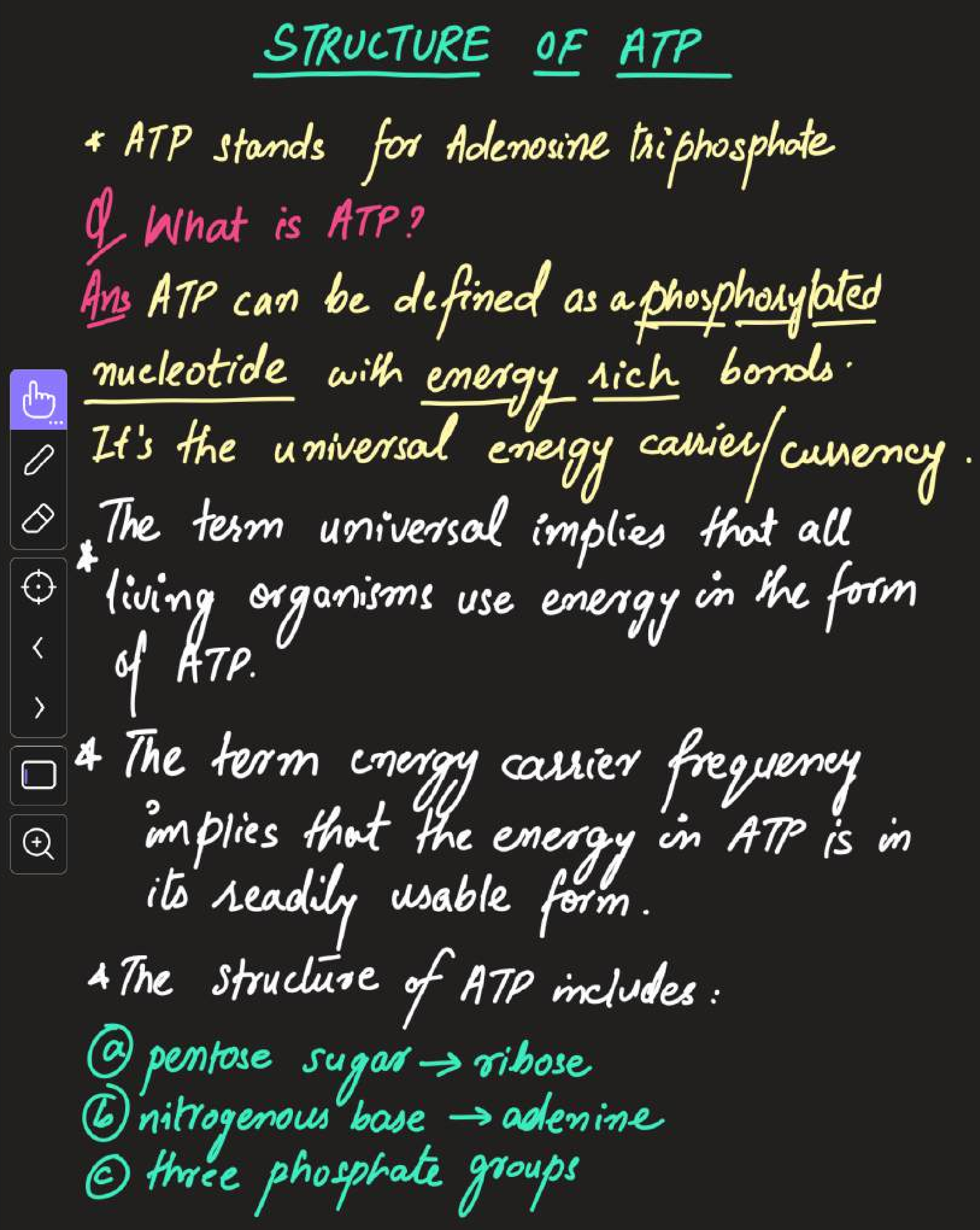
* Structure of ATP



* Adenosine = adenine + ribose

* AMP → nucleotide

* ADP & ATP have extra phosphates attached with energy rich bonds and thus, are termed as **phosphorylated nucleotides**.



STRUCTURE OF ATP

- ATP stands for Adenosine triphosphate

Q What is ATP?

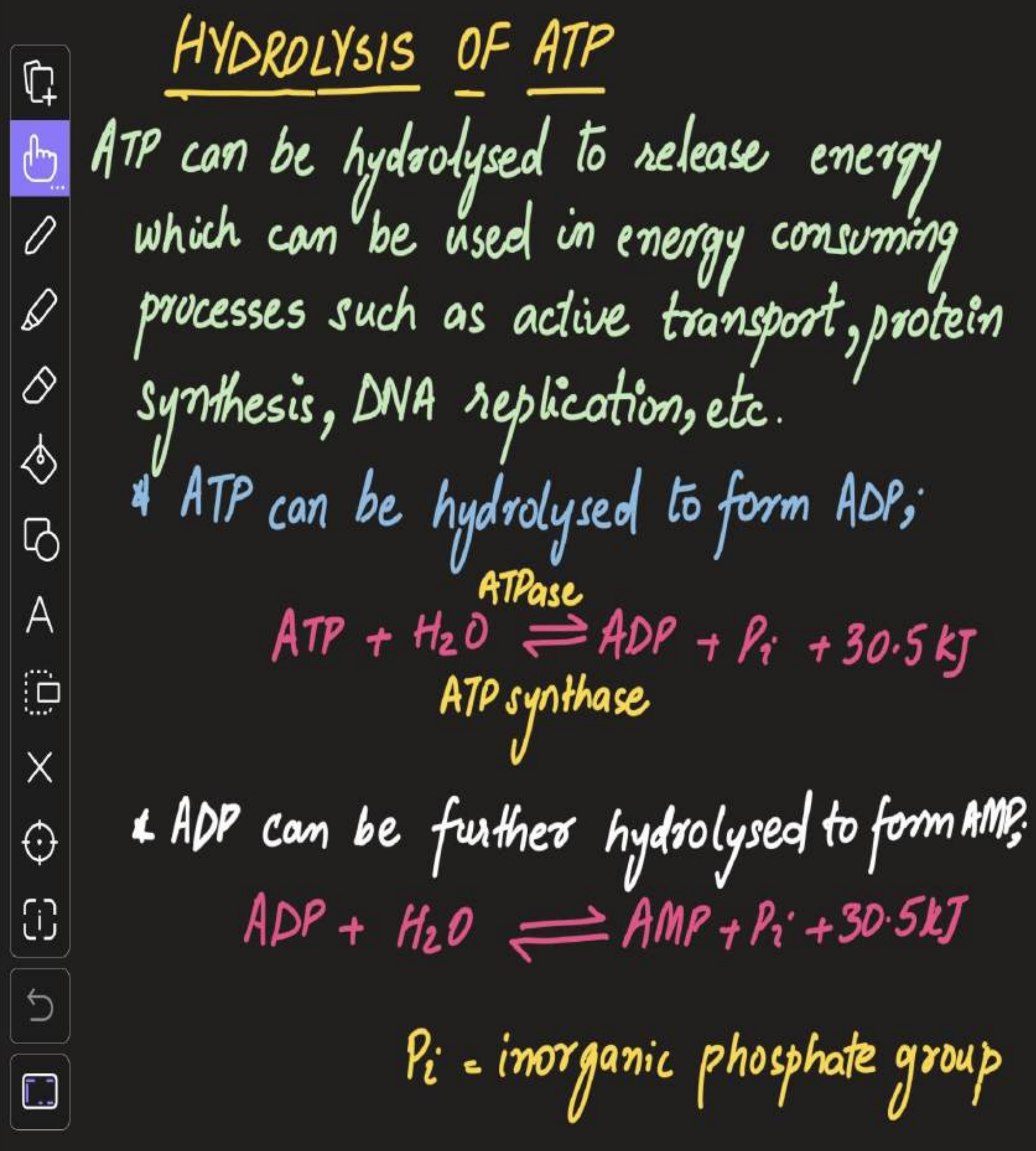
Ans ATP can be defined as a phosphorylated nucleotide with energy rich bonds. It's the universal energy carrier/currency.

- The term universal implies that all living organisms use energy in the form of ATP.

- The term energy carrier frequency implies that the energy in ATP is in its readily usable form.

- The structure of ATP includes:

ⓐ pentose sugar → ribose
ⓑ nitrogenous base → adenine
ⓒ three phosphate groups



HYDROLYSIS OF ATP

ATP can be hydrolysed to release energy which can be used in energy consuming processes such as active transport, protein synthesis, DNA replication, etc.

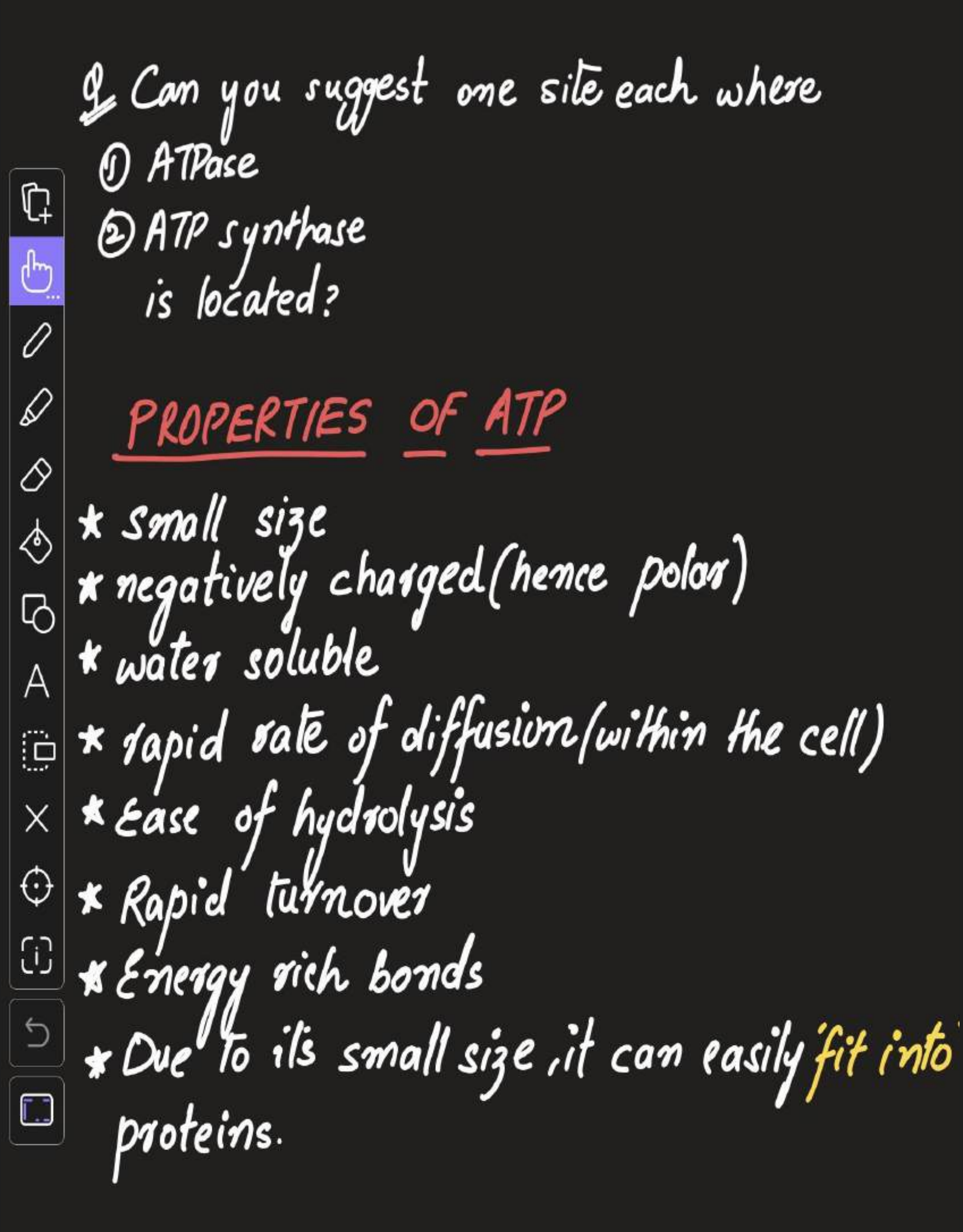
- ATP can be hydrolysed to form ADP;

$$ATP + H_2O \underset{\text{ATP synthase}}{\overset{\text{ATPase}}{\rightleftharpoons}} ADP + P_i + 30.5\,kJ$$

- ADP can be further hydrolysed to form AMP;

$$ADP + H_2O \rightleftharpoons AMP + P_i + 30.5\,kJ$$

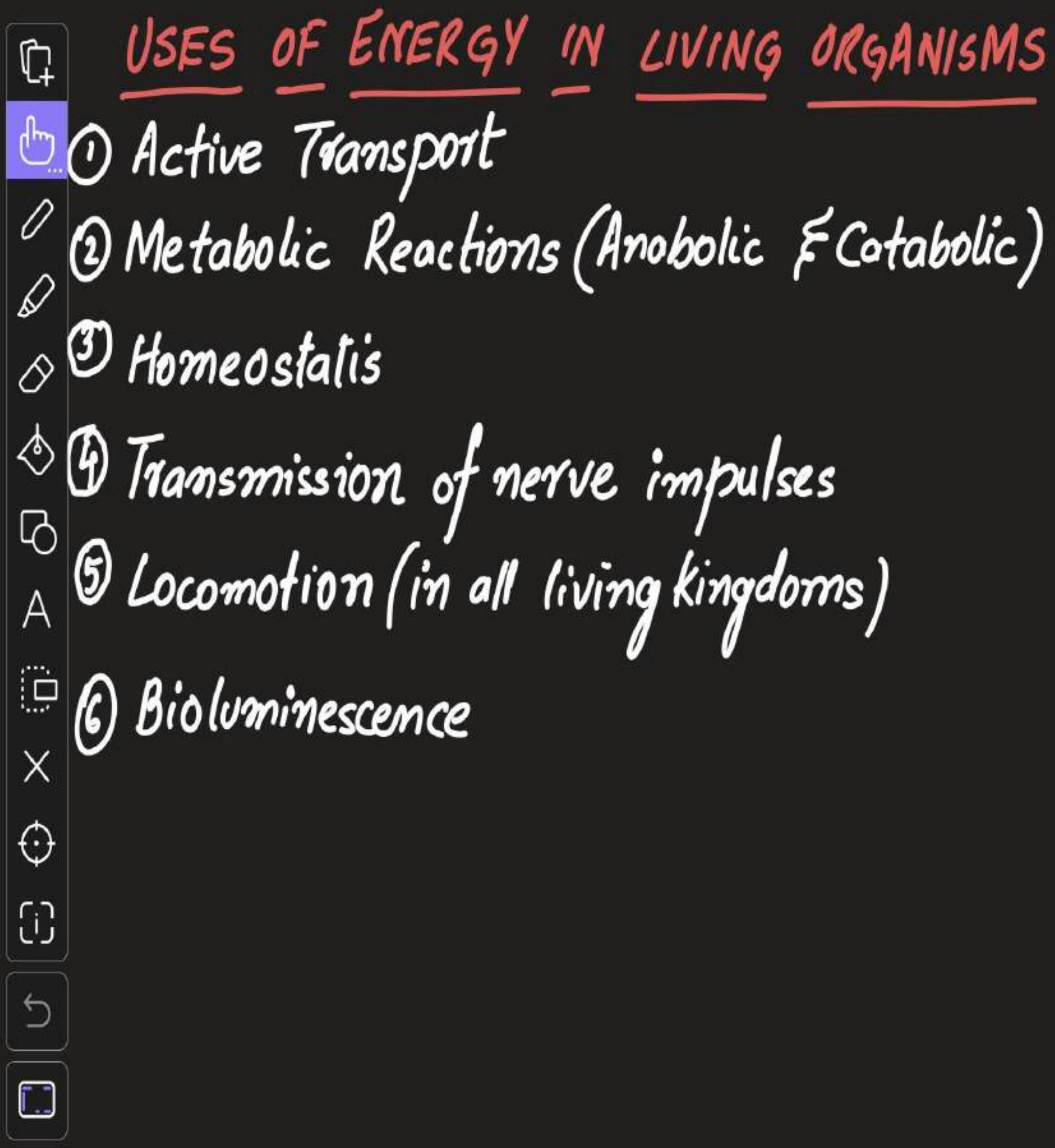
P_i = inorganic phosphate group



Q Can you suggest one site each where
① ATPase
② ATP synthase
is located?

PROPERTIES OF ATP

- small size
- negatively charged (hence polar)
- water soluble
- rapid rate of diffusion (within the cell)
- Ease of hydrolysis
- Rapid turnover
- Energy rich bonds
- Due to its small size, it can easily fit into proteins.



USES OF ENERGY IN LIVING ORGANISMS

① Active Transport

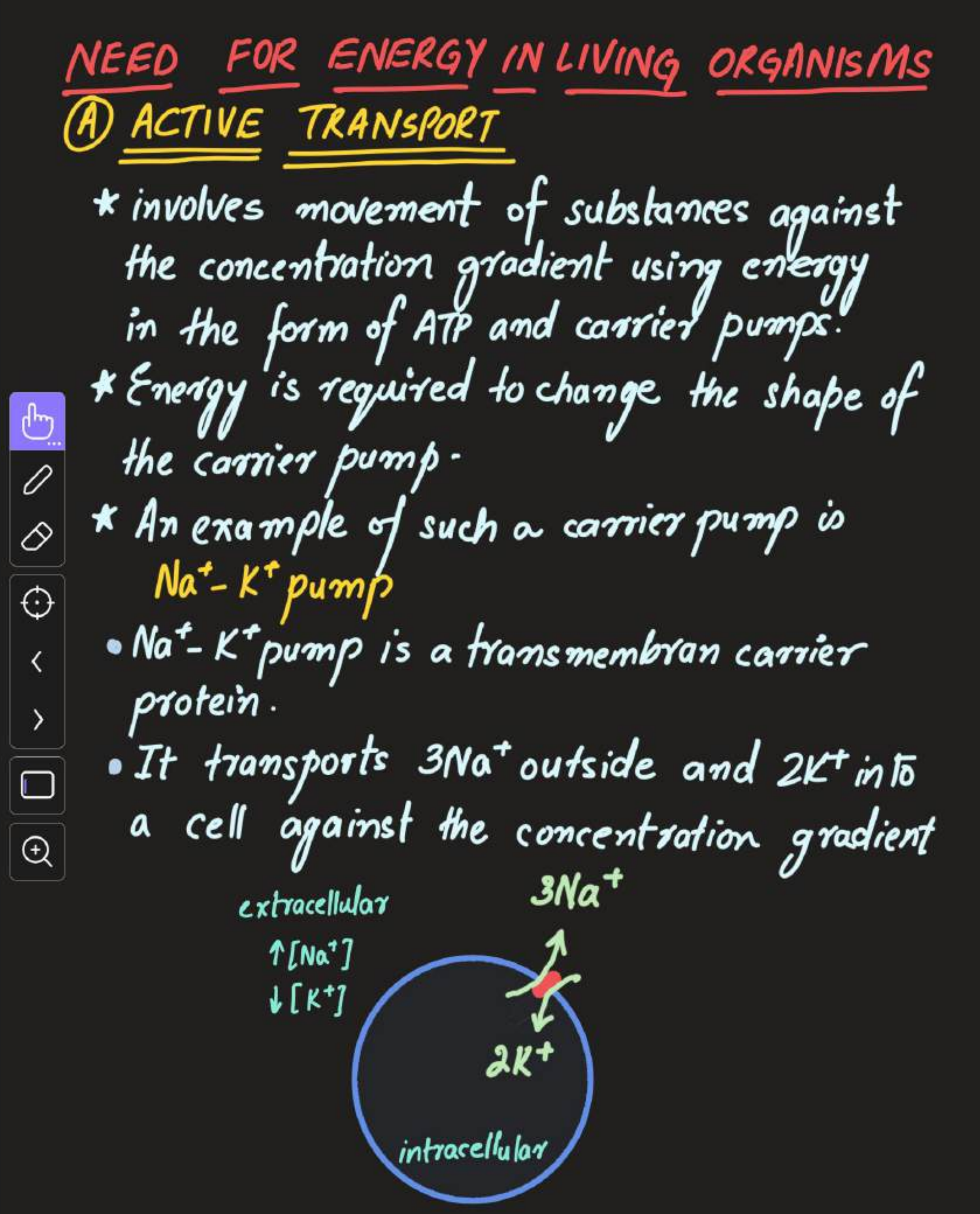
② Metabolic Reactions (Anobolic & Cotabolic)

③ Homeostatis

④ Transmission of nerve impulses

⑤ Locomotion (in all living kingdoms)

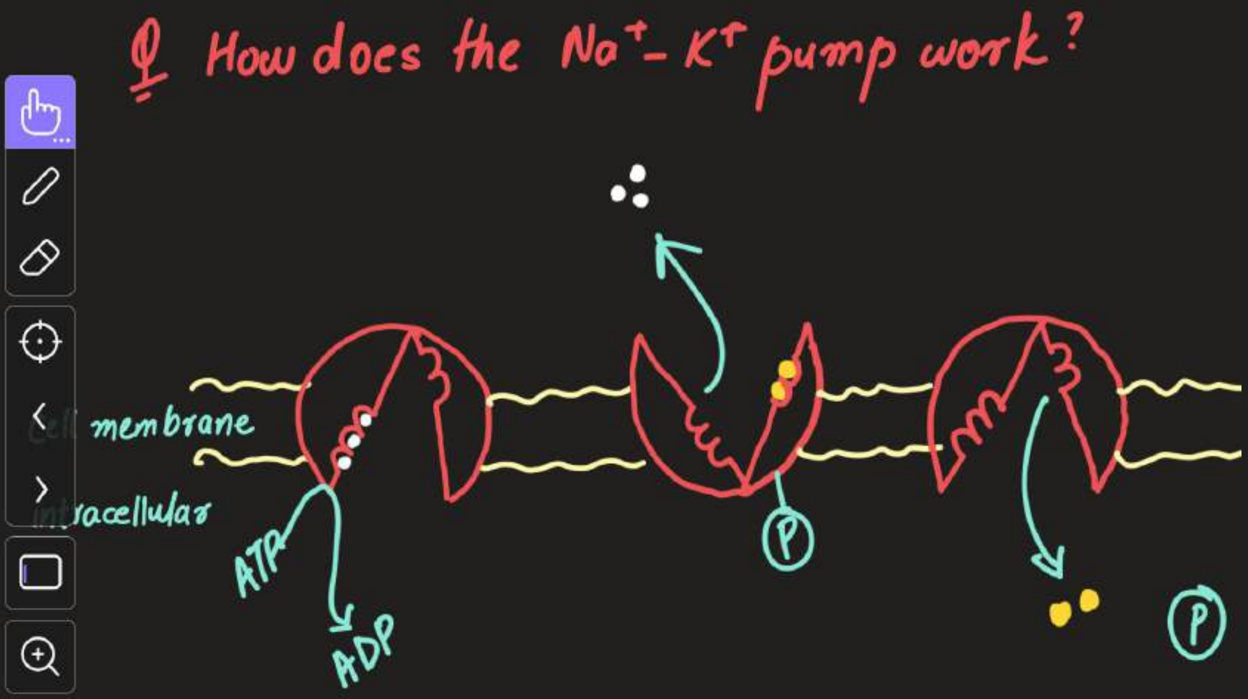
⑥ Bioluminescence



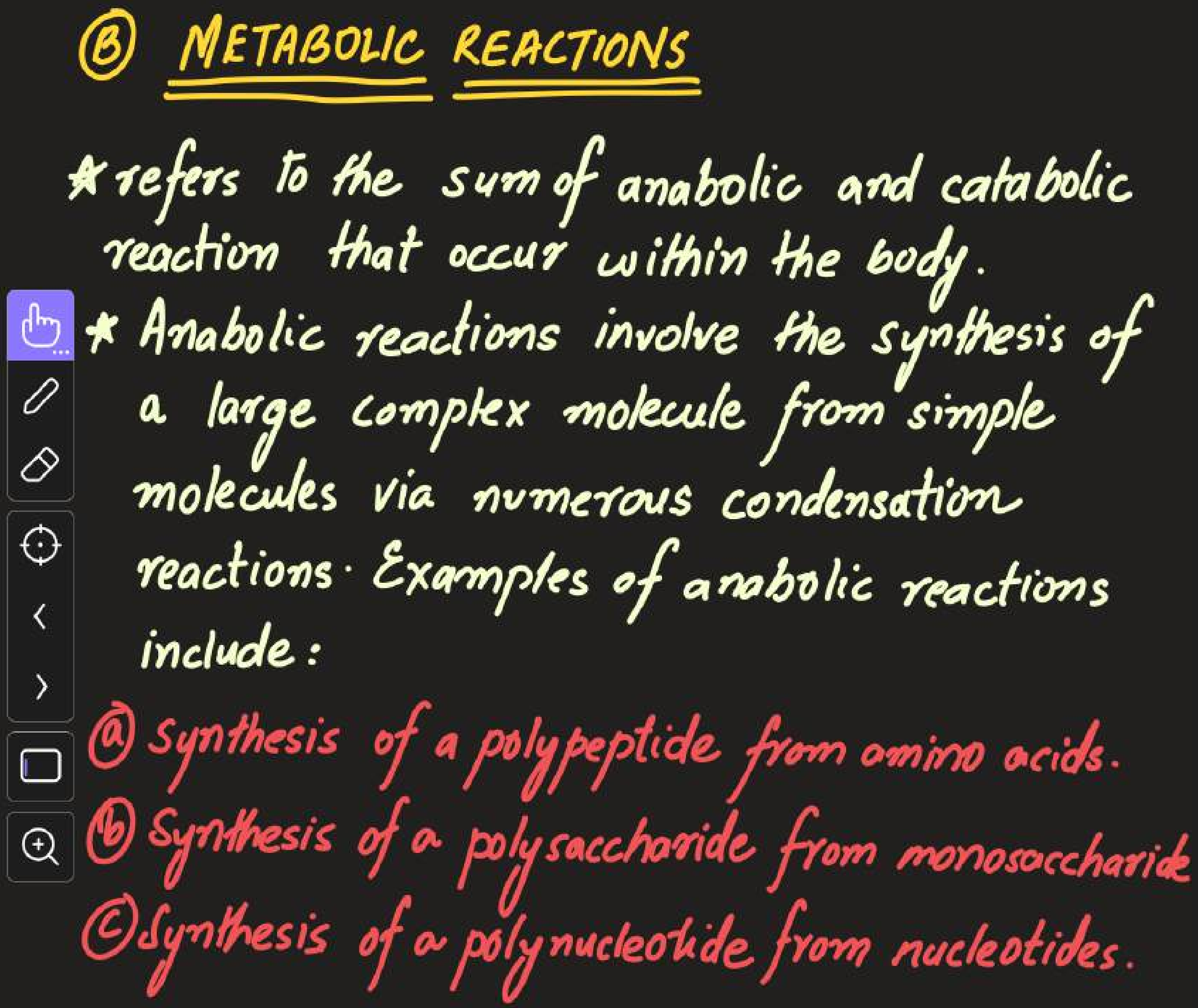
NEED FOR ENERGY IN LIVING ORGANISMS

(A) ACTIVE TRANSPORT

- ★ involves movement of substances against the concentration gradient using energy in the form of ATP and carrier pumps.
- ★ Energy is required to change the shape of the carrier pump.
- ★ An example of such a carrier pump is Na^+-K^+ pump
  - Na^+-K^+ pump is a transmembran carrier protein.
  - It transports $3Na^+$ outside and $2K^+$ into a cell against the concentration gradient



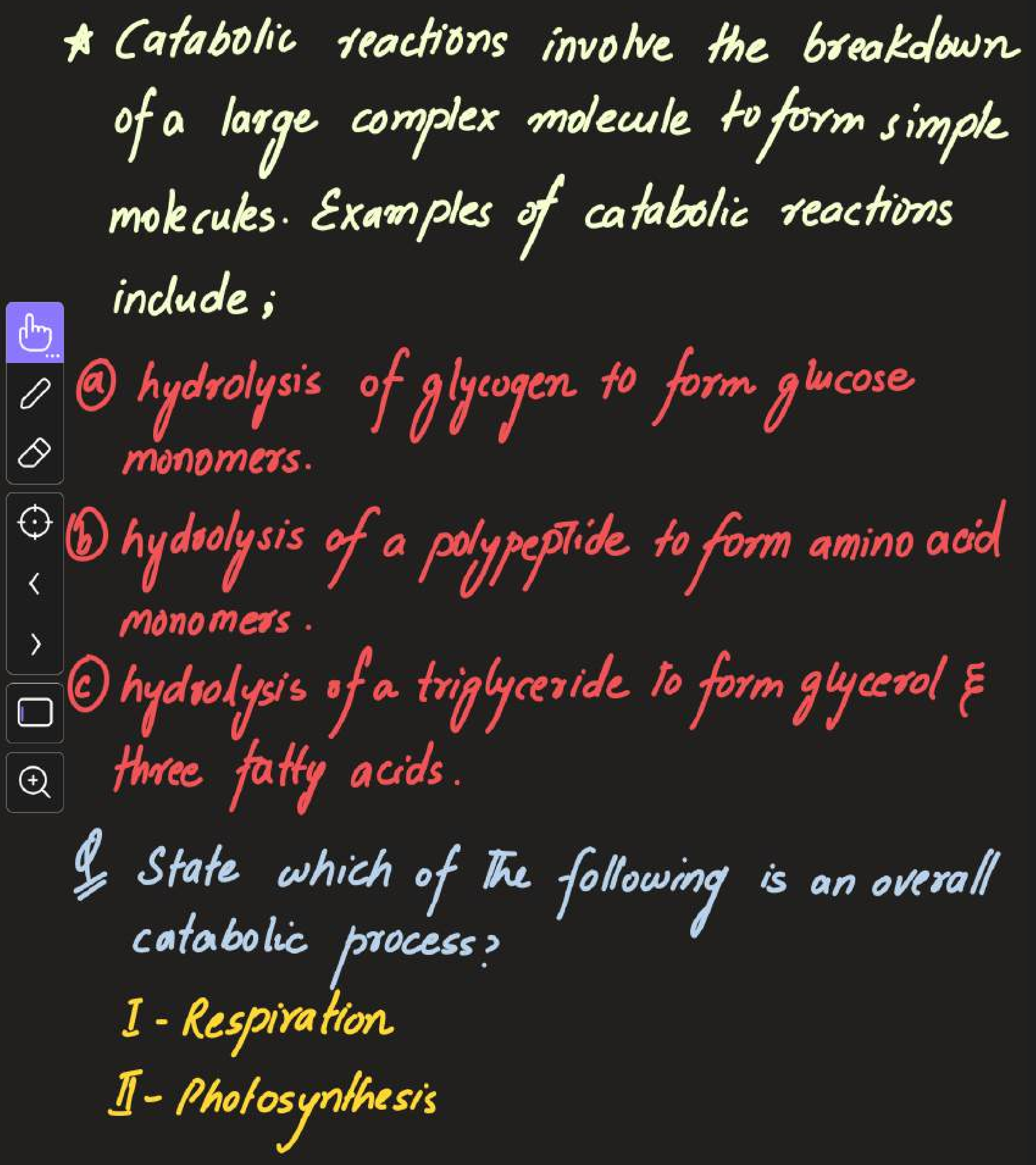
Q How does the Na^+-K^+ pump work?



Ⓑ METABOLIC REACTIONS

- ★ refers to the sum of anabolic and catabolic reaction that occur within the body.
- ★ Anabolic reactions involve the synthesis of a large complex molecule from simple molecules via numerous condensation reactions. Examples of anabolic reactions include:

ⓐ Synthesis of a polypeptide from amino acids.
ⓑ Synthesis of a polysaccharide from monosaccharide
ⓒ Synthesis of a polynucleotide from nucleotides.



★ Catabolic reactions involve the breakdown of a large complex molecule to form simple molecules. Examples of catabolic reactions include;

ⓐ hydrolysis of glycogen to form glucose monomers.

ⓑ hydrolysis of a polypeptide to form amino acid monomers.

ⓒ hydrolysis of a triglyceride to form glycerol & three fatty acids.

Q State which of the following is an overall catabolic process?

I - Respiration

II - Photosynthesis

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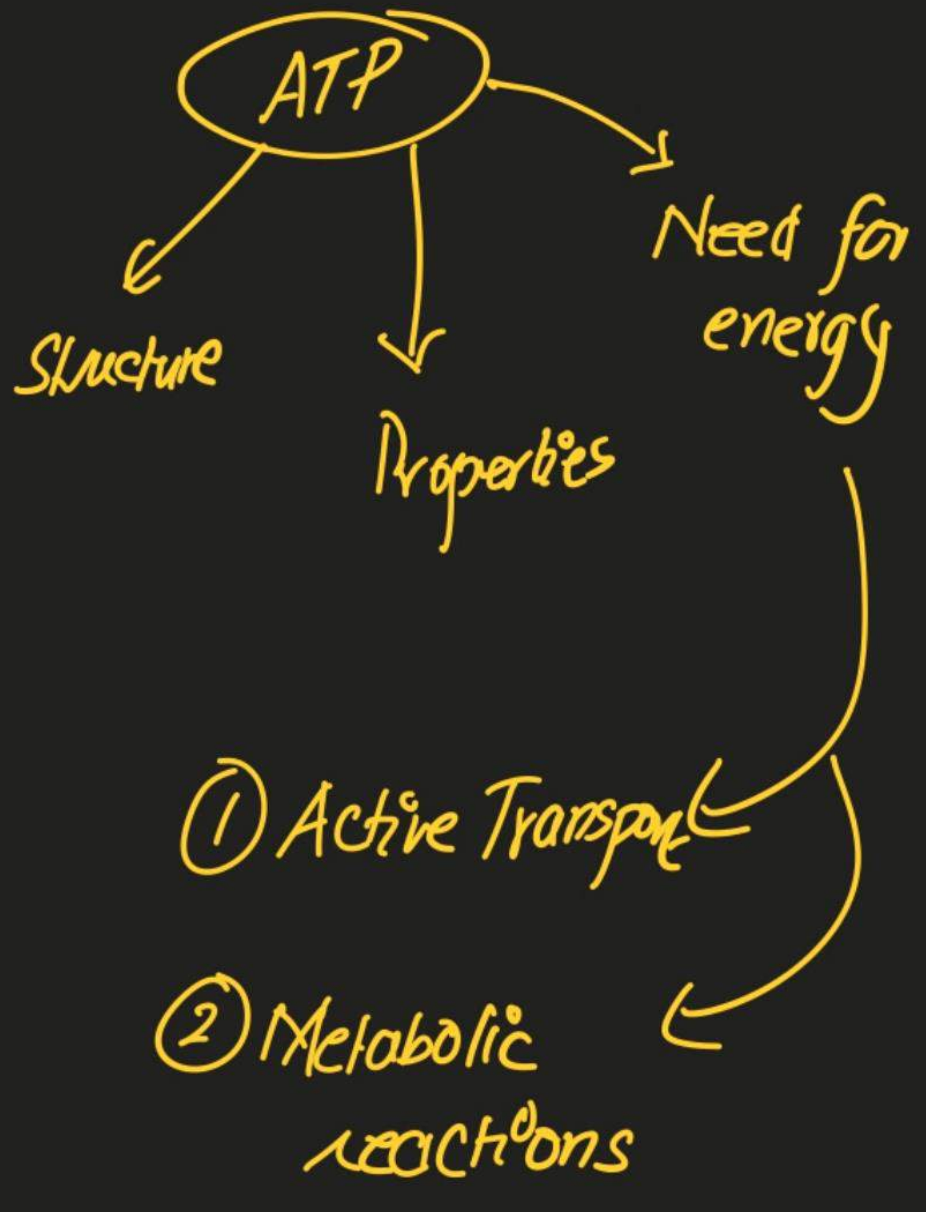
Energy & Respiration



With

Mohammad Hussham Arshad, MD

ADVANCED LEVEL BIOLOGY 9700

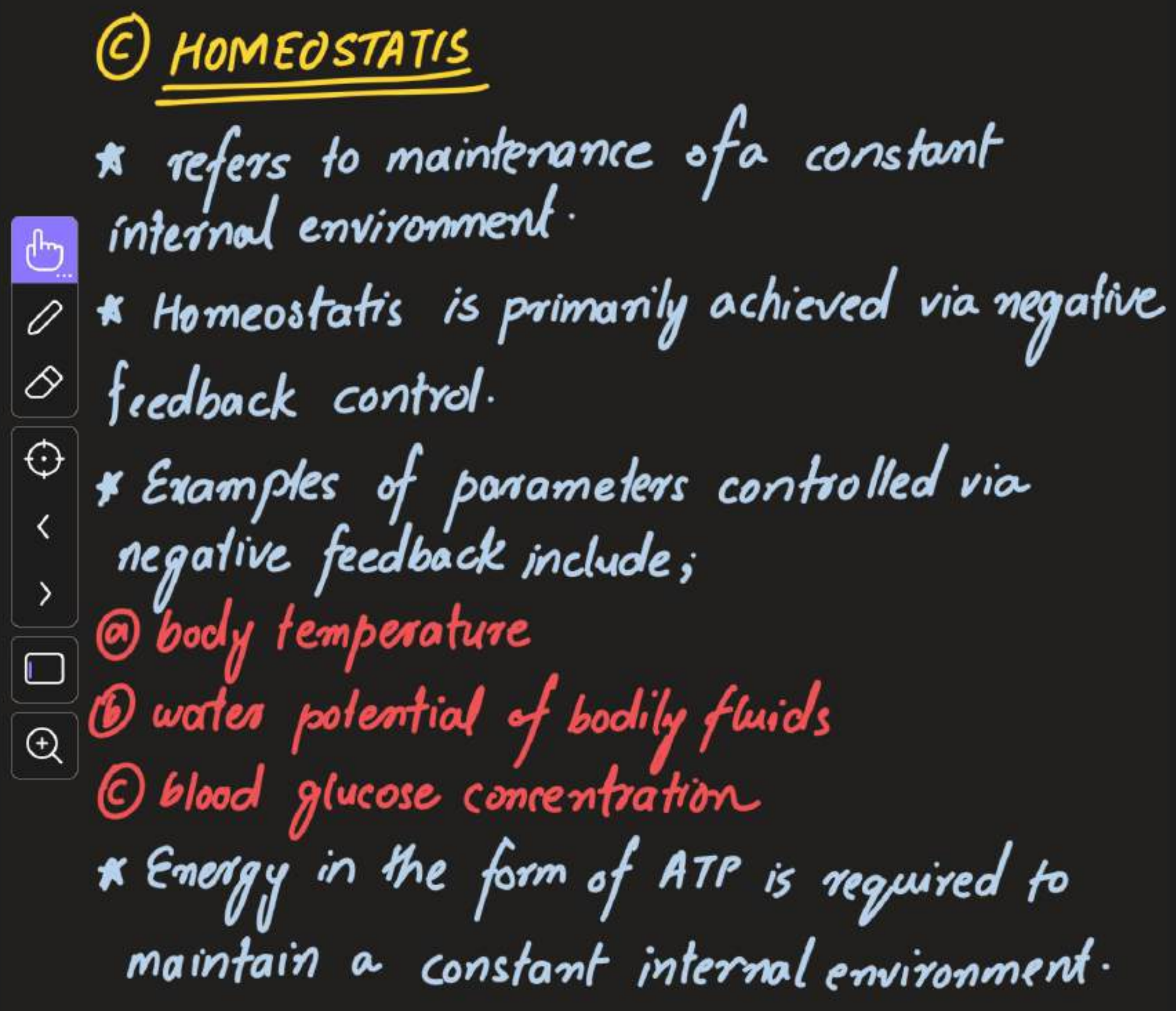
UNIT 12: ENERGY AND RESPIRATION

Learning Objectives:

- Overview of Respiration
- Need of Energy

Video Lecture 2 Slides

Mohammad Hussham Arshad, MD
Biology Department



ⓒ HOMEOSTATIS

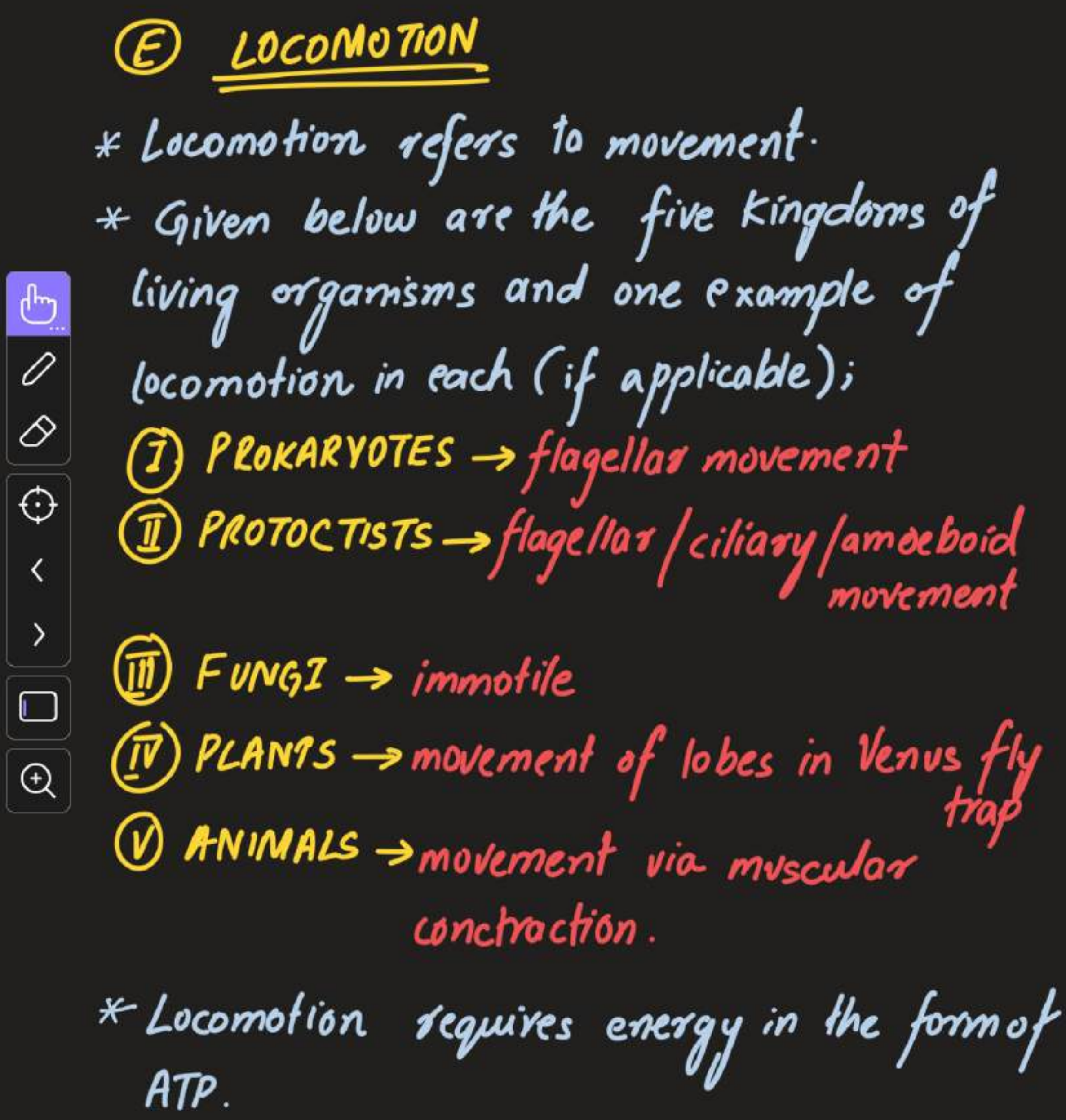
- refers to maintenance of a constant internal environment.
- Homeostatis is primarily achieved via negative feedback control.
- Examples of parameters controlled via negative feedback include;

ⓐ body temperature
ⓑ water potential of bodily fluids
ⓒ blood glucose concentration

- Energy in the form of ATP is required to maintain a constant internal environment.

Ⓓ TRANSMISSION OF NERVE IMPULSES

- Transmission of nerve impulses is via electrical means along the neurone and via chemical means between the neuron
- Energy is required in the form of ATP to enable electrical impulses to travel along and between the neurones



Ⓔ LOCOMOTION

* Locomotion refers to movement.

* Given below are the five kingdoms of living organisms and one example of locomotion in each (if applicable);

(I) PROKARYOTES → flagellar movement

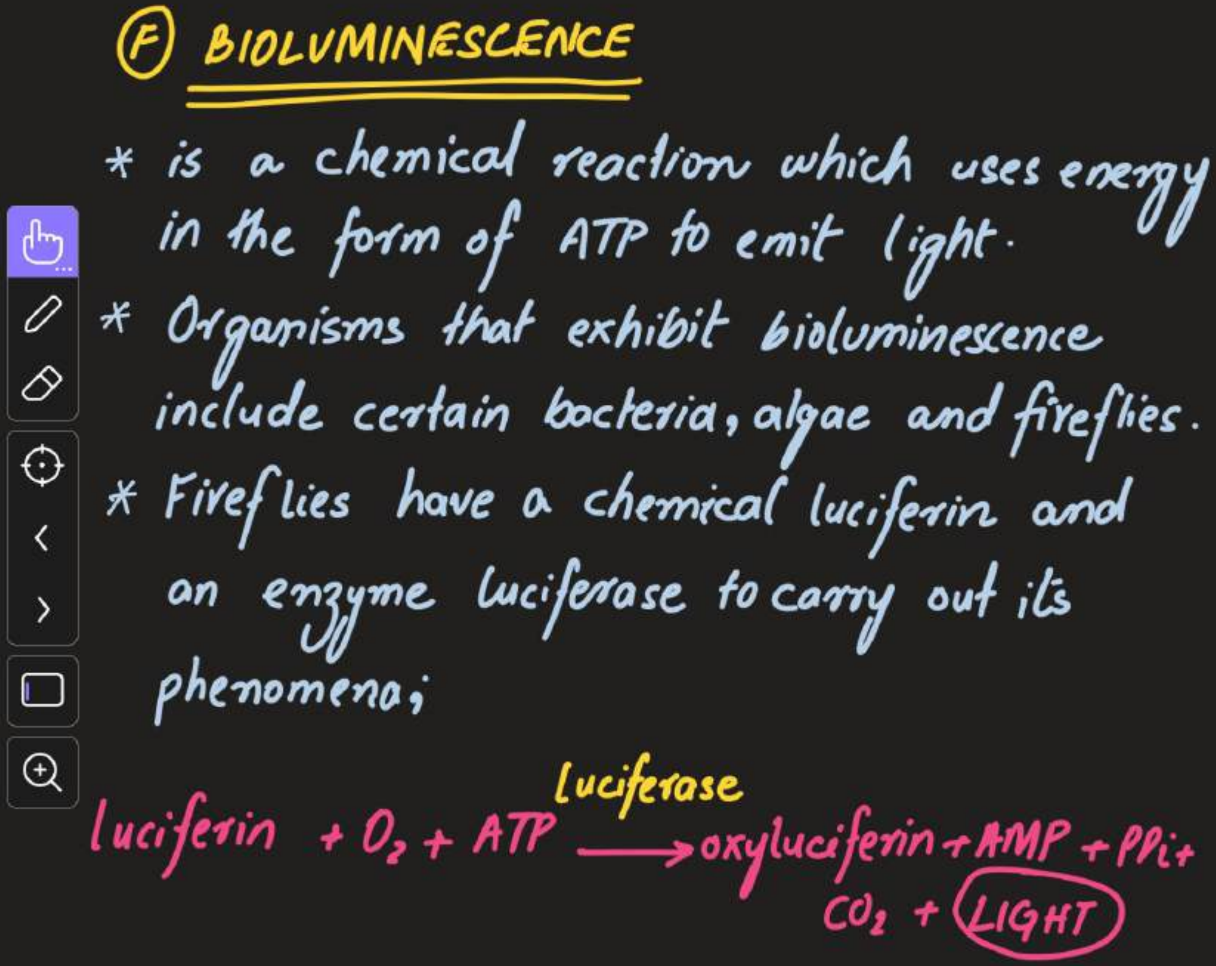
(II) PROTOCTISTS → flagellar / ciliary / amoeboid movement

(III) FUNGI → immotile

(IV) PLANTS → movement of lobes in Venus fly trap

(V) ANIMALS → movement via muscular contraction.

* Locomotion requires energy in the form of ATP.



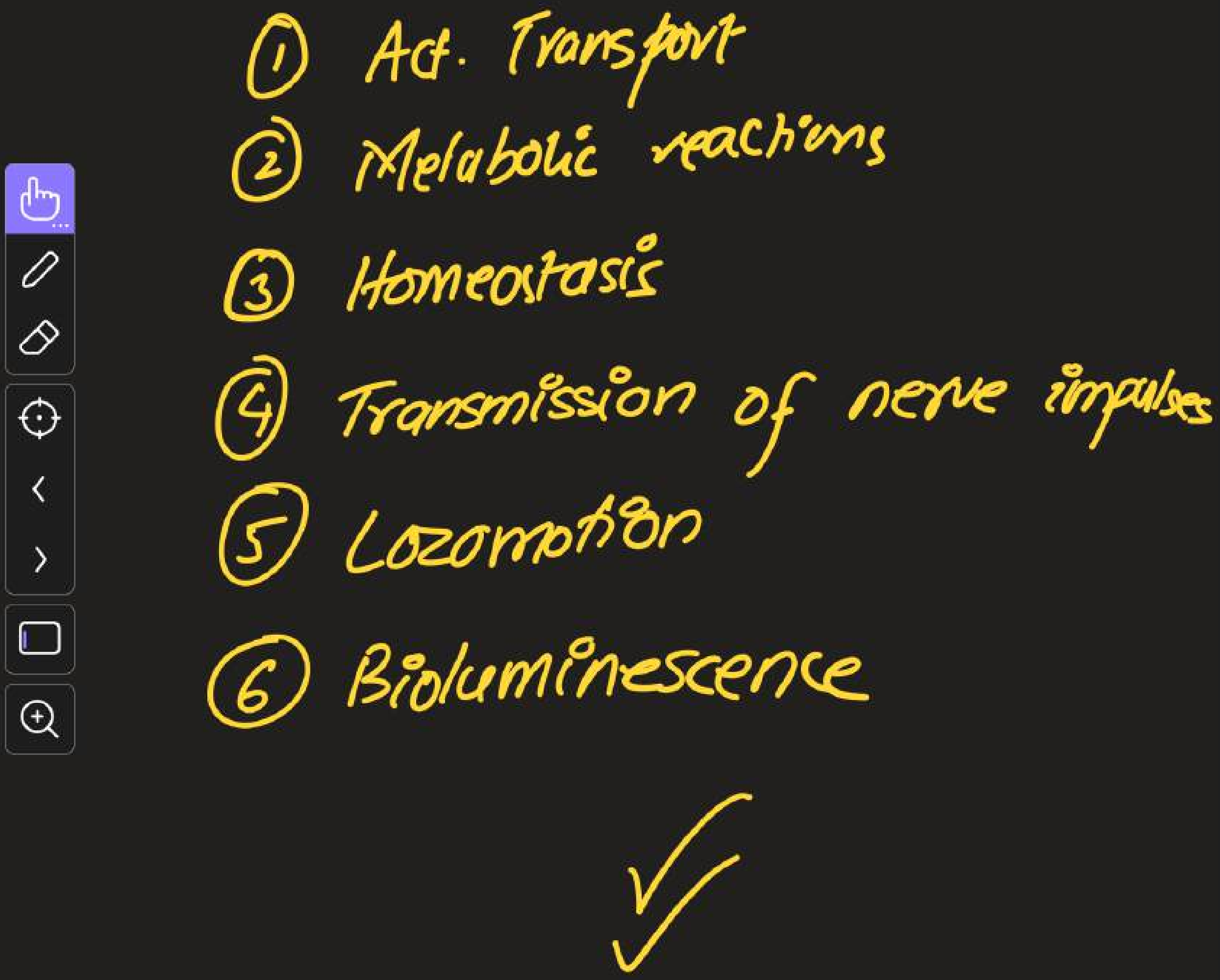
Ⓕ BIOLUMINESCENCE

* is a chemical reaction which uses energy in the form of ATP to emit light.

* Organisms that exhibit bioluminescence include certain bacteria, algae and fireflies.

* Fireflies have a chemical luciferin and an enzyme luciferase to carry out it's phenomena;

$$\text{luciferin} + O_2 + \text{ATP} \xrightarrow{\text{Luciferase}} \text{oxyluciferin} + \text{AMP} + \text{PPi} + CO_2 + \boxed{\text{LIGHT}}$$



① Act. Transport

② Metabolic reactions

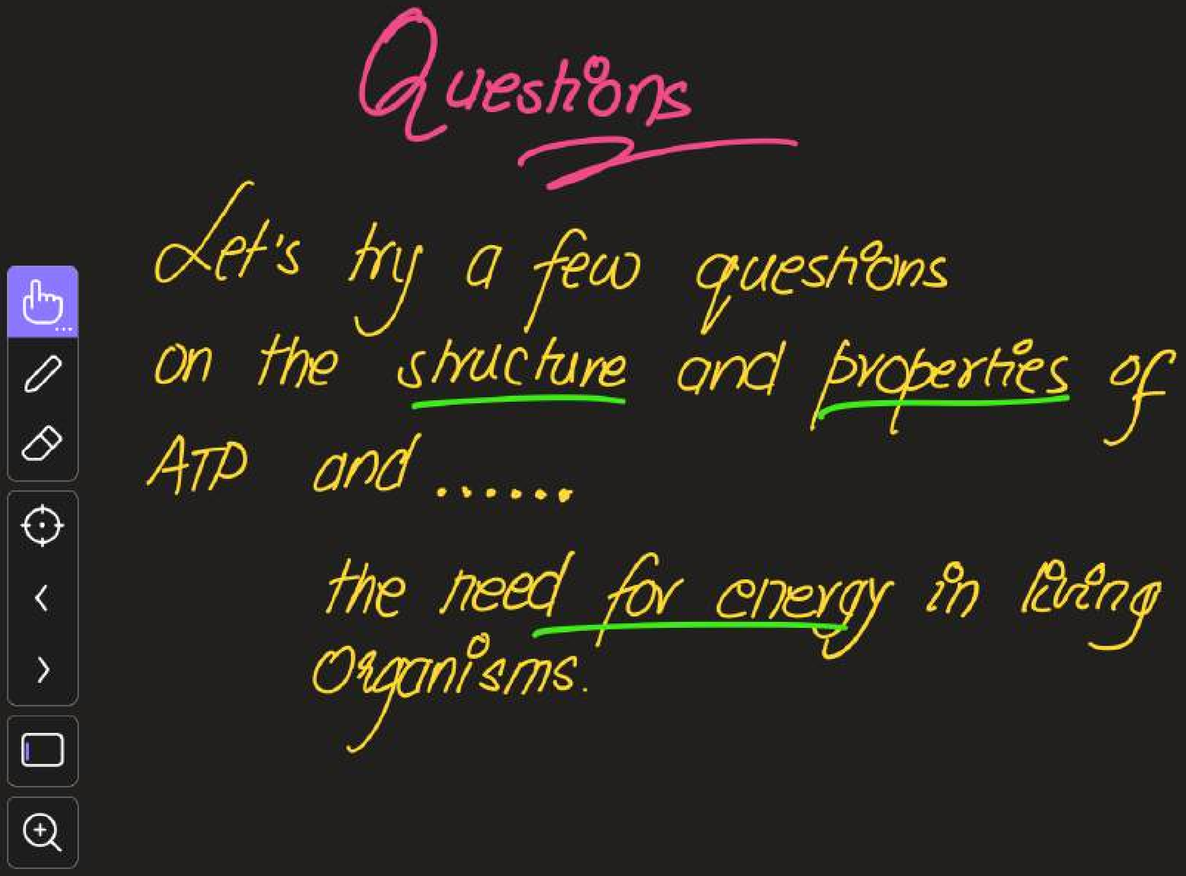
③ Homeostasis

④ Transmission of nerve impulses

⑤ Lozomotion

⑥ Bioluminescence

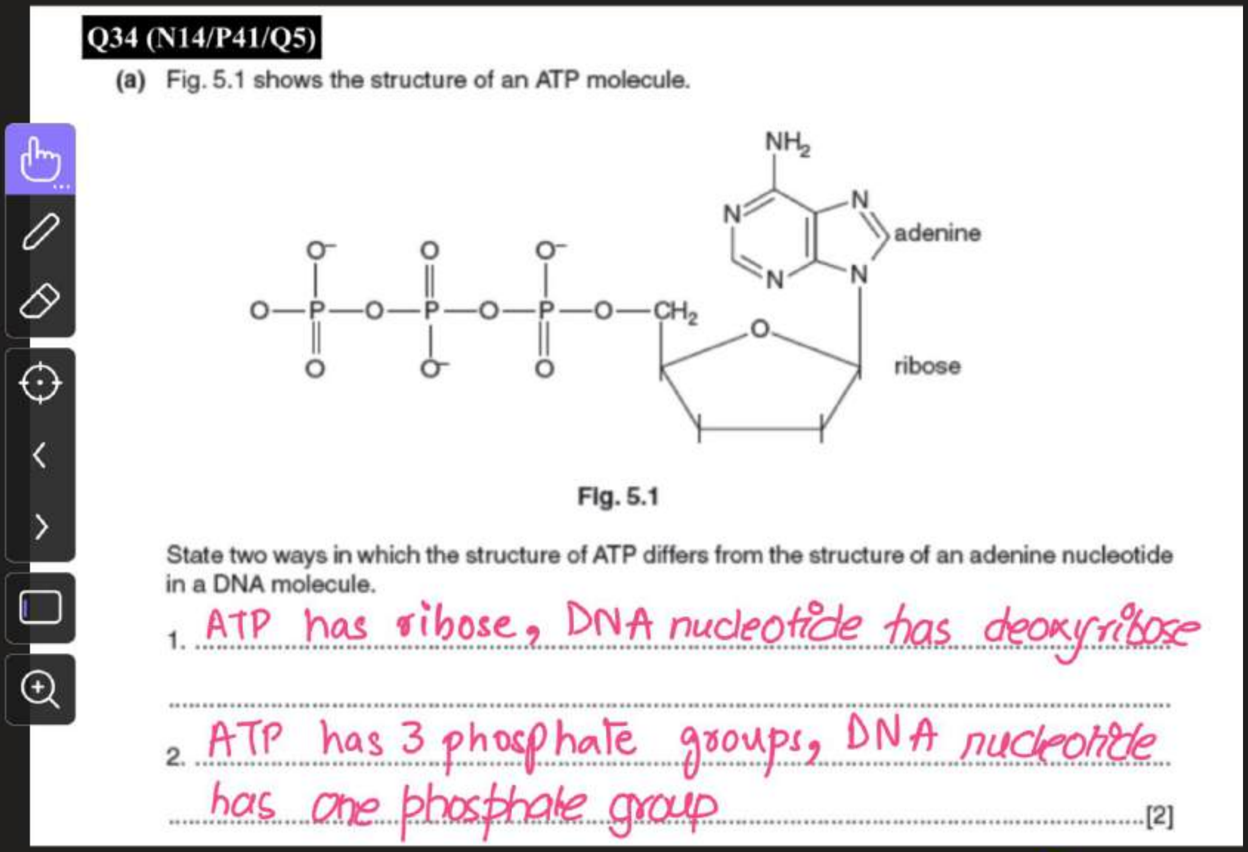
✓



Questions

Let's try a few questions on the structure and properties of ATP and ......

the need for energy in living organisms.



Q34 (N14/P41/Q5)

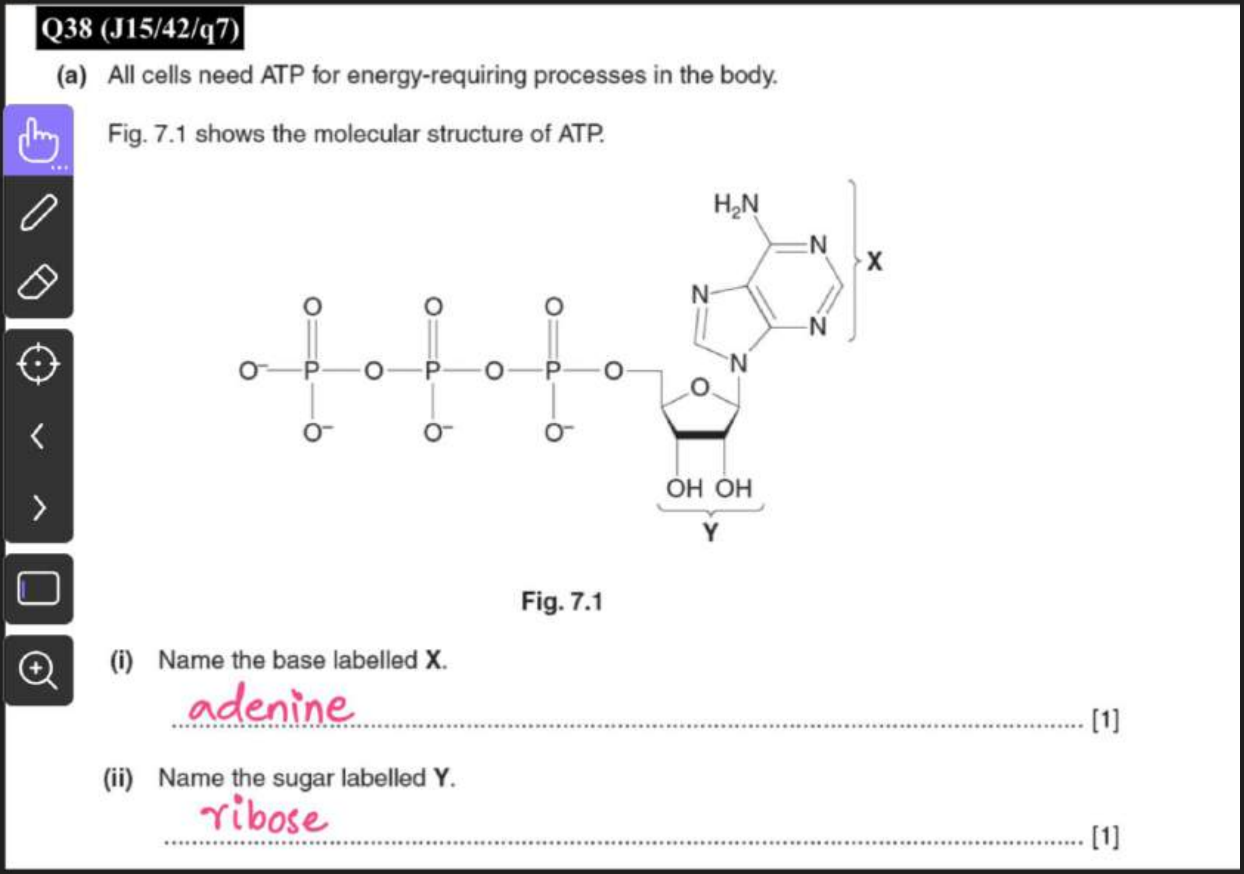
(a) Fig. 5.1 shows the structure of an ATP molecule.

Fig. 5.1

State two ways in which the structure of ATP differs from the structure of an adenine nucleotide in a DNA molecule.

1. ATP has ribose, DNA nucleotide has deoxyribose

2. ATP has 3 phosphate groups, DNA nucleotide has one phosphate group [2]



Q38 (J15/42/q7)

(a) All cells need ATP for energy-requiring processes in the body.

Fig. 7.1 shows the molecular structure of ATP.

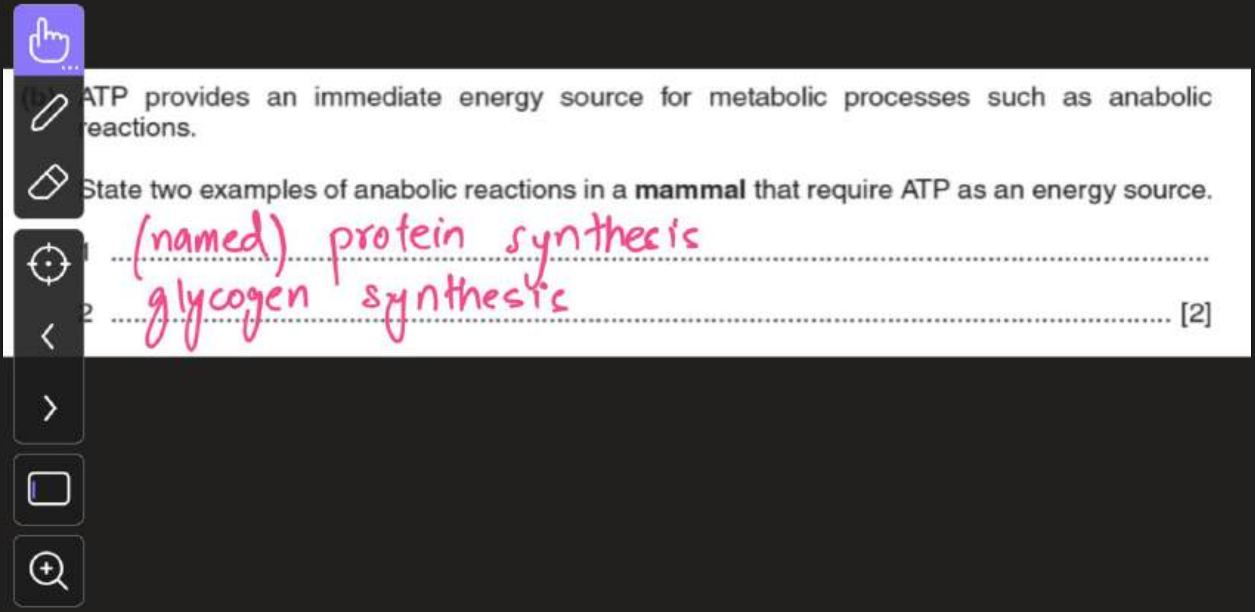
Fig. 7.1

(i) Name the base labelled **X**.

adenine .... [1]

(ii) Name the sugar labelled **Y**.

ribose .... [1]

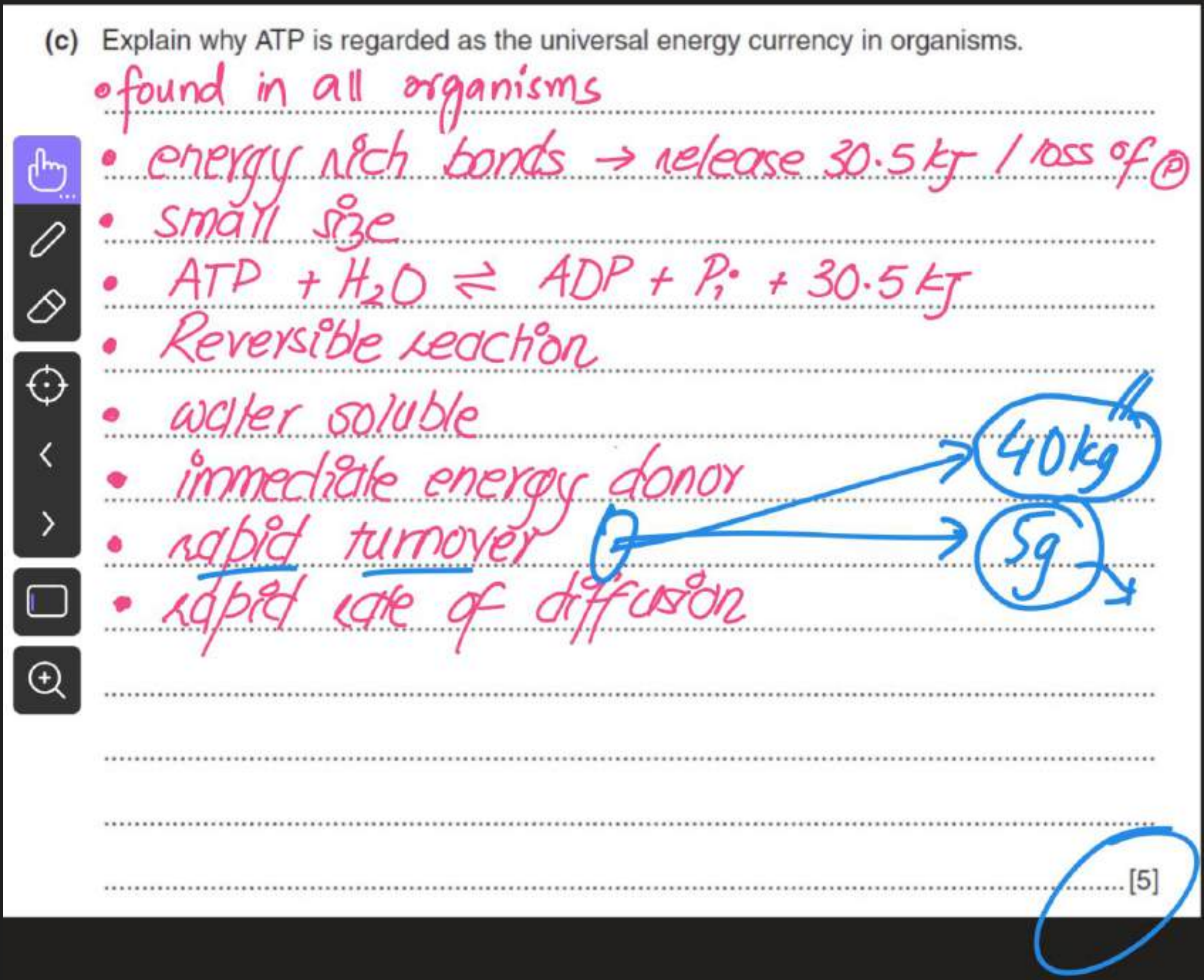


(b) ATP provides an immediate energy source for metabolic processes such as anabolic reactions.

State two examples of anabolic reactions in a **mammal** that require ATP as an energy source.

1 (named) protein synthesis

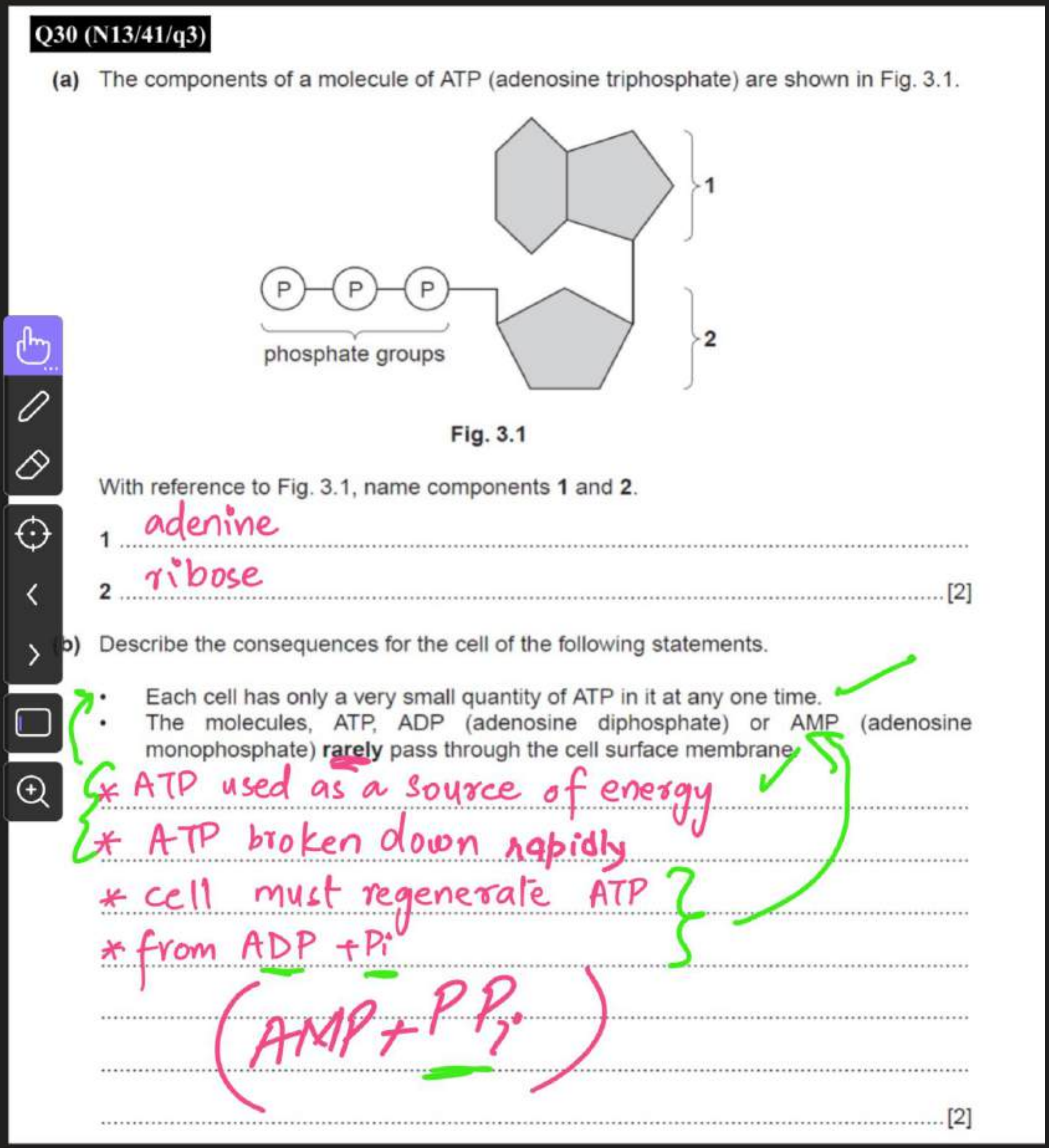
2 glycogen synthesis [2]



(c) Explain why ATP is regarded as the universal energy currency in organisms.

- found in all organisms
- energy rich bonds → release 30.5 kJ / loss of Ⓟ
- small size
- $ATP + H_2O \rightleftharpoons ADP + P_i + 30.5\ kJ$
- Reversible reaction
- water soluble
- immediate energy donor
- rapid turnover
- rapid rate of diffusion

[5]



Q30 (N13/41/q3)

(a) The components of a molecule of ATP (adenosine triphosphate) are shown in Fig. 3.1.

Fig. 3.1

With reference to Fig. 3.1, name components **1** and **2**.

1 adenine

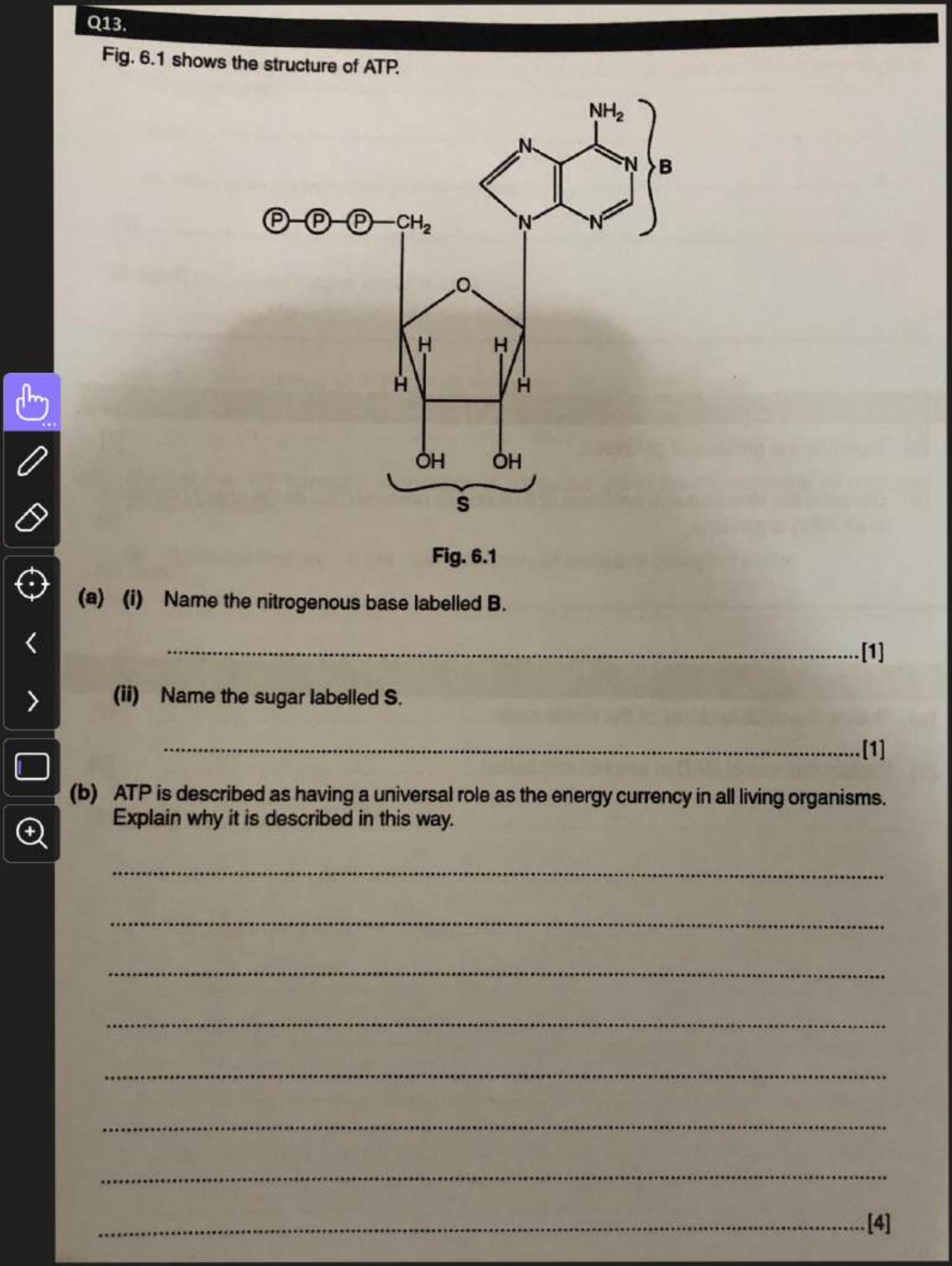
2 ribose [2]

(b) Describe the consequences for the cell of the following statements.

- Each cell has only a very small quantity of ATP in it at any one time.
- The molecules, ATP, ADP (adenosine diphosphate) or AMP (adenosine monophosphate) **rarely** pass through the cell surface membrane.

* ATP used as a source of energy
* ATP broken down rapidly
* cell must regenerate ATP
* from ADP + Pi
(AMP + PPi)

[2]



Q13.

Fig. 6.1 shows the structure of ATP.

Fig. 6.1

(a) **(i)** Name the nitrogenous base labelled **B**.

....[1]

(ii) Name the sugar labelled **S**.

....[1]

(b) ATP is described as having a universal role as the energy currency in all living organisms. Explain why it is described in this way.

....

....

....

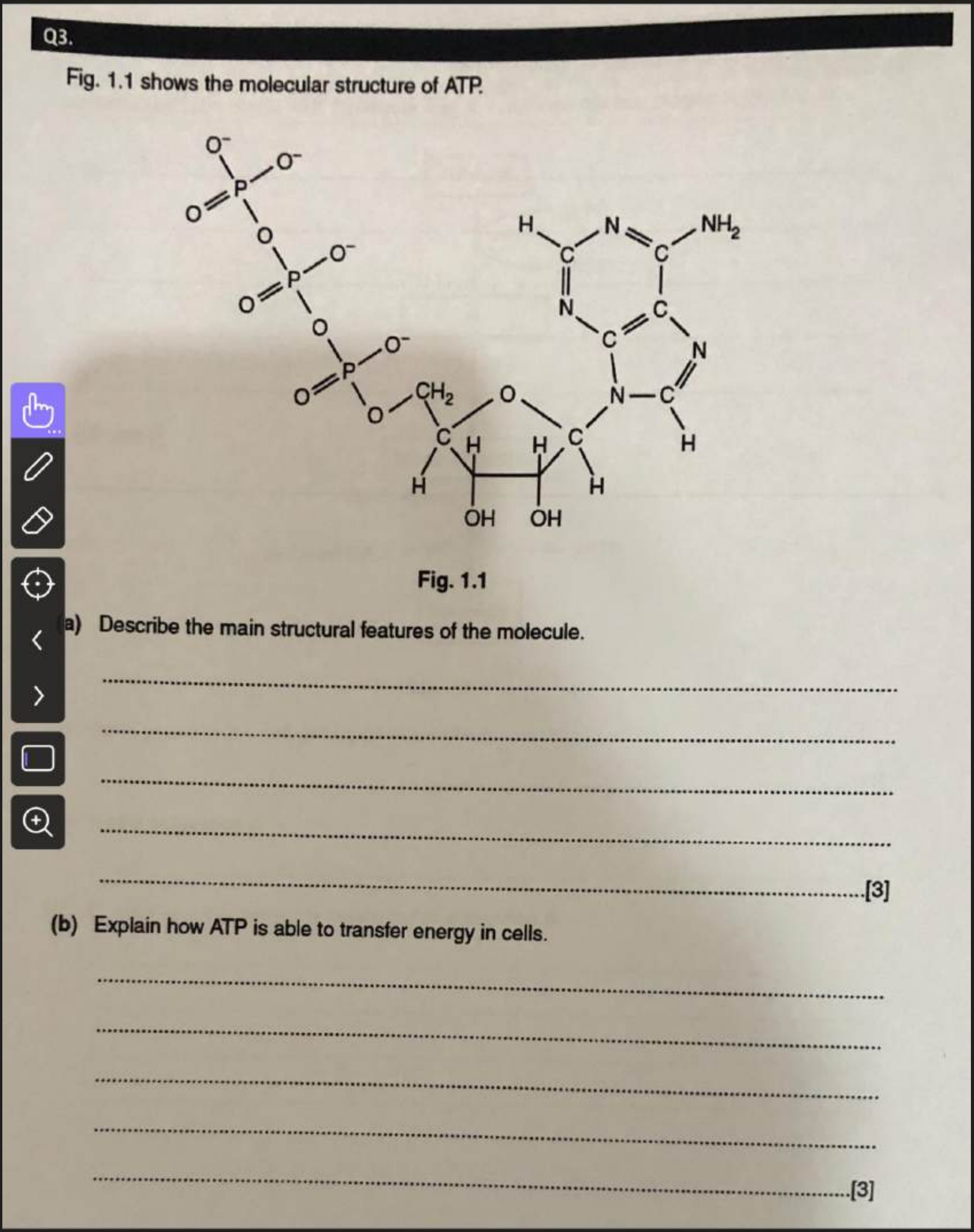
....

....

....

....

....[4]



Q3.

Fig. 1.1 shows the molecular structure of ATP.

Fig. 1.1

a) Describe the main structural features of the molecule.

....

....

....

....

.... [3]

(b) Explain how ATP is able to transfer energy in cells.

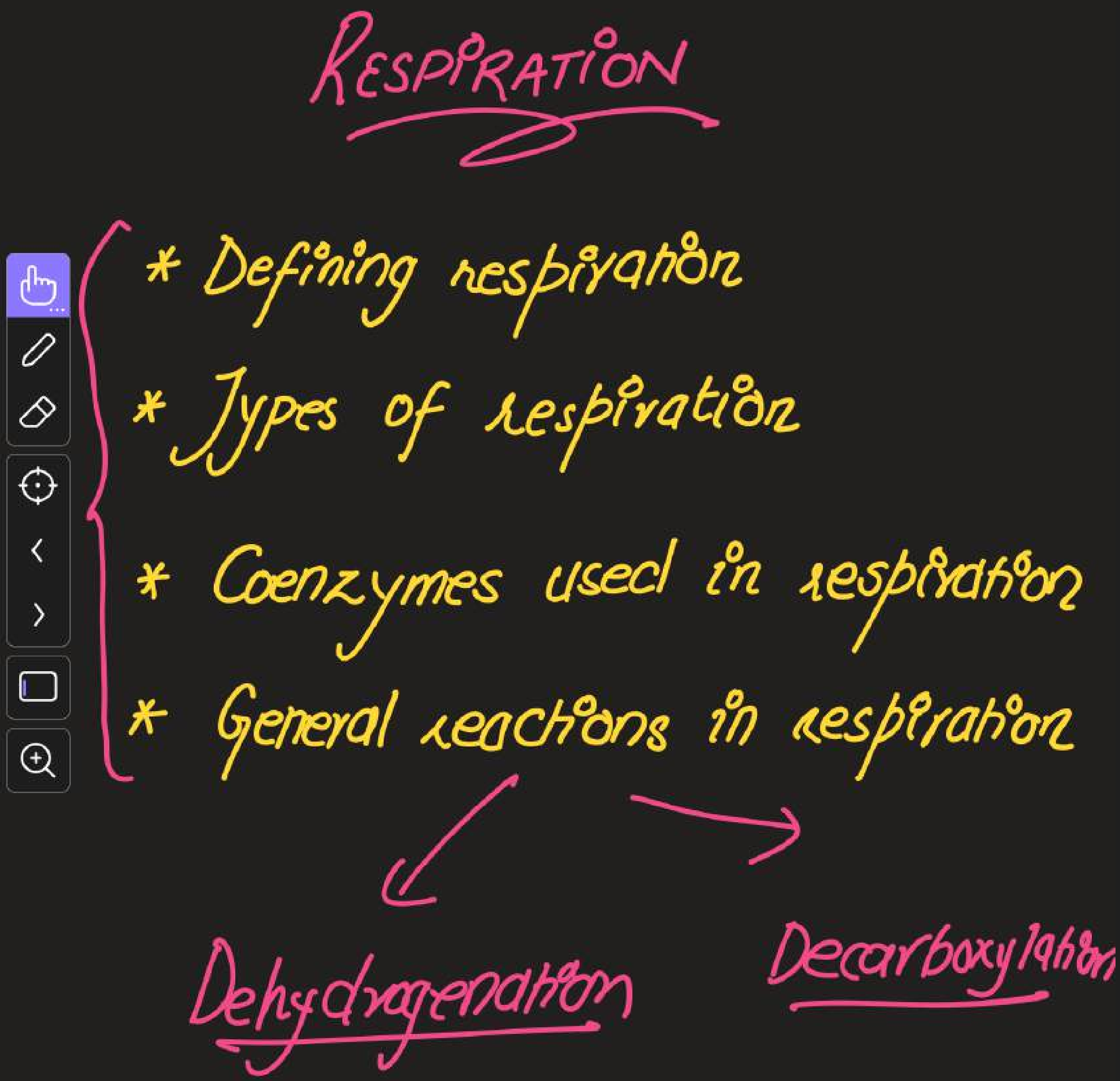
....

....

....

....

.... [3]

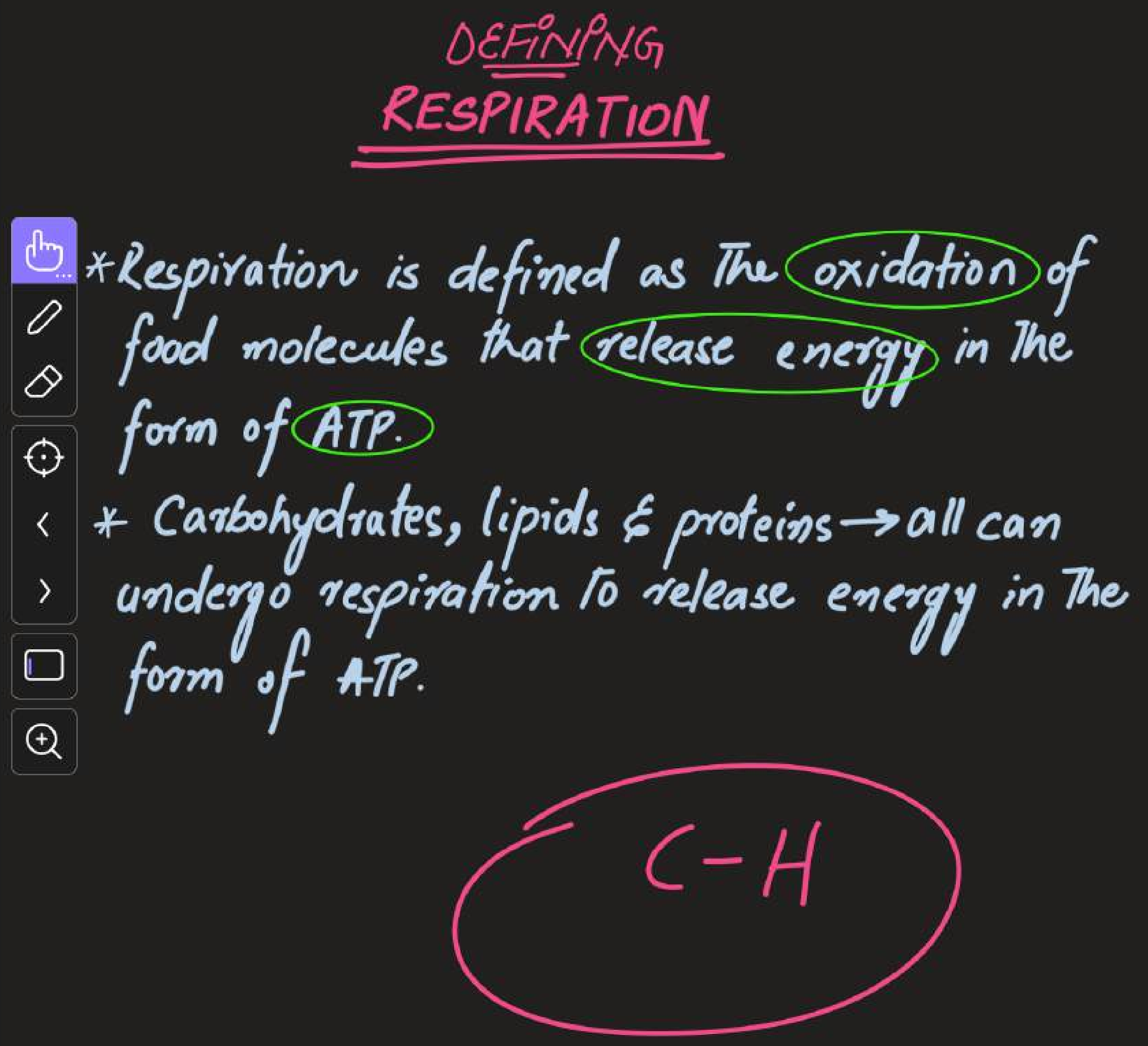


RESPIRATION

- * Defining respiration
- * Types of respiration
- * Coenzymes used in respiration
- * General reactions in respiration

Dehydrogenation

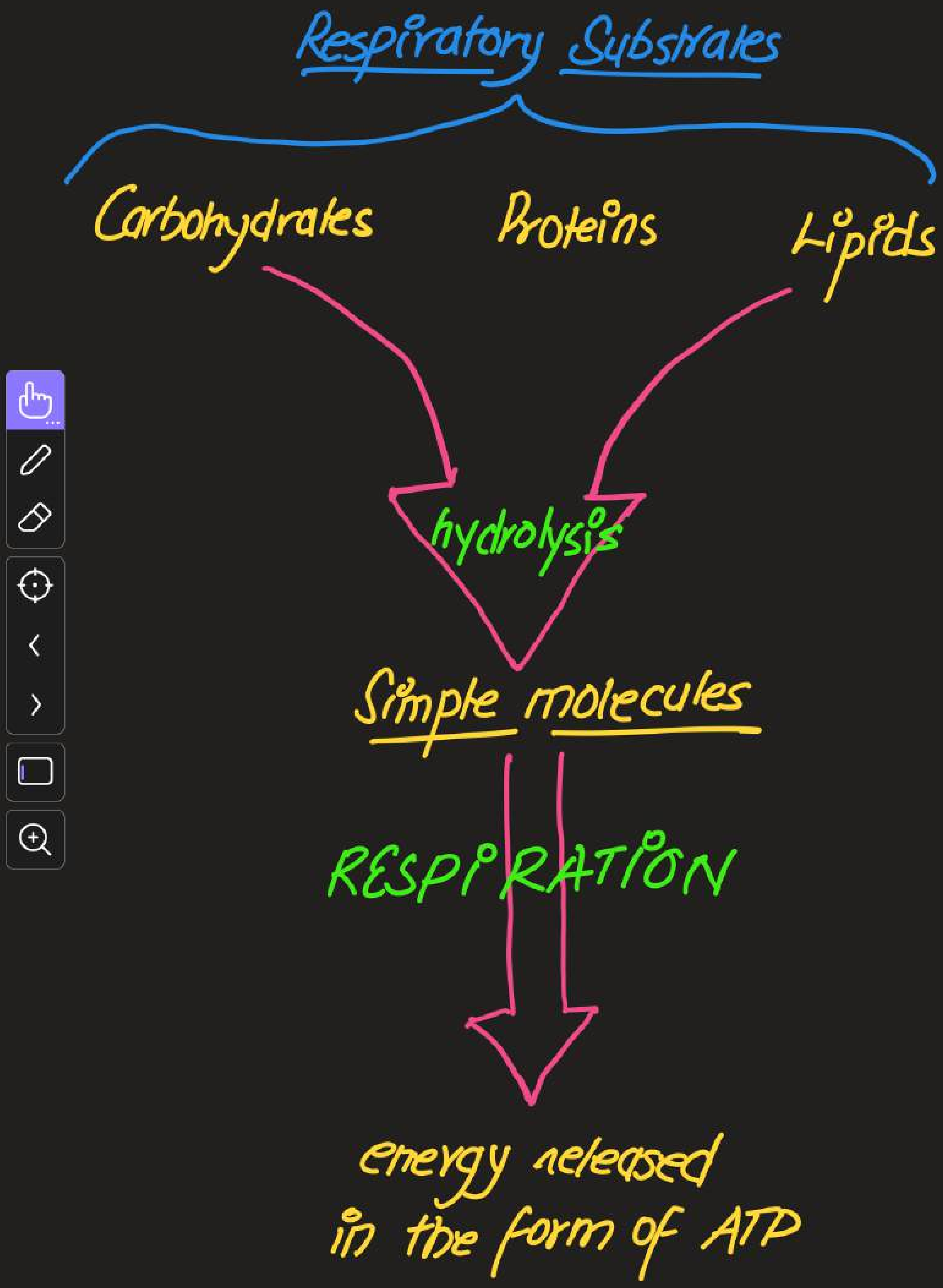
Decarboxylation

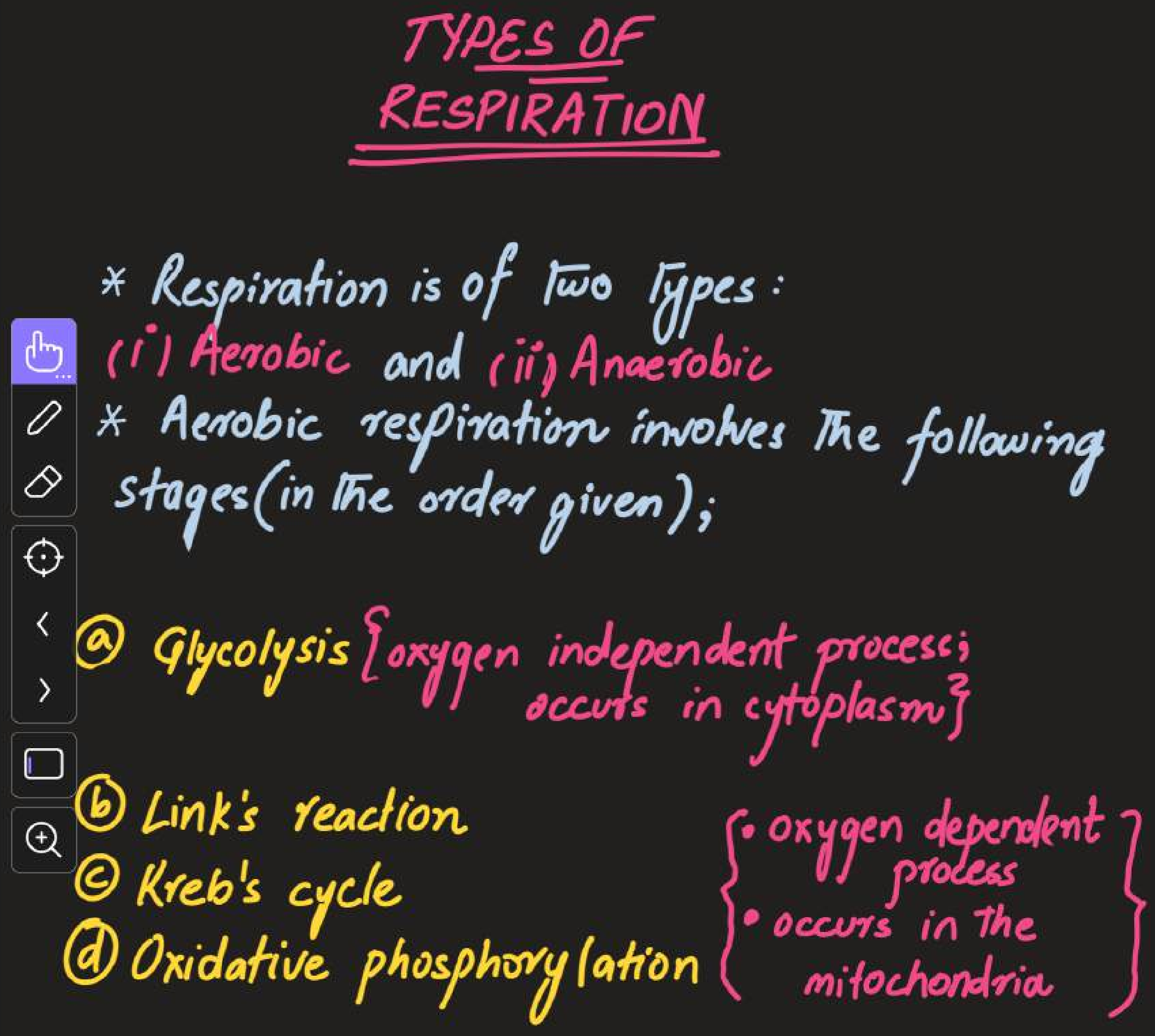


DEFINING
RESPIRATION

- *Respiration is defined as the oxidation of food molecules that release energy in the form of ATP.
- * Carbohydrates, lipids & proteins → all can undergo respiration to release energy in the form of ATP.

C-H


Respiratory Substrates
Carbohydrates
Proteins
Lipids
hydrolysis
Simple molecules
RESPIRATION
energy released
in the form of ATP



TYPES OF RESPIRATION

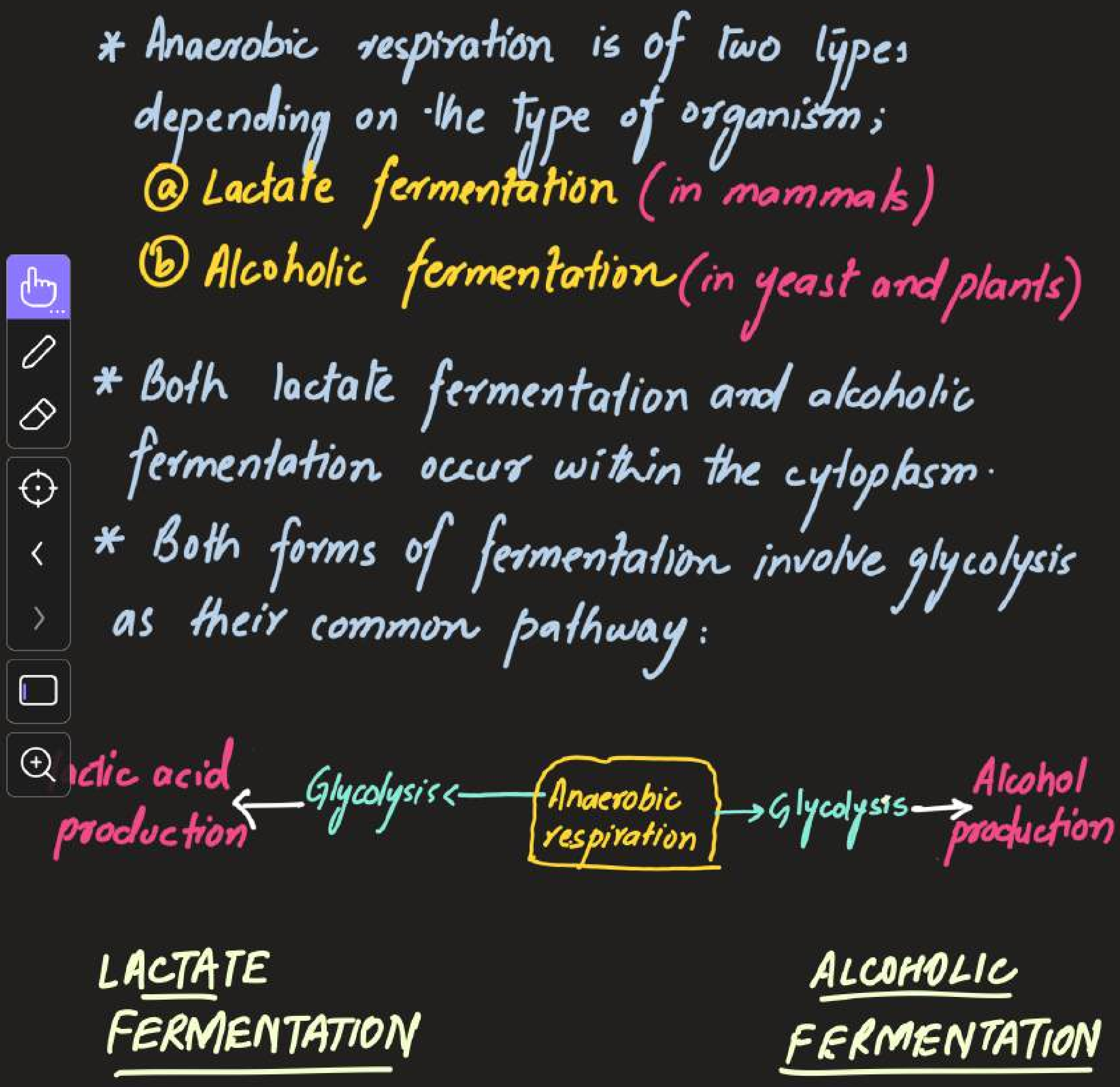
* Respiration is of two types:
(i) Aerobic and (ii) Anaerobic

* Aerobic respiration involves the following stages (in the order given);

ⓐ Glycolysis {oxygen independent process; occurs in cytoplasm}

ⓑ Link's reaction
ⓒ Kreb's cycle
ⓓ Oxidative phosphorylation

{• oxygen dependent process
• occurs in the mitochondria}



* Anaerobic respiration is of two types depending on the type of organism;

ⓐ Lactate fermentation (in mammals)

ⓑ Alcoholic fermentation (in yeast and plants)

* Both lactate fermentation and alcoholic fermentation occur within the cytoplasm.
* Both forms of fermentation involve glycolysis as their common pathway:

ctic acid production ← Glycolysis ← Anaerobic respiration → Glycolysis → Alcohol production

LACTATE FERMENTATION

ALCOHOLIC FERMENTATION

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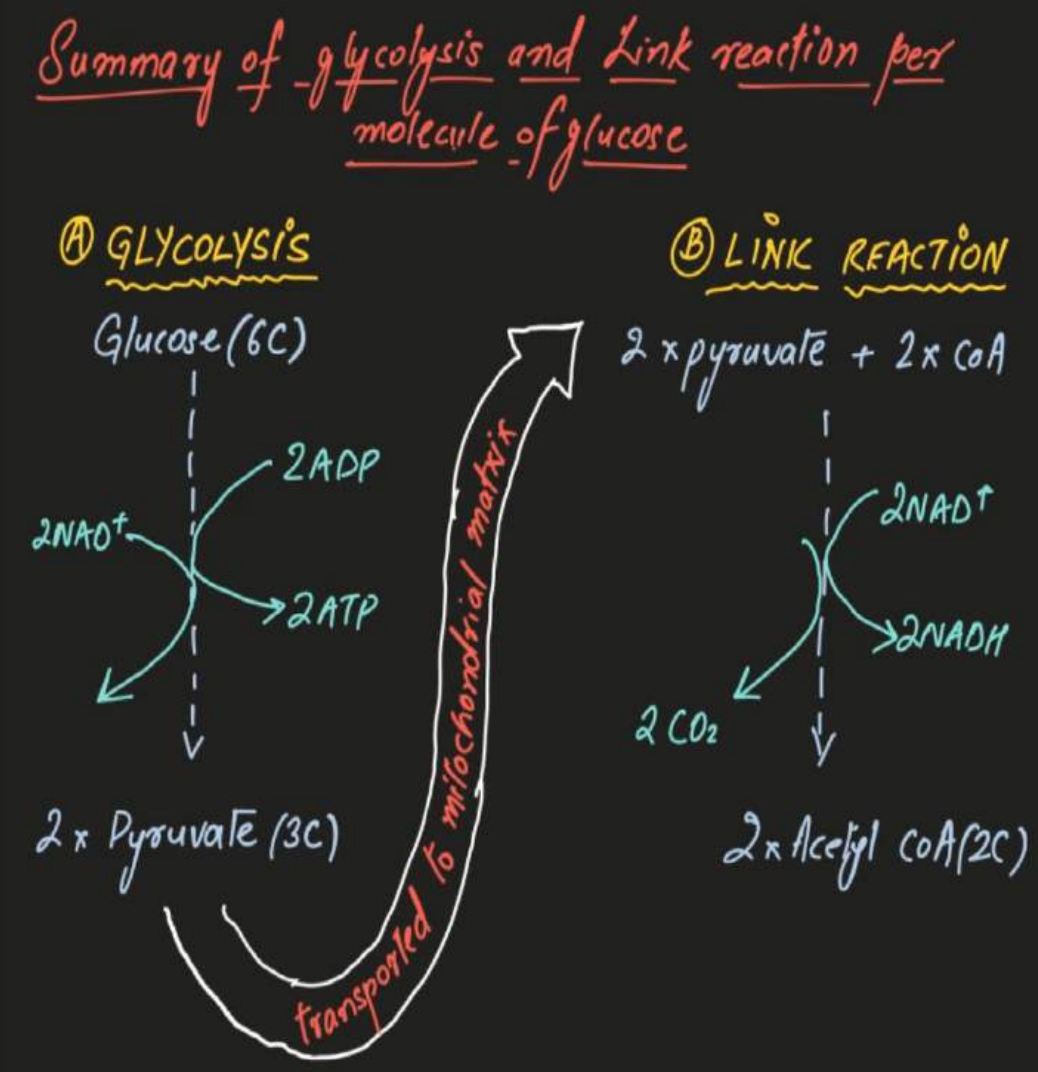
Energy & Respiration



With

Mohammad Hussham Arshad, MD

ADVANCED LEVEL BIOLOGY 9700

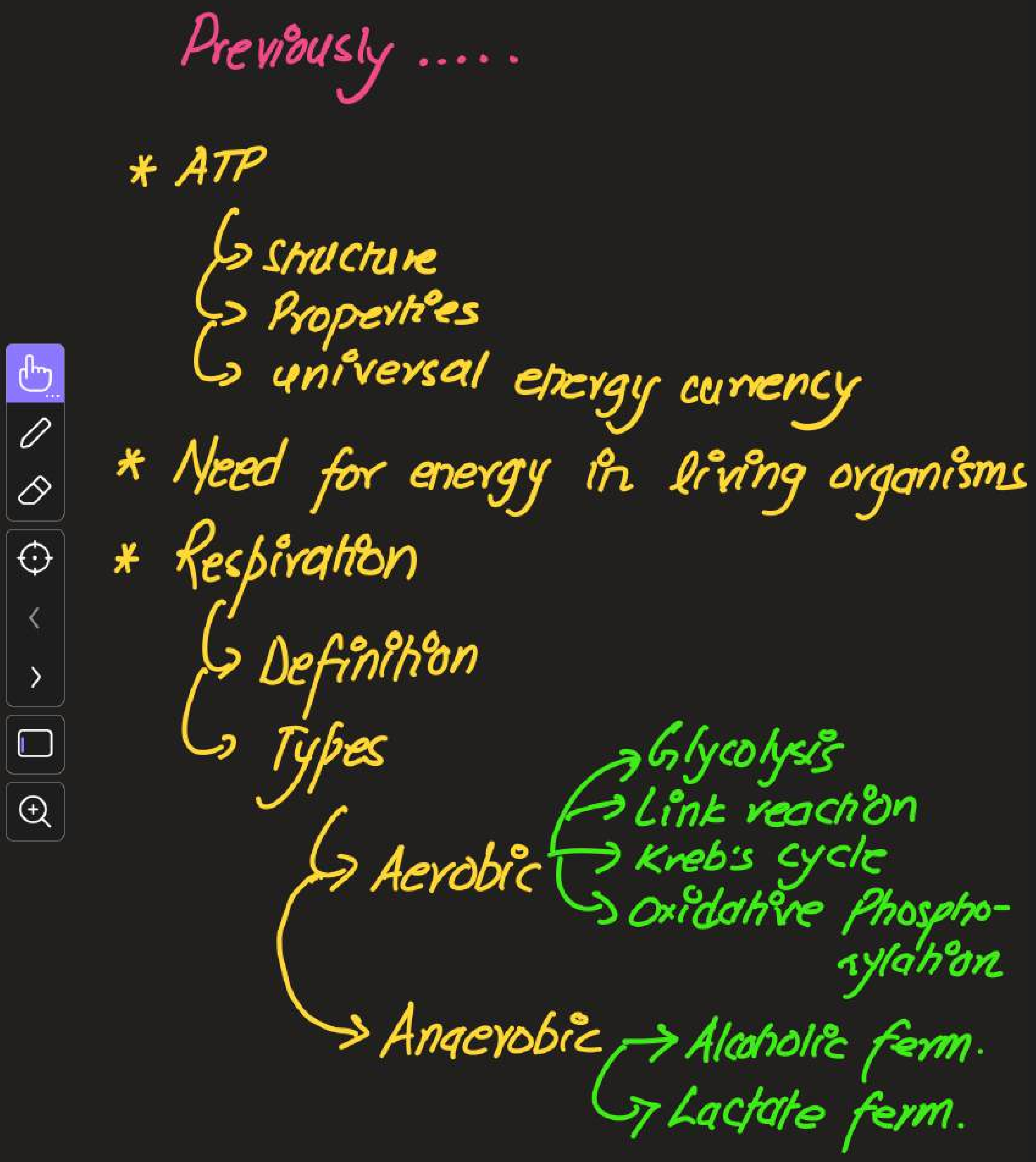
UNIT 12: ENERGY AND RESPIRATION

Learning Objectives:

- Co-Enzymes
- Dehydrogenation and Decarboxylation reaction

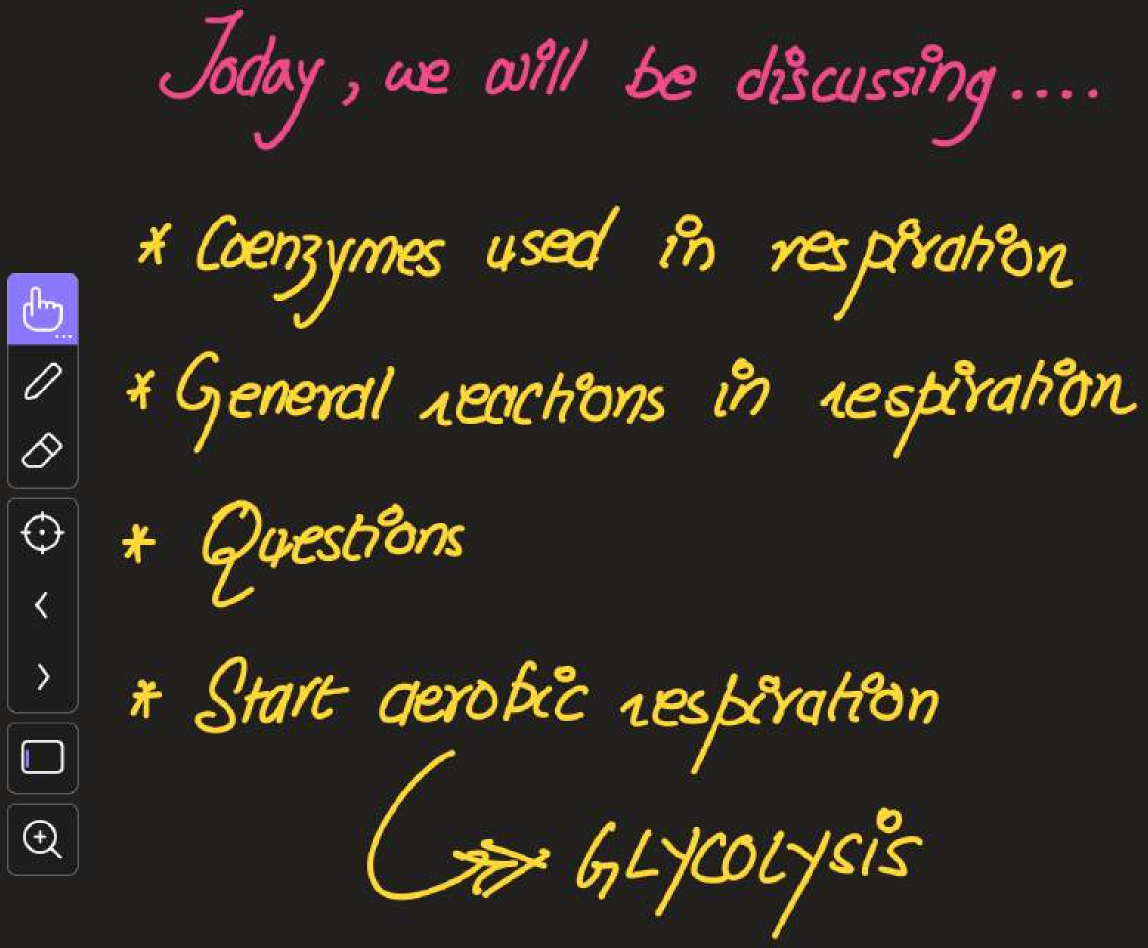
Video Lecture 3 Slides

Mohammad Hussham Arshad, MD
Biology Department



Previously .....

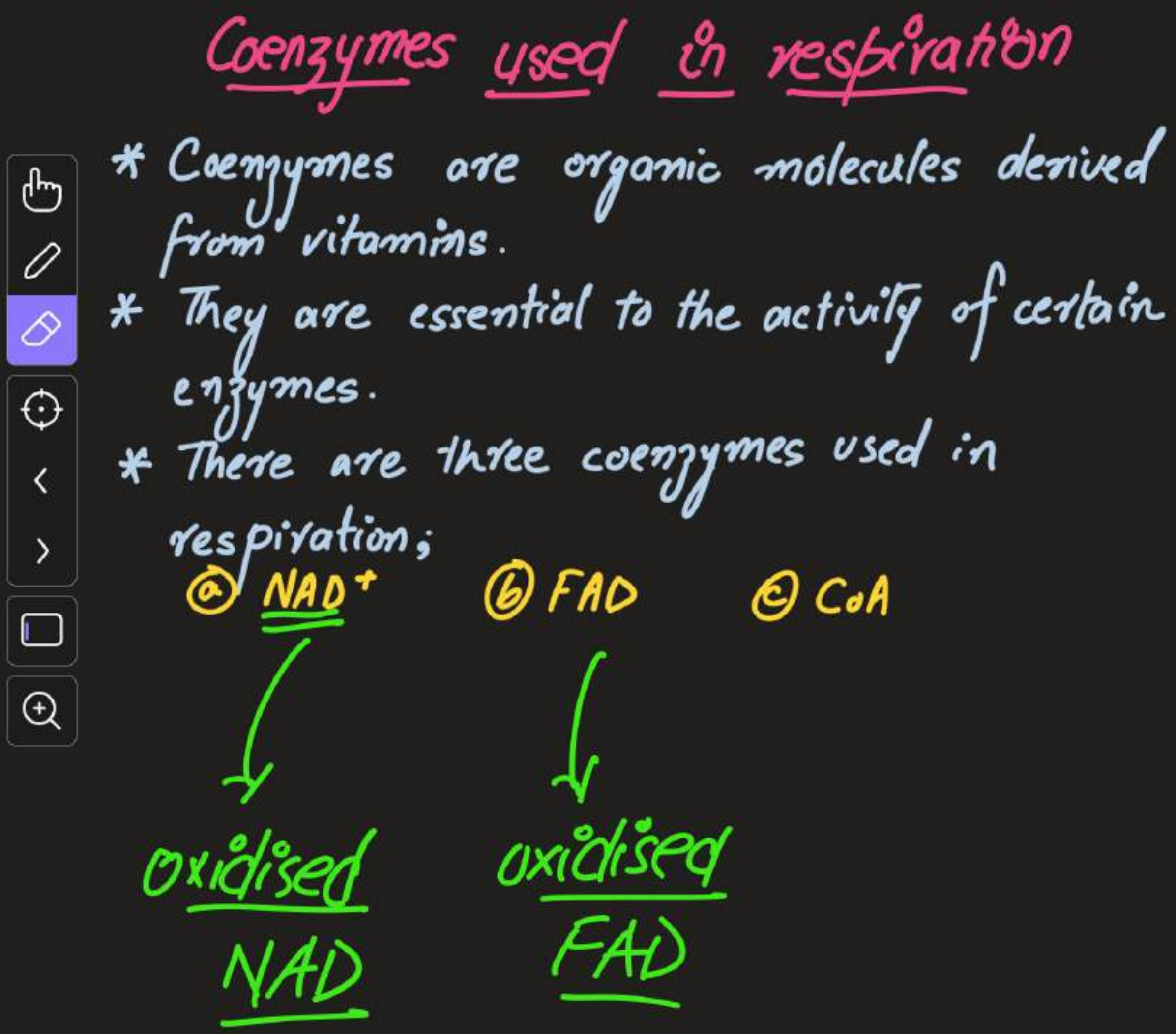
* ATP
  - Structure
  - Properties
  - universal energy currency
* Need for energy in living organisms
* Respiration
  - Definition
  - Types
    - Aerobic
      - Glycolysis
      - Link reaction
      - Kreb's cycle
      - Oxidative Phosphorylation
    - Anaerobic
      - Alcoholic ferm.
      - Lactate ferm.



Today, we will be discussing....

- * Coenzymes used in respiration
- * General reactions in respiration
- * Questions
- * Start aerobic respiration

  ⇒ GLYCOLYSIS



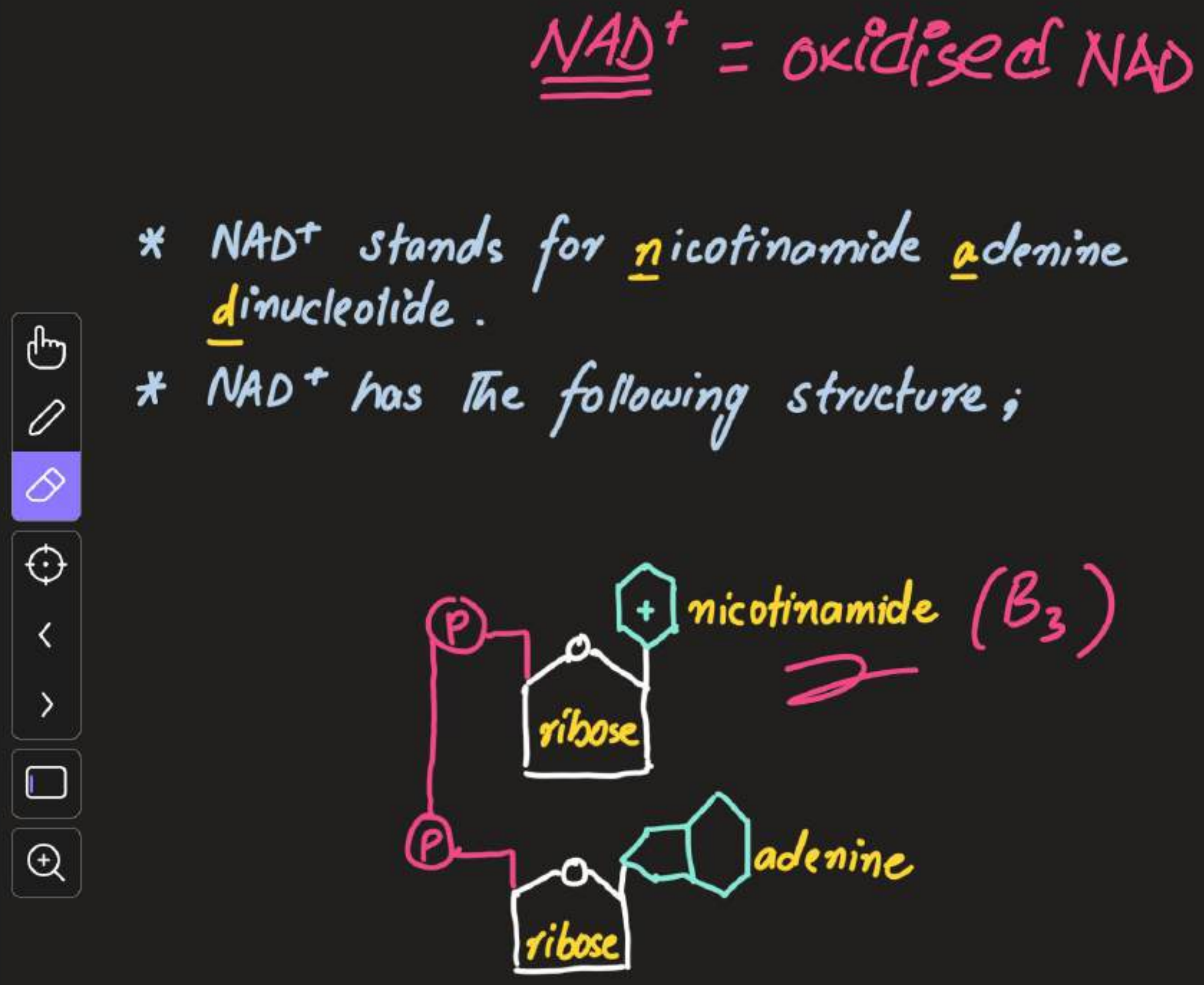
Coenzymes used in respiration

* Coenzymes are organic molecules derived from vitamins.
* They are essential to the activity of certain enzymes.
* There are three coenzymes used in respiration;

ⓐ NAD^+ ⓑ FAD ⓒ CoA

NAD^+ → oxidised NAD

FAD → oxidised FAD

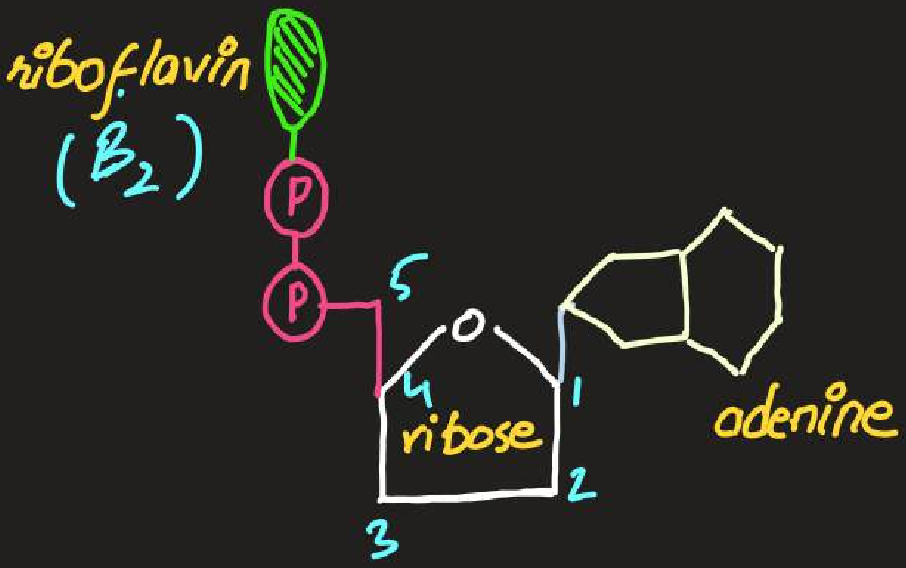


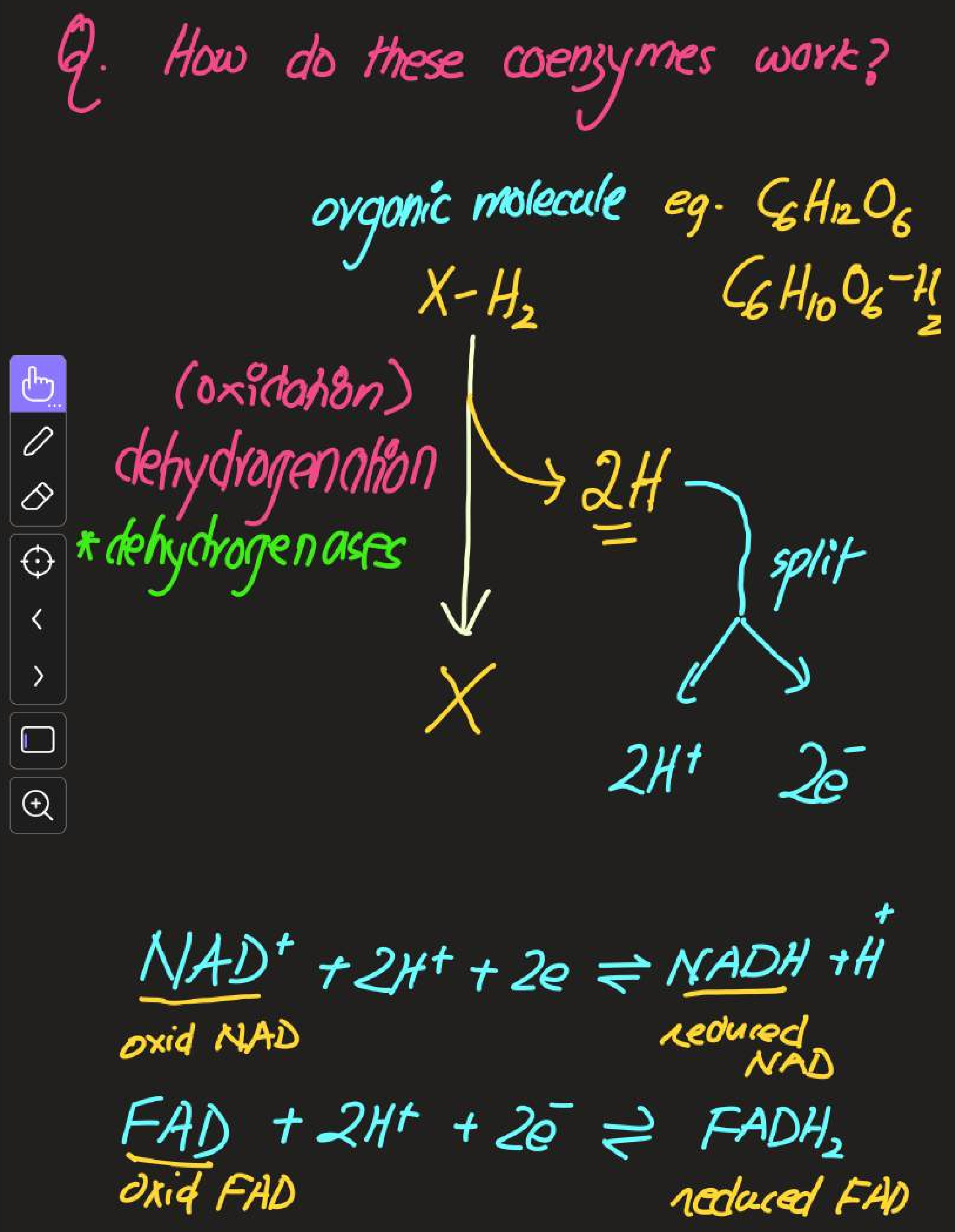
NAD$^+$ = oxidised NAD

- NAD$^+$ stands for nicotinamide adenine dinucleotide.
- NAD$^+$ has the following structure;

FAD = oxidised FAD

- * FAD stands for flavin adenine dinucleotide.
- * FAD has the following structure;





Q. How do these coenzymes work?

organic molecule eg. $C_6H_{12}O_6$

$X-H_2$ $C_6H_{10}O_6-H_2$

(oxidation)

dehydrogenation

* dehydrogenases

$\underline{2H}$

split

$2H^+$ $2e^-$

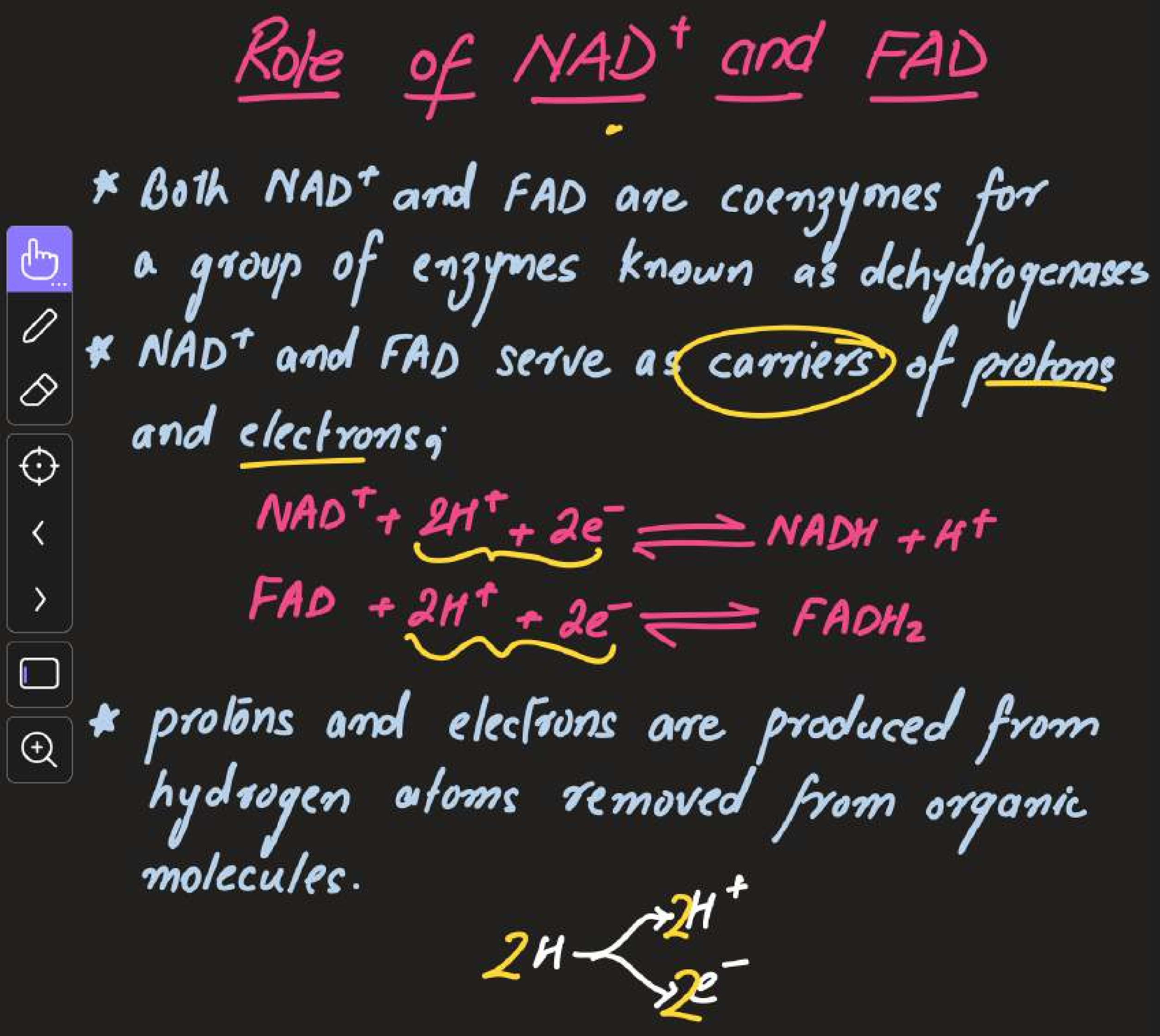
X

$\underline{NAD^+} + 2H^+ + 2e \rightleftharpoons \underline{NADH} + H^+$

oxid NAD reduced NAD

$\underline{FAD} + 2H^+ + 2e^- \rightleftharpoons FADH_2$

oxid FAD reduced FAD



Role of NAD^+ and FAD

- Both NAD^+ and FAD are coenzymes for a group of enzymes known as dehydrogenases
- NAD^+ and FAD serve as carriers of protons and electrons;

$$NAD^+ + \underbrace{2H^+ + 2e^-}_{} \rightleftharpoons NADH + H^+$$

$$FAD + \underbrace{2H^+ + 2e^-}_{} \rightleftharpoons FADH_2$$

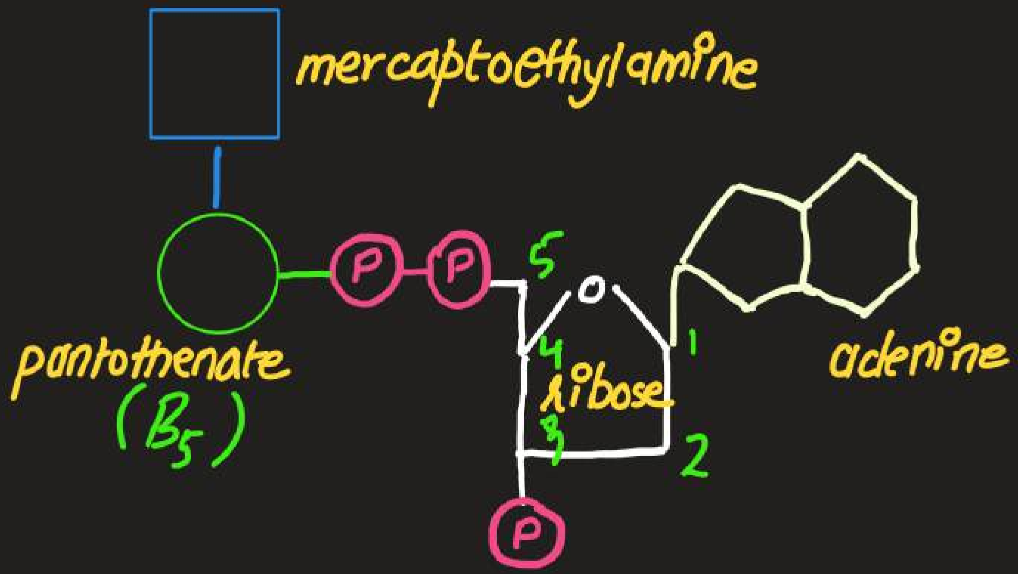
- protons and electrons are produced from hydrogen atoms removed from organic molecules.

$$2H \begin{cases} \to 2H^+ \\ \to 2e^- \end{cases}$$

CoA

* CoA stands for coenzyme A.

* The structure of coenzyme A:



* It serves as a carrier of acetyl (2C) groups.

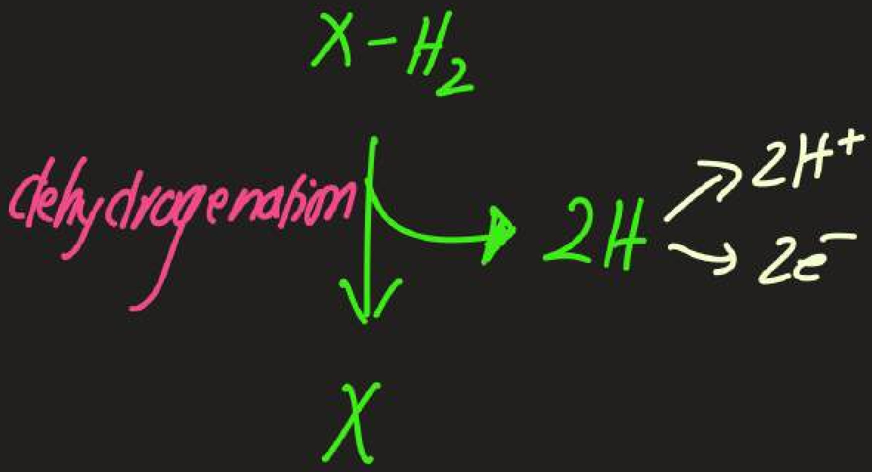
CoA + acetyl ⇌ acetyl CoA

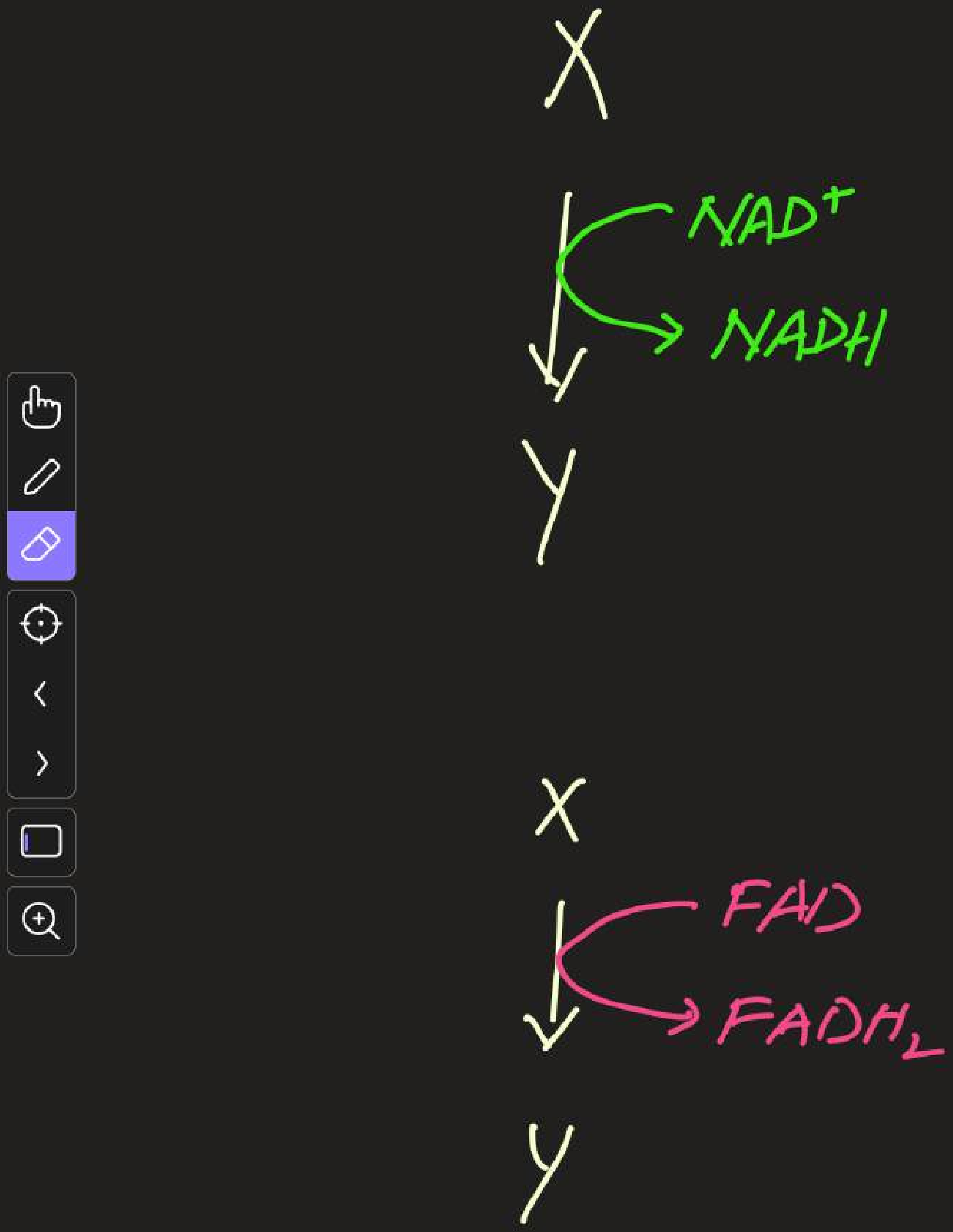
General reactions in respiration

* We will come across two reactions very commonly in respiration;

Ⓐ DEHYDROGENATION

* Dehydrogenation is a form of oxidation which involves removal of hydrogen atoms from organic molecules $(X-H_2)$ in the presence of dehydrogenases.



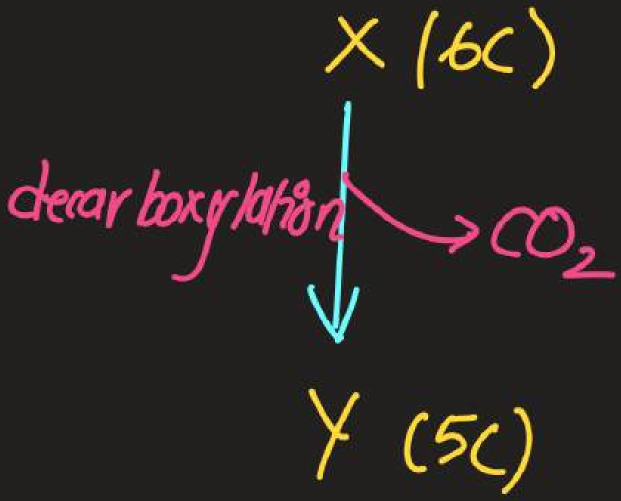

X
NAD+
NADH
Y
X
FAD
FADH2
Y

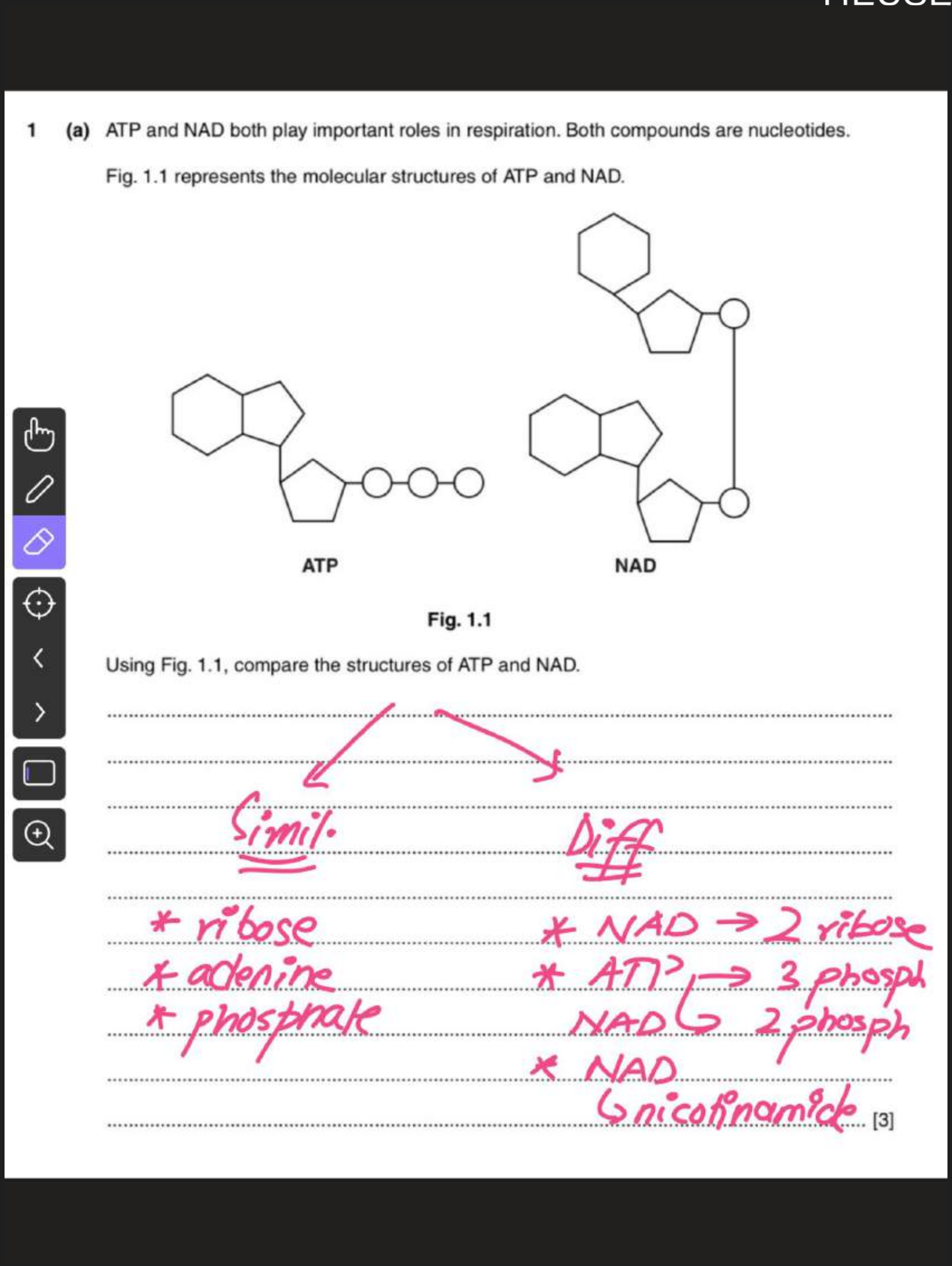
Ⓑ DECARBOXYLATION

* Decarboxylation refers to the removal of carbon dioxide (CO_2) from an organic molecule.

* Decarboxylation is an enzyme-controlled process.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$





1 **(a)** ATP and NAD both play important roles in respiration. Both compounds are nucleotides.

Fig. 1.1 represents the molecular structures of ATP and NAD.

Fig. 1.1

Using Fig. 1.1, compare the structures of ATP and NAD.

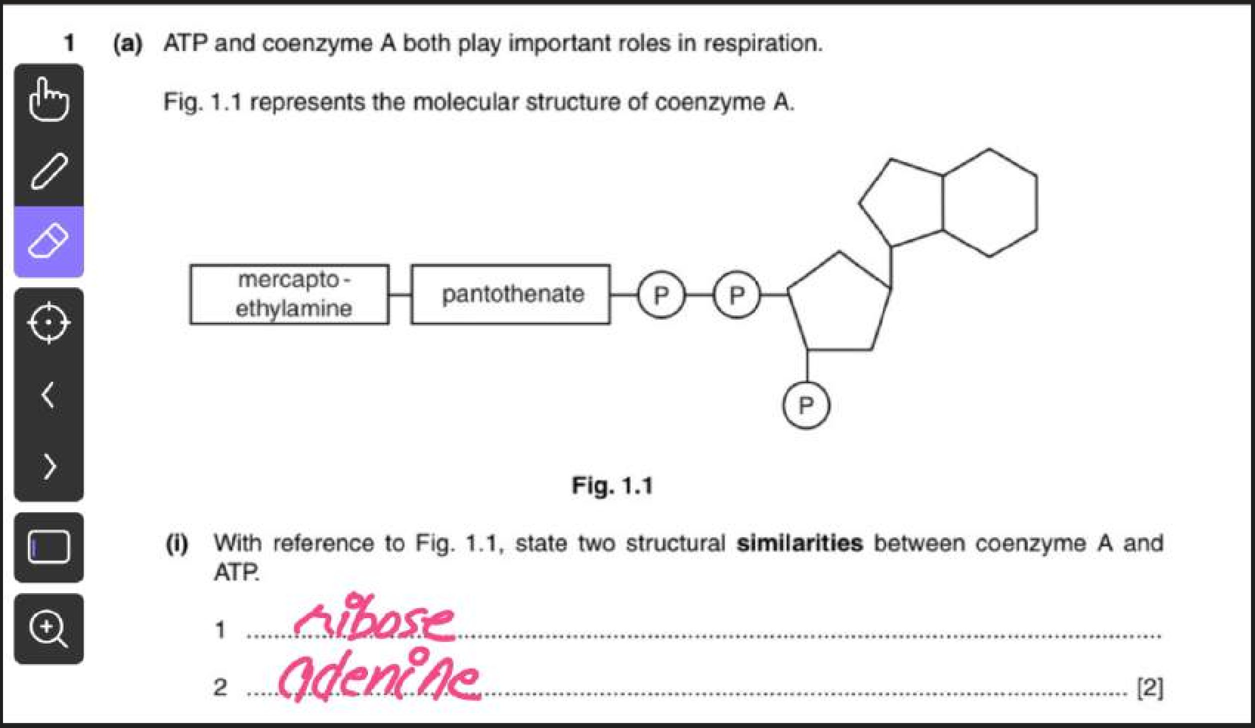
Simil.

Diff

* ribose
* adenine
* phosphate

* NAD → 2 ribose
* ATP → 3 phosph
NAD ↳ 2 phosph
* NAD
↳ nicotinamide

[3]



1 **(a)** ATP and coenzyme A both play important roles in respiration.

Fig. 1.1 represents the molecular structure of coenzyme A.

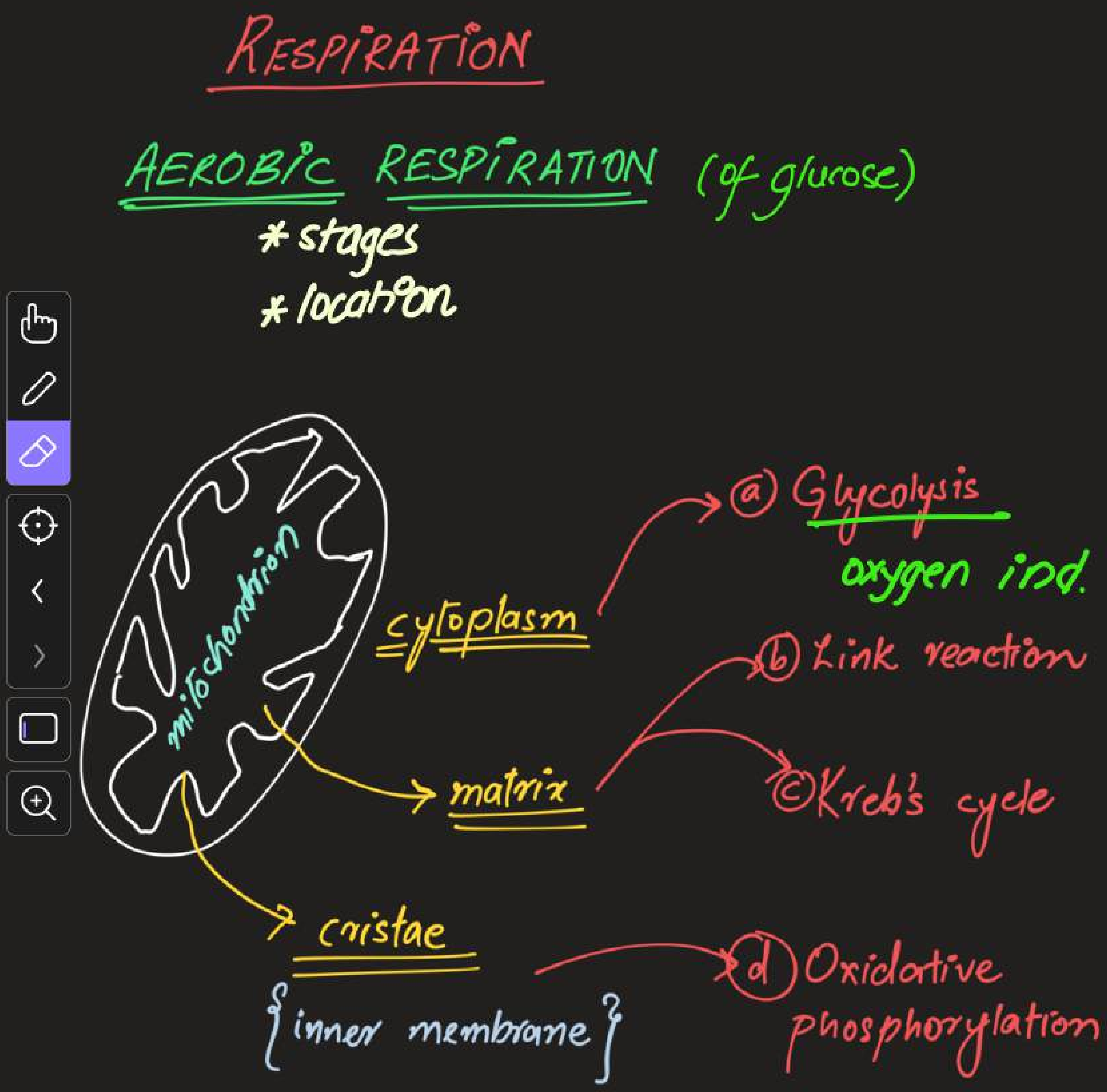
Fig. 1.1

(i) With reference to Fig. 1.1, state two structural **similarities** between coenzyme A and ATP.

1 ribose

2 adenine [2]

Let's start with aerobic respiration in detail . . . .



RESPIRATION

AEROBIC RESPIRATION (of glucose)

- * stages
- * location

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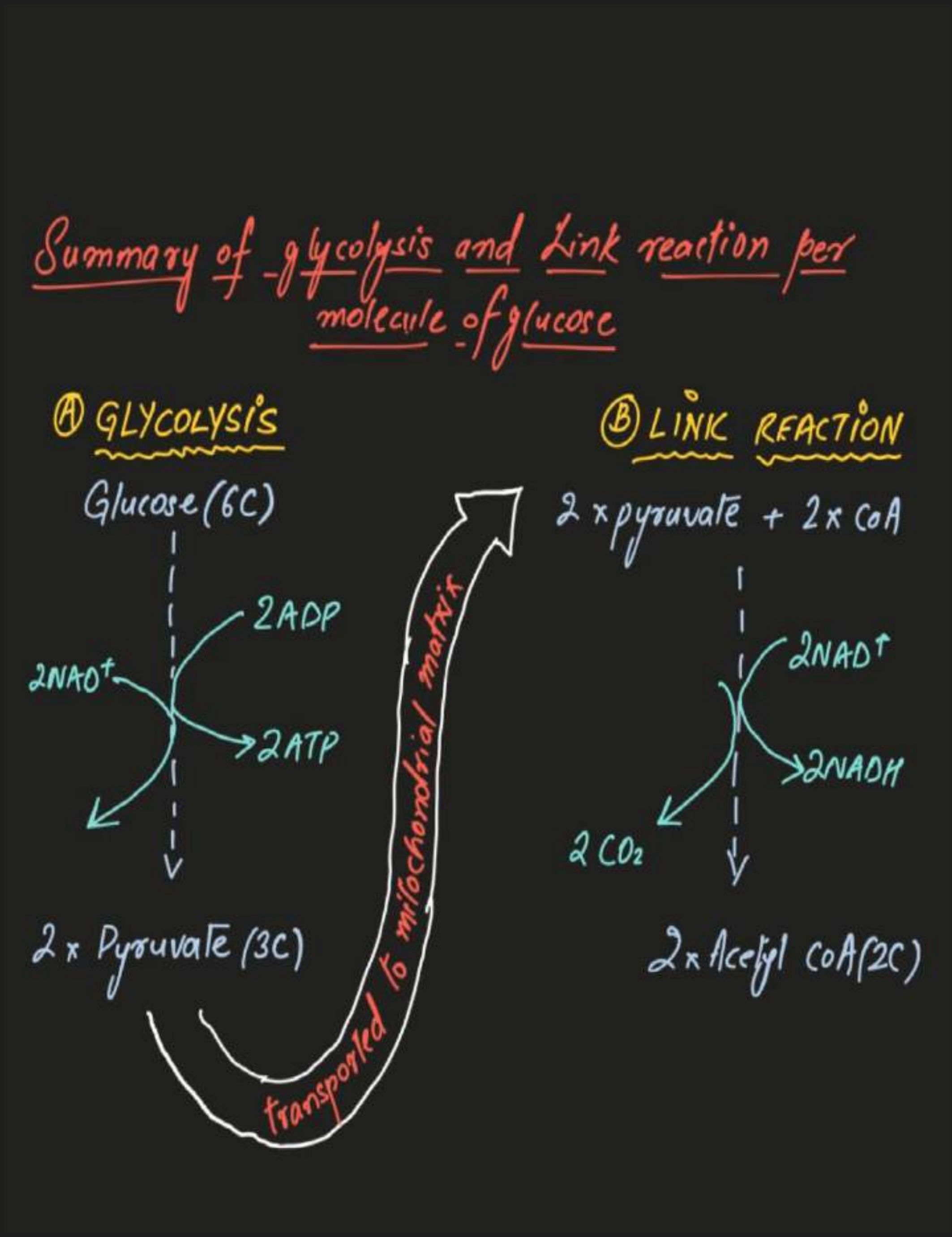
Energy & Respiration



With

Mohammad Hussham Arshad, MD

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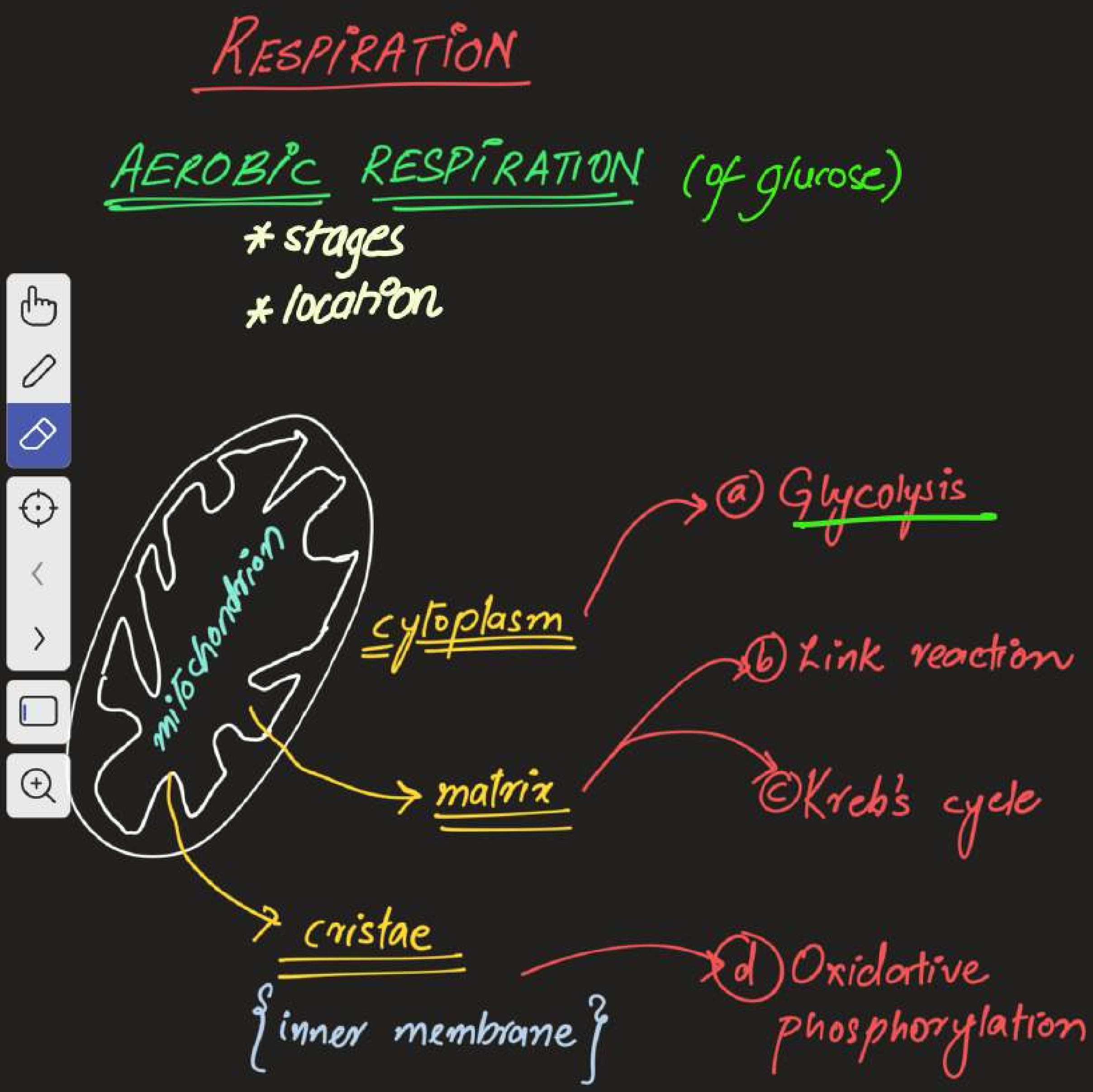
ADVANCED LEVEL BIOLOGY 9700

UNIT 12: ENERGY AND RESPIRATION

Learning Objectives:

- Glycolysis and Link reaction

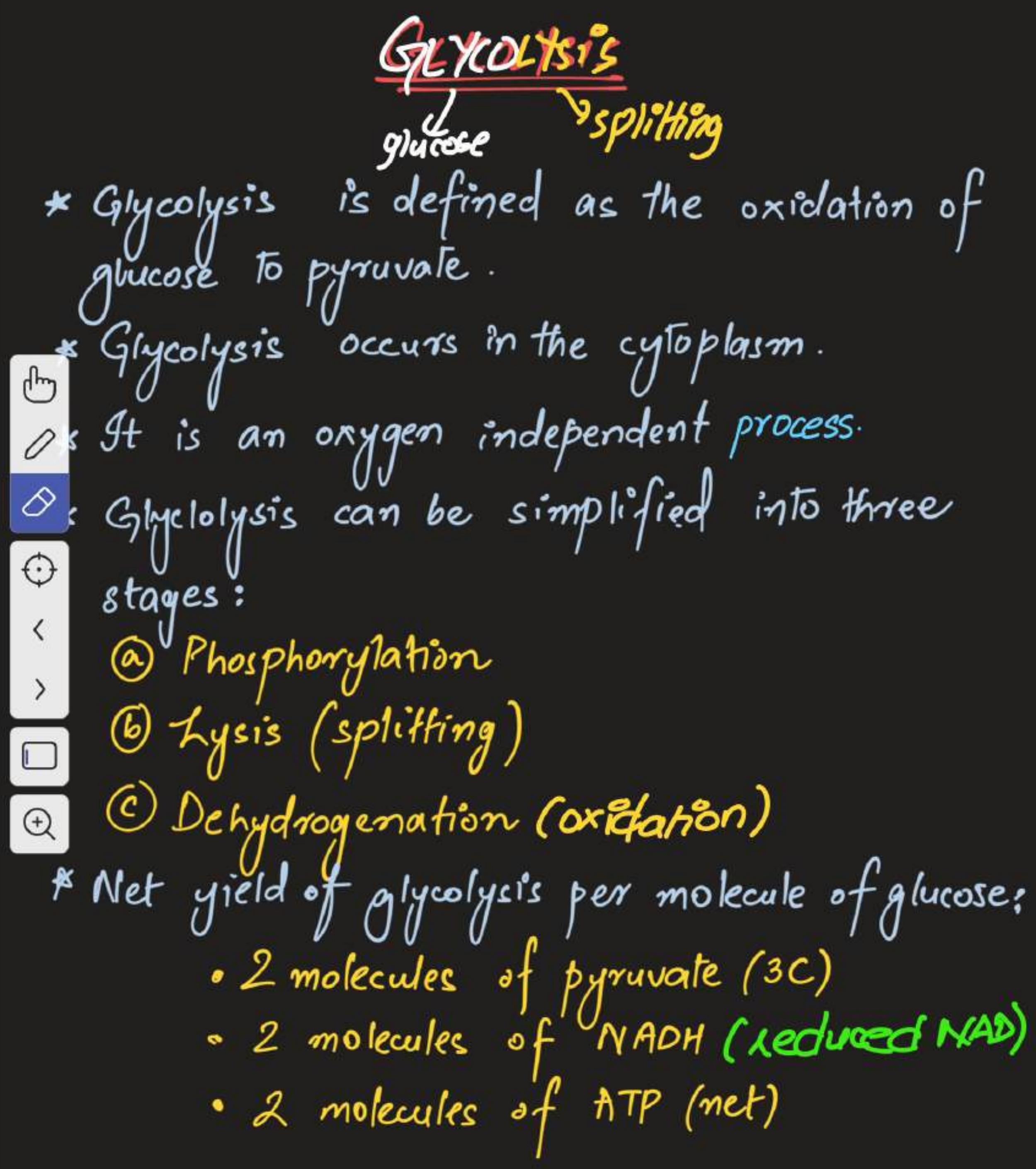
Video Lecture 4 Slides
Mohammad Hussham Arshad, MD
Biology Department



RESPIRATION

AEROBIC RESPIRATION (of glucose)

- * stages
- * location

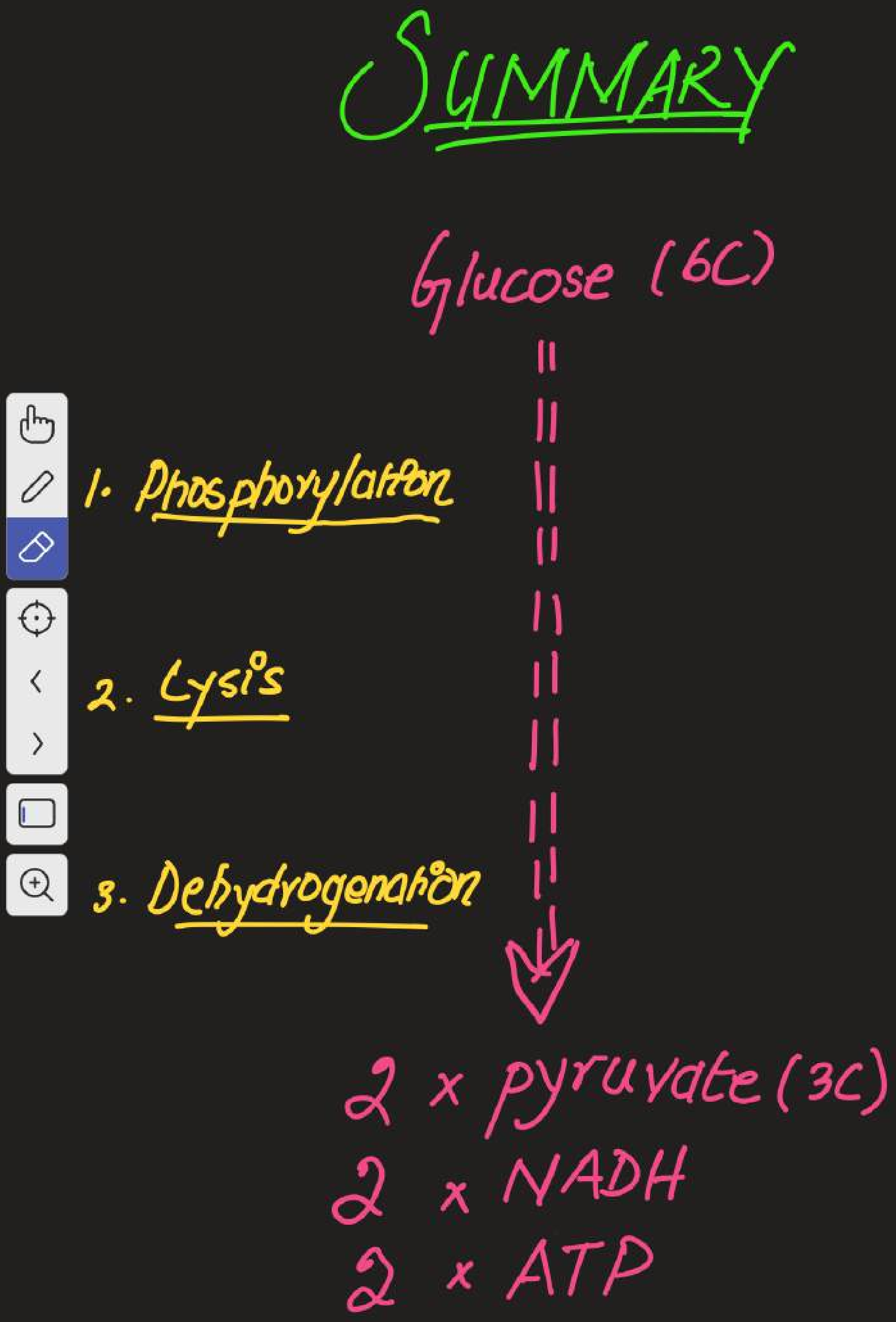


GLYCOLYSIS

glucose

splitting

* Glycolysis is defined as the oxidation of glucose to pyruvate.
* Glycolysis occurs in the cytoplasm.
* It is an oxygen independent process.
* Glyclolysis can be simplified into three stages:
  ⓐ Phosphorylation
  ⓑ Lysis (splitting)
  ⓒ Dehydrogenation (oxidation)
* Net yield of glycolysis per molecule of glucose:
  - 2 molecules of pyruvate (3C)
  - 2 molecules of NADH (reduced NAD)
  - 2 molecules of ATP (net)



SUMMARY

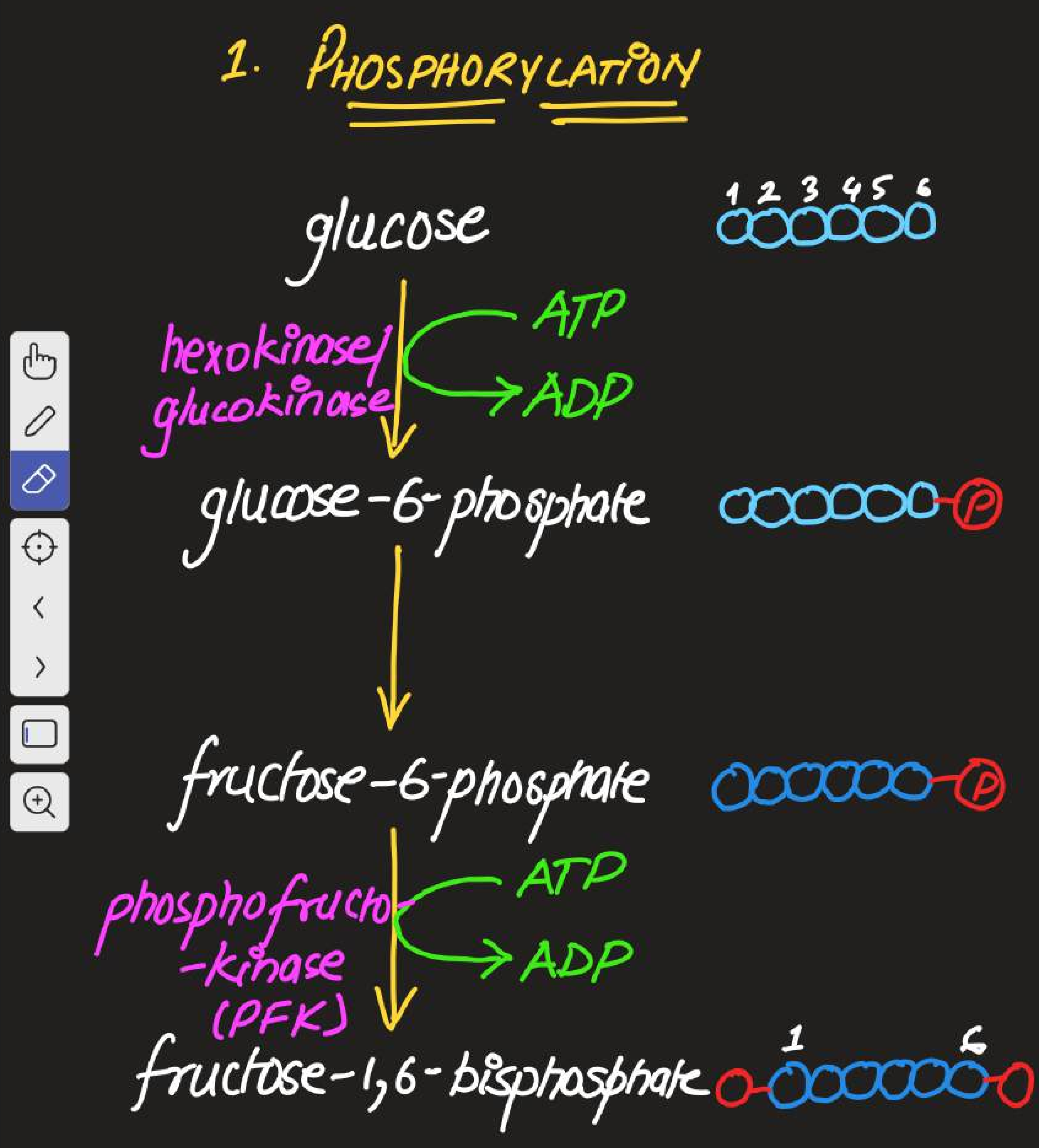
Glucose (6C)

1. Phosphorylation

2. Lysis

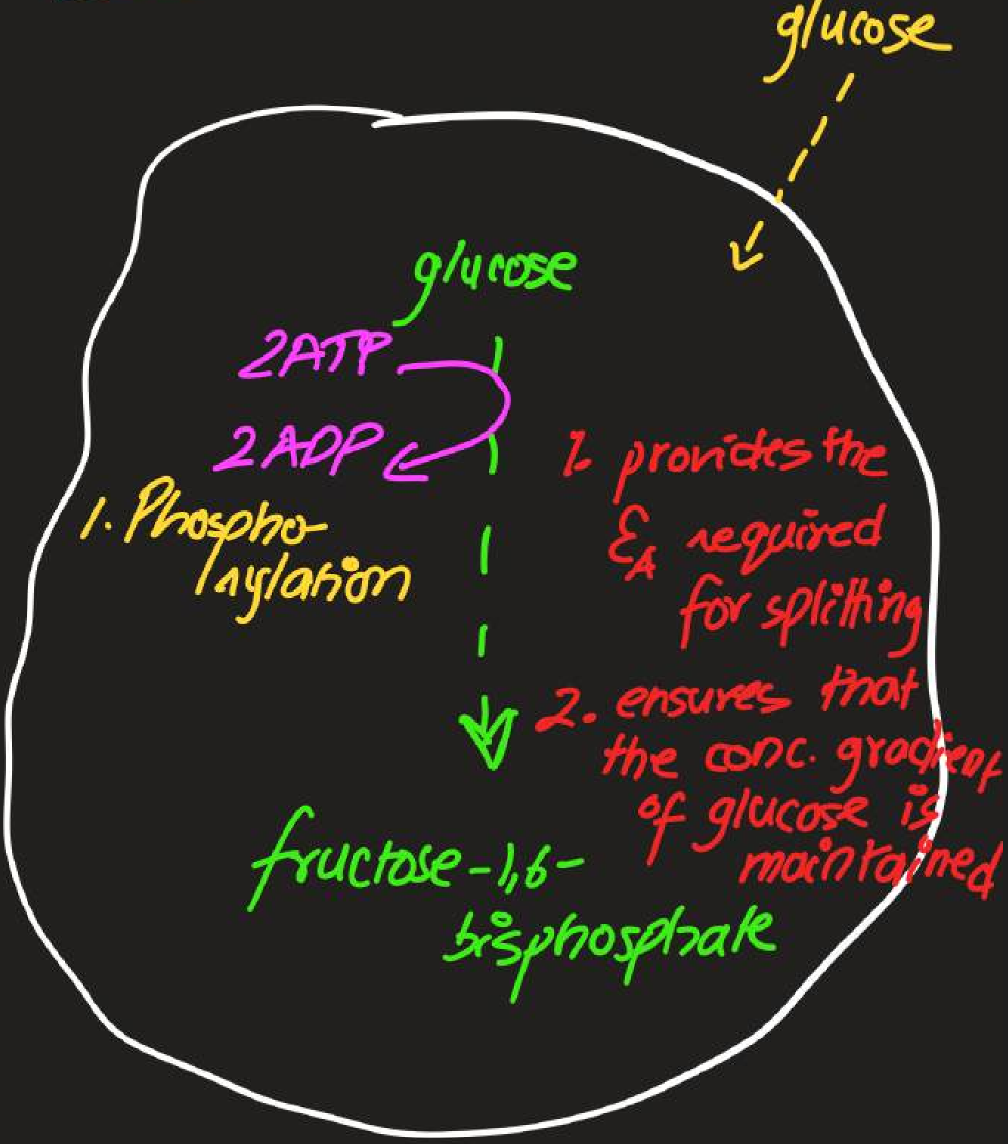
3. Dehydrogenation

2 x pyruvate (3C)
2 x NADH
2 x ATP



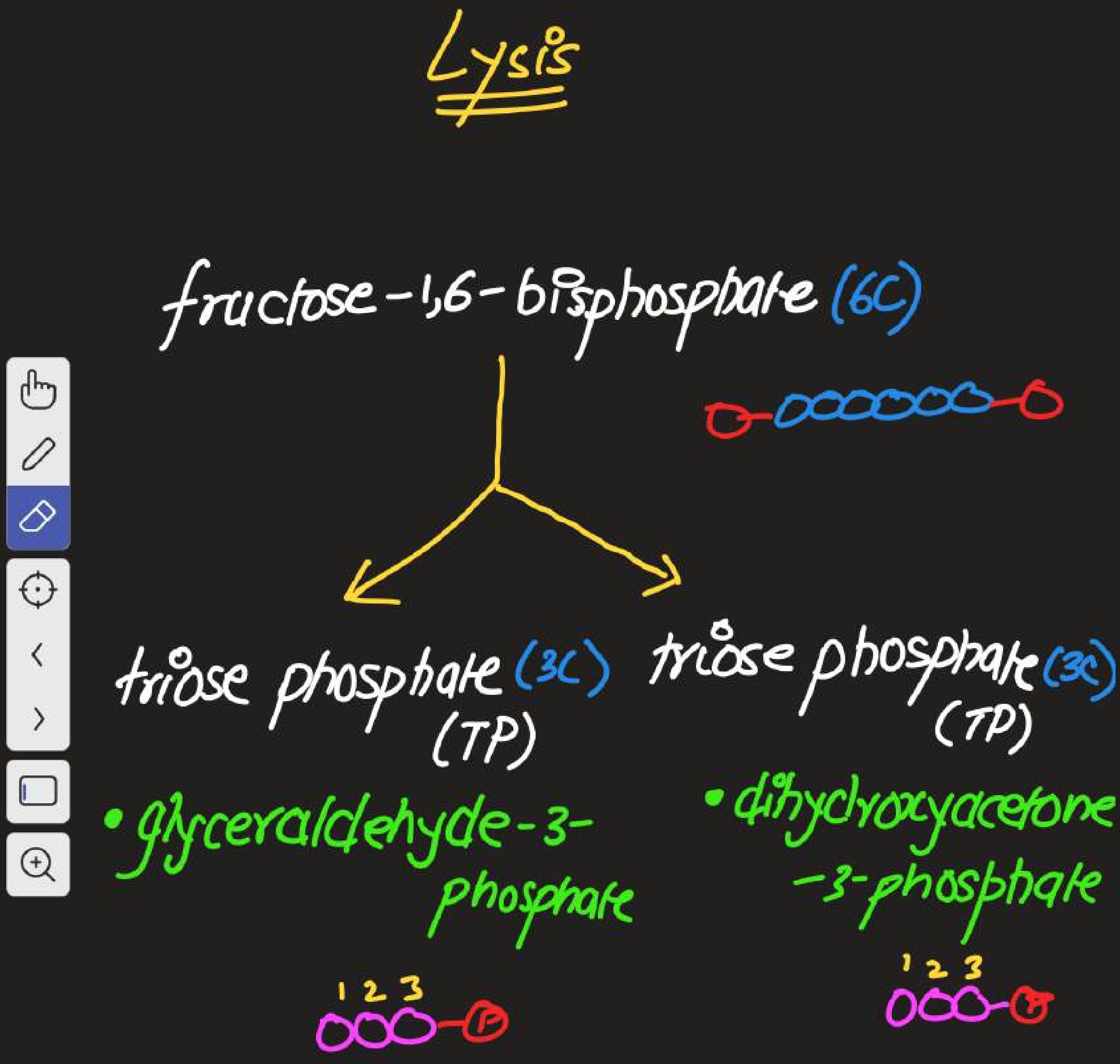
1. PHOSPHORYLATION

PHOSPHORYLATION – Benefits ??



1. provides the E_A required for splitting

2. ensures that the conc. gradient of glucose is maintained



Lysis

fructose-1,6-bisphosphate (6C)

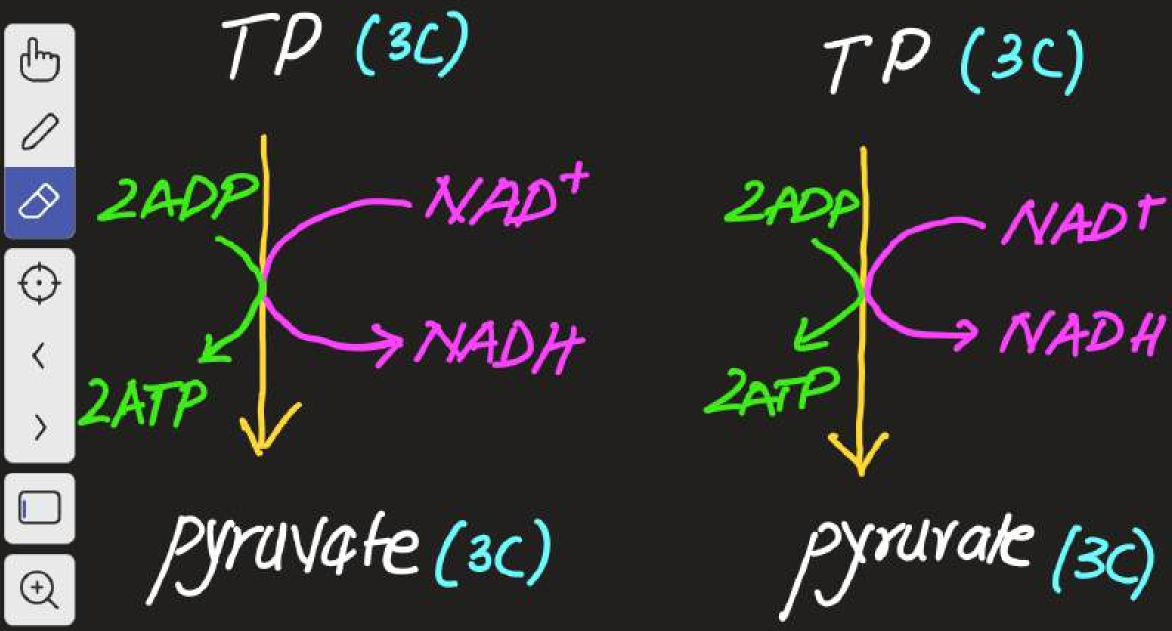
triose phosphate (3C)
(TP)

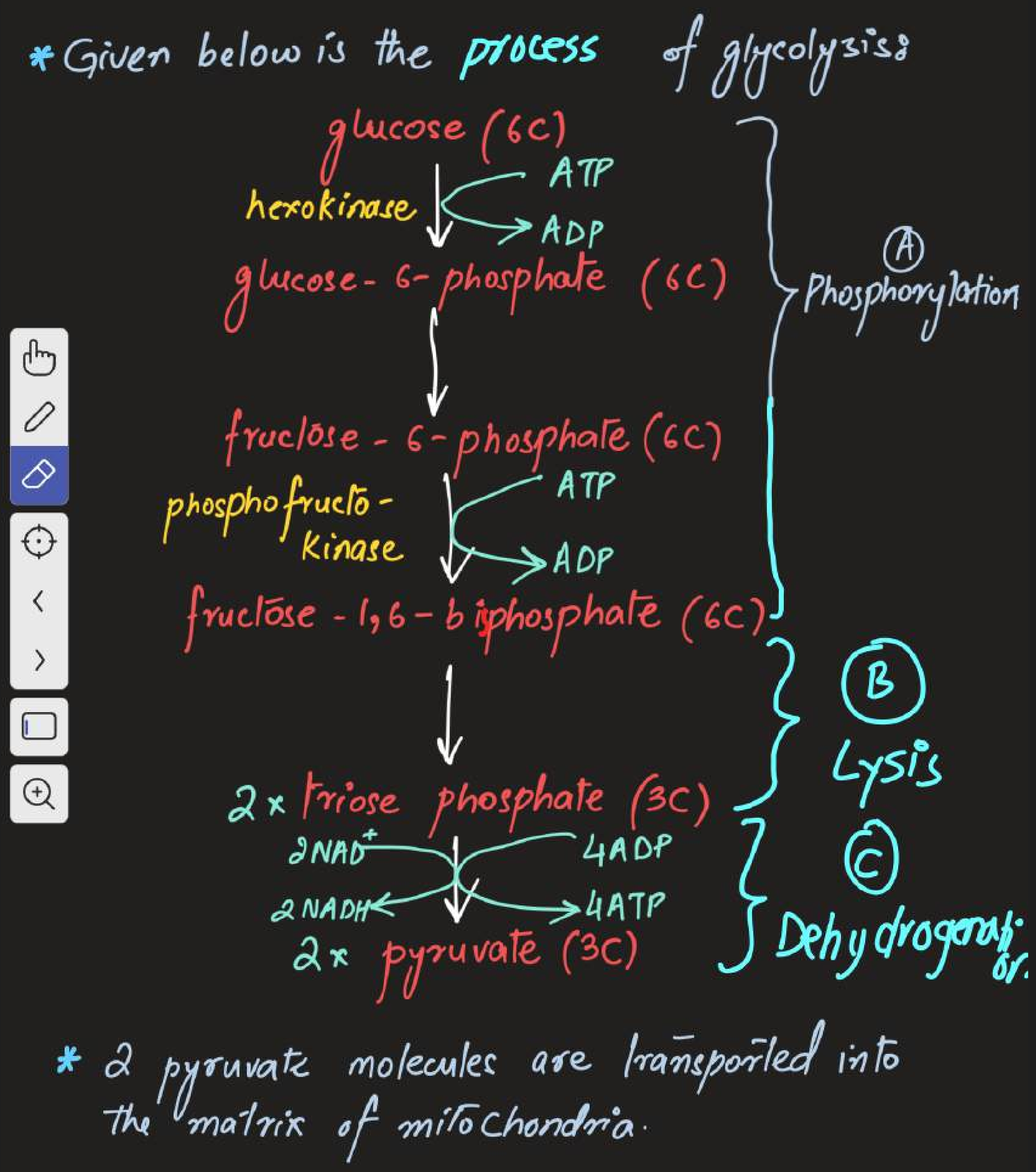
triose phosphate (3C)
(TP)

- glyceraldehyde-3-phosphate

- dihydroxyacetone-3-phosphate

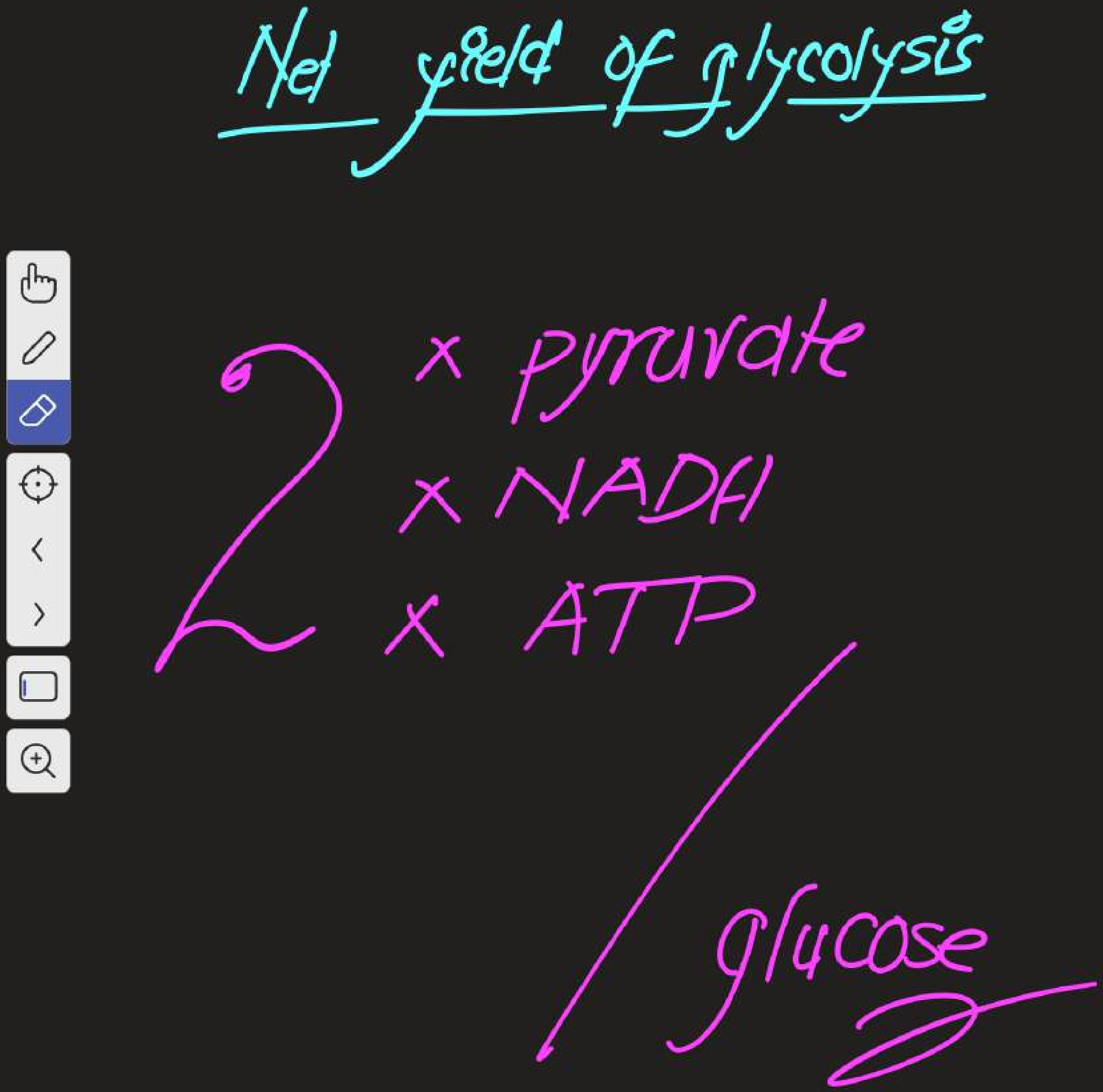
DEHYDROGENATION





* Given below is the process of glycolysis:

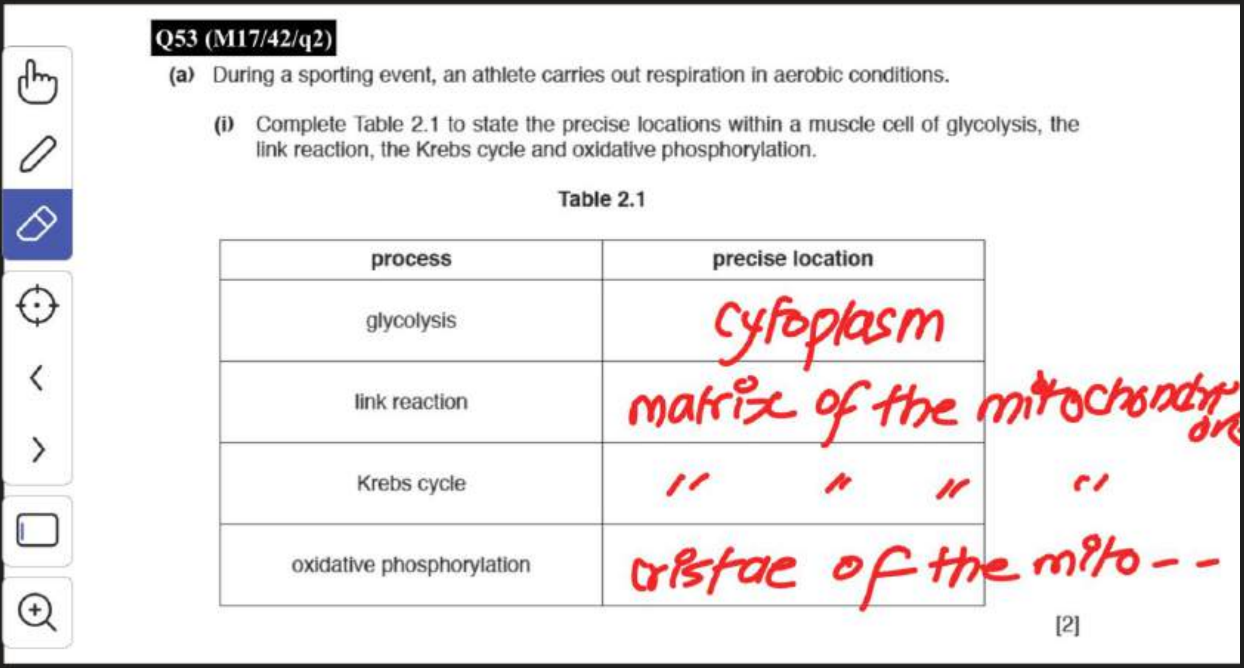
* 2 pyruvate molecules are transported into the matrix of mitochondria.



Net yield of glycolysis

2 × pyruvate
× NADH
× ATP

/ glucose



Q53 (M17/42/q2)

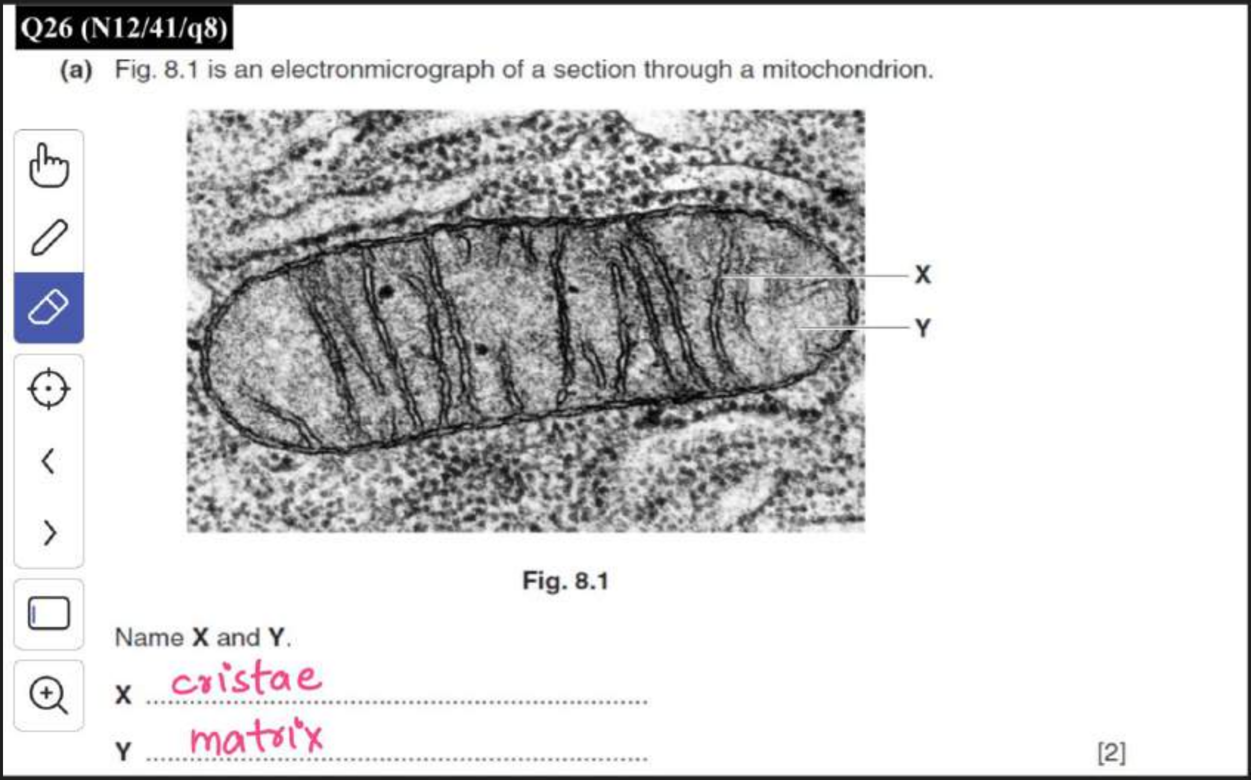
(a) During a sporting event, an athlete carries out respiration in aerobic conditions.

(i) Complete Table 2.1 to state the precise locations within a muscle cell of glycolysis, the link reaction, the Krebs cycle and oxidative phosphorylation.

Table 2.1

process	precise location
glycolysis	cytoplasm
link reaction	matrix of the mitochondri
Krebs cycle	" " " "
oxidative phosphorylation	cristae of the mito - -

[2]



Q26 (N12/41/q8)

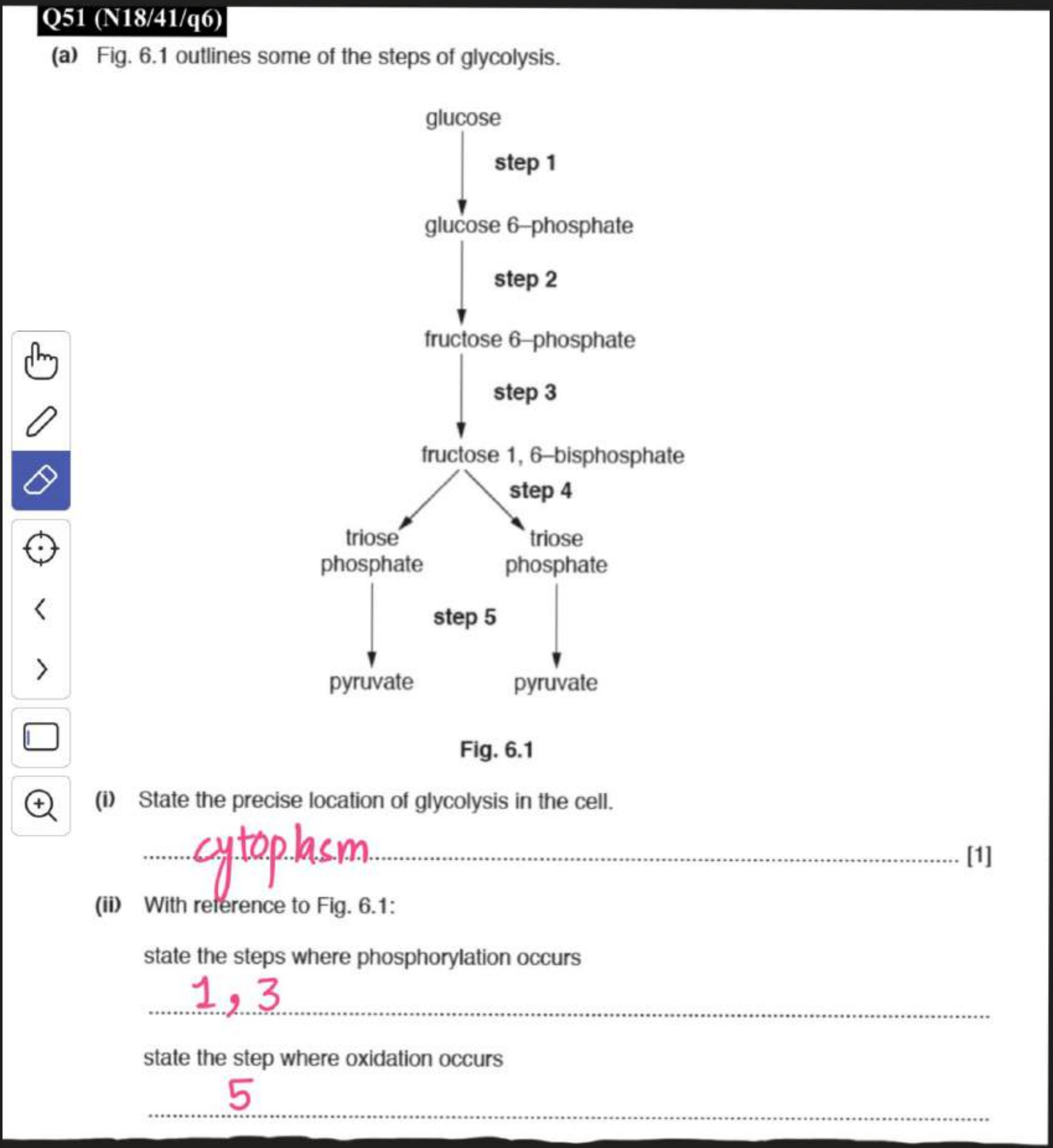
(a) Fig. 8.1 is an electronmicrograph of a section through a mitochondrion.

Fig. 8.1

Name **X** and **Y**.

X cristae

Y matrix [2]



Q51 (N18/41/q6)

(a) Fig. 6.1 outlines some of the steps of glycolysis.

Fig. 6.1

(i) State the precise location of glycolysis in the cell.

cytoplasm .... [1]

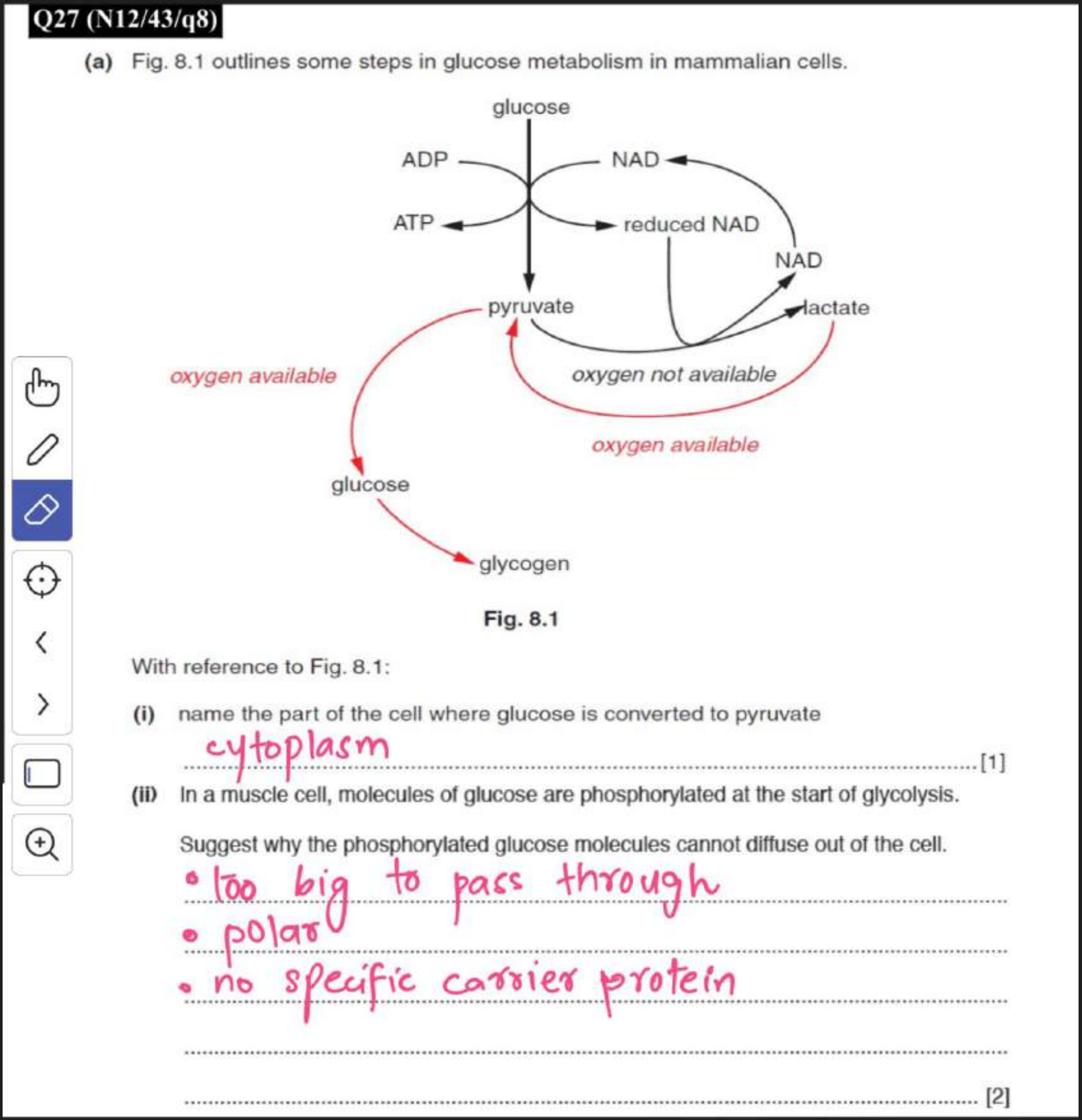
(ii) With reference to Fig. 6.1:

state the steps where phosphorylation occurs

1, 3 ....

state the step where oxidation occurs

5 ....



Q27 (N12/43/q8)

(a) Fig. 8.1 outlines some steps in glucose metabolism in mammalian cells.

Fig. 8.1

With reference to Fig. 8.1:

(i) name the part of the cell where glucose is converted to pyruvate

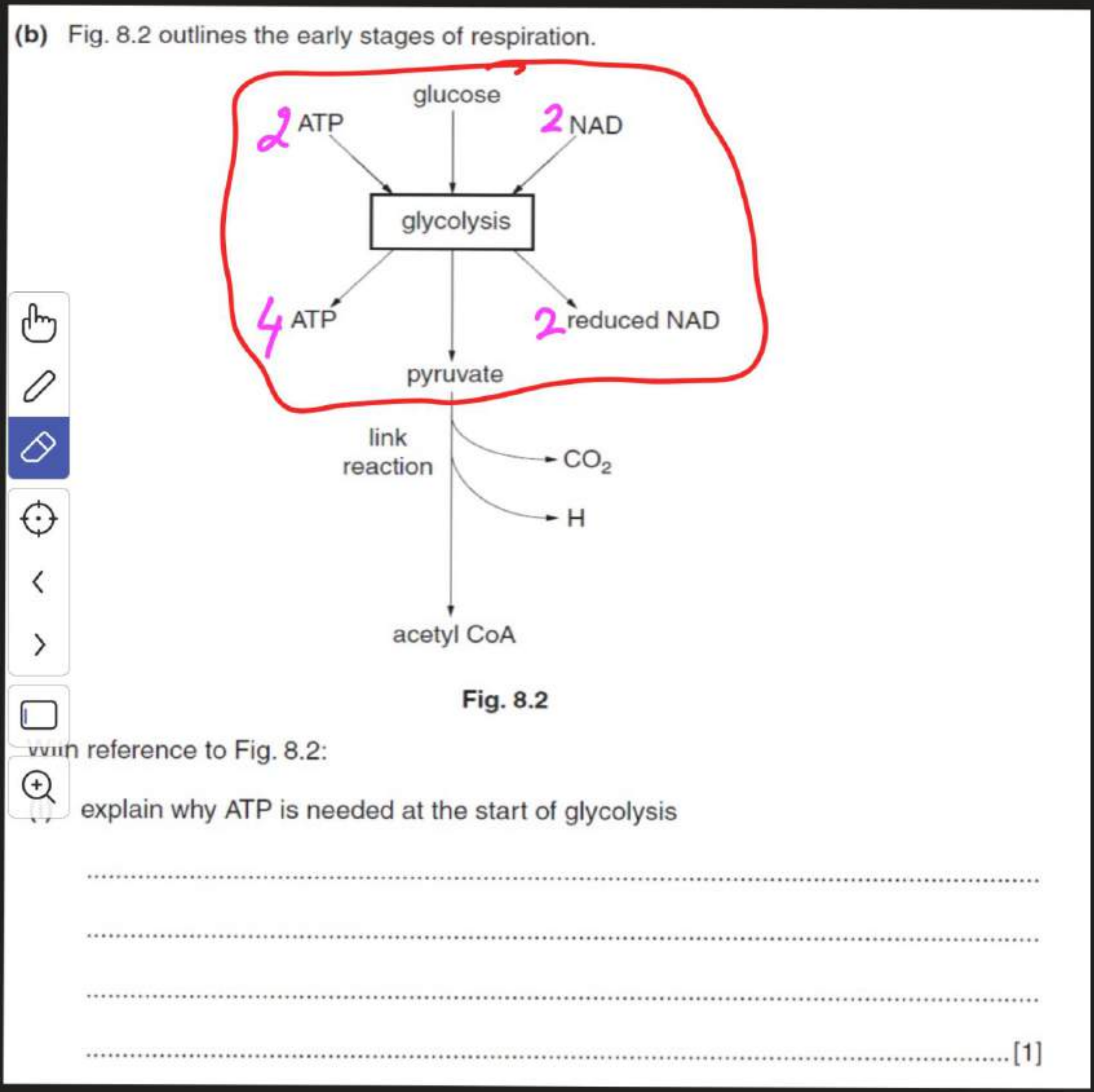
cytoplasm [1]

(ii) In a muscle cell, molecules of glucose are phosphorylated at the start of glycolysis.

Suggest why the phosphorylated glucose molecules cannot diffuse out of the cell.

- too big to pass through
- polar
- no specific carrier protein

[2]



(b) Fig. 8.2 outlines the early stages of respiration.

Fig. 8.2

With reference to Fig. 8.2:

explain why ATP is needed at the start of glycolysis

....

....

....

....[1]

LINK REACTION

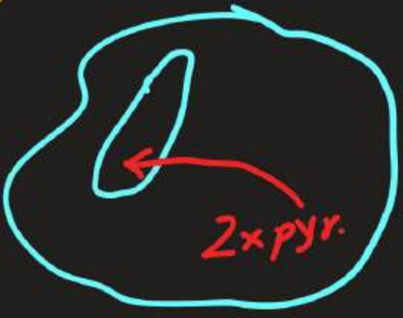
* Link reaction involves the conversion of a pyruvate molecule into acetyl CoA through a dehydrogenation and a decarboxylation reaction

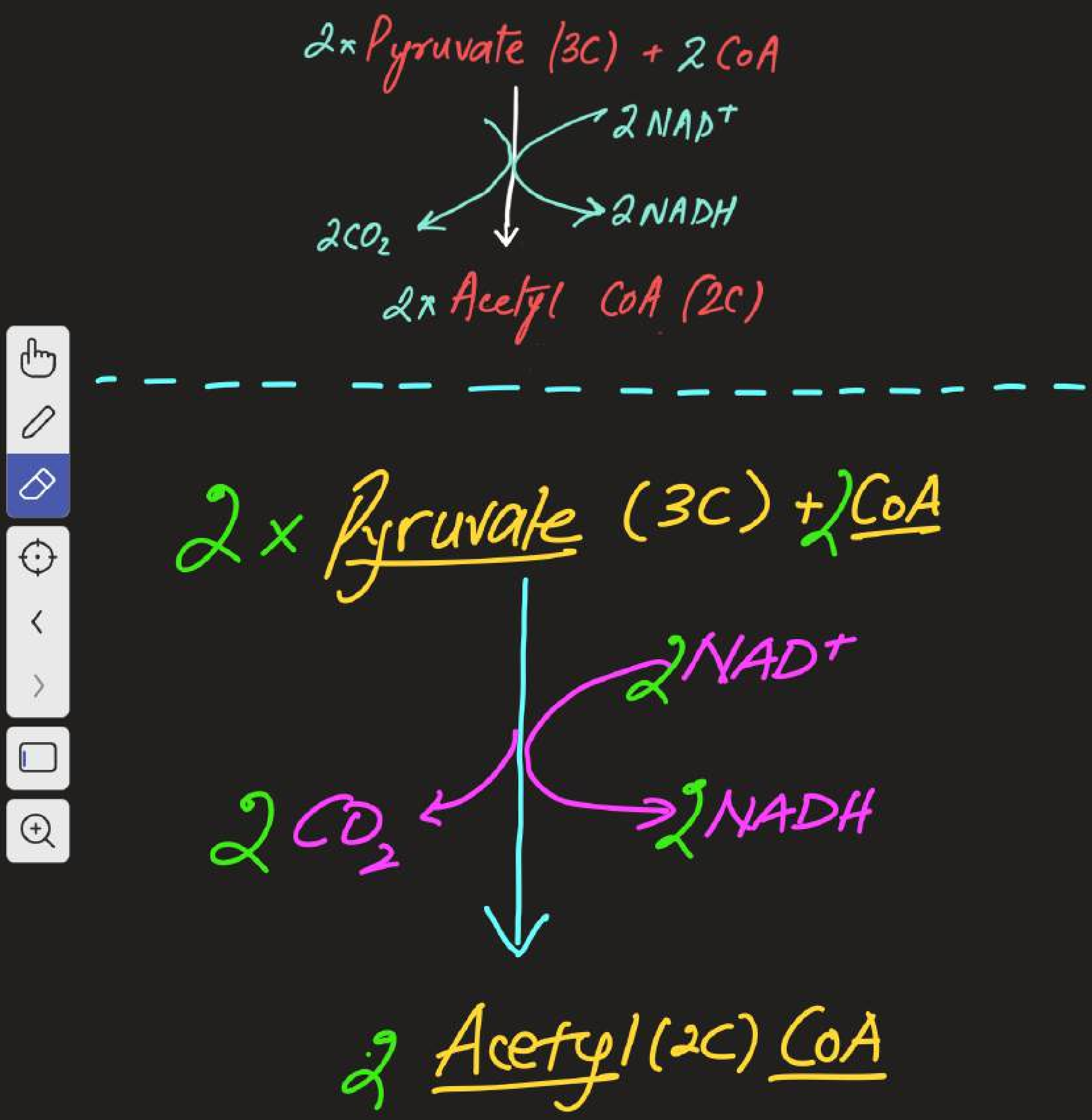
* It occurs in the matrix of the mitochondrion.

* It's an oxygen dependent process.

* Yield of link reaction per molecule of glucose:

- 2 molecules of NADH
- 2 molecules of CO_2
- 2 molecules of acetyl CoA




2× Pyruvate (3C) + 2 CoA
2 NAD+
2 NADH
2CO2
2× Acetyl CoA (2C)
2 × Pyruvate (3C) + 2 CoA
2 NAD+
2 CO2
2 NADH
2 Acetyl (2C) CoA

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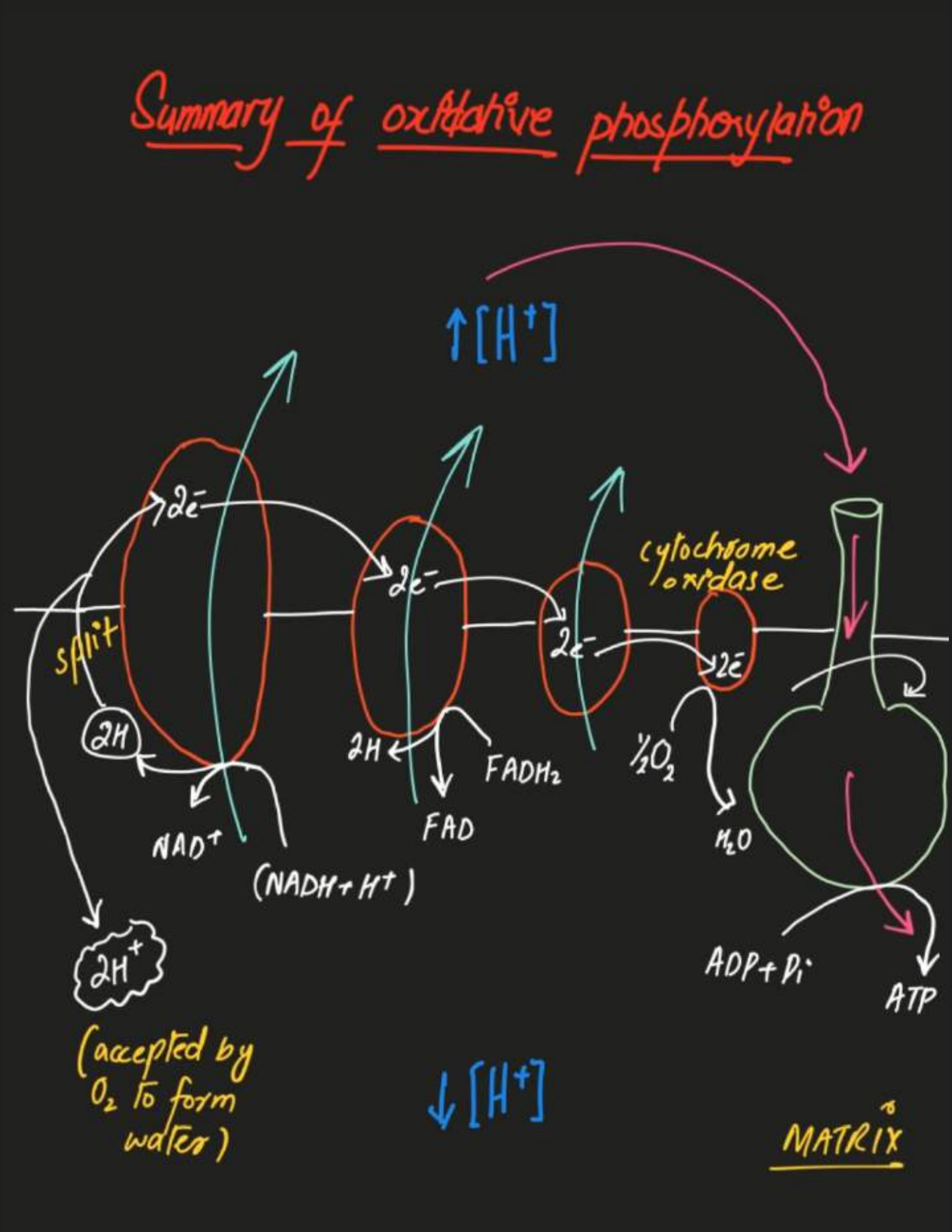
Energy & Respiration



With

Mohammad Hussham Arshad, MD

ADVANCED LEVEL BIOLOGY 9700

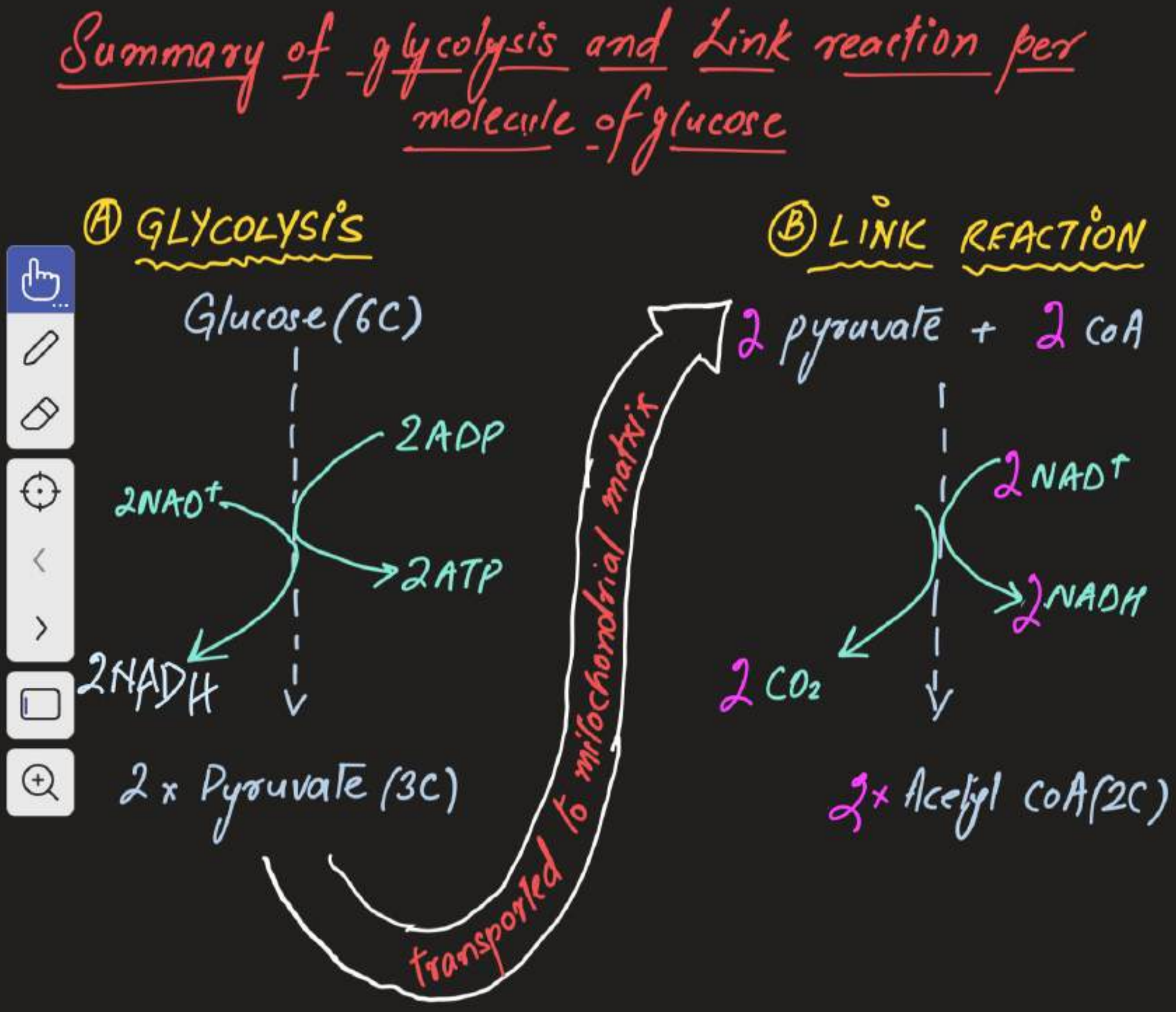
UNIT 12: ENERGY AND RESPIRATION

Learning Objectives:

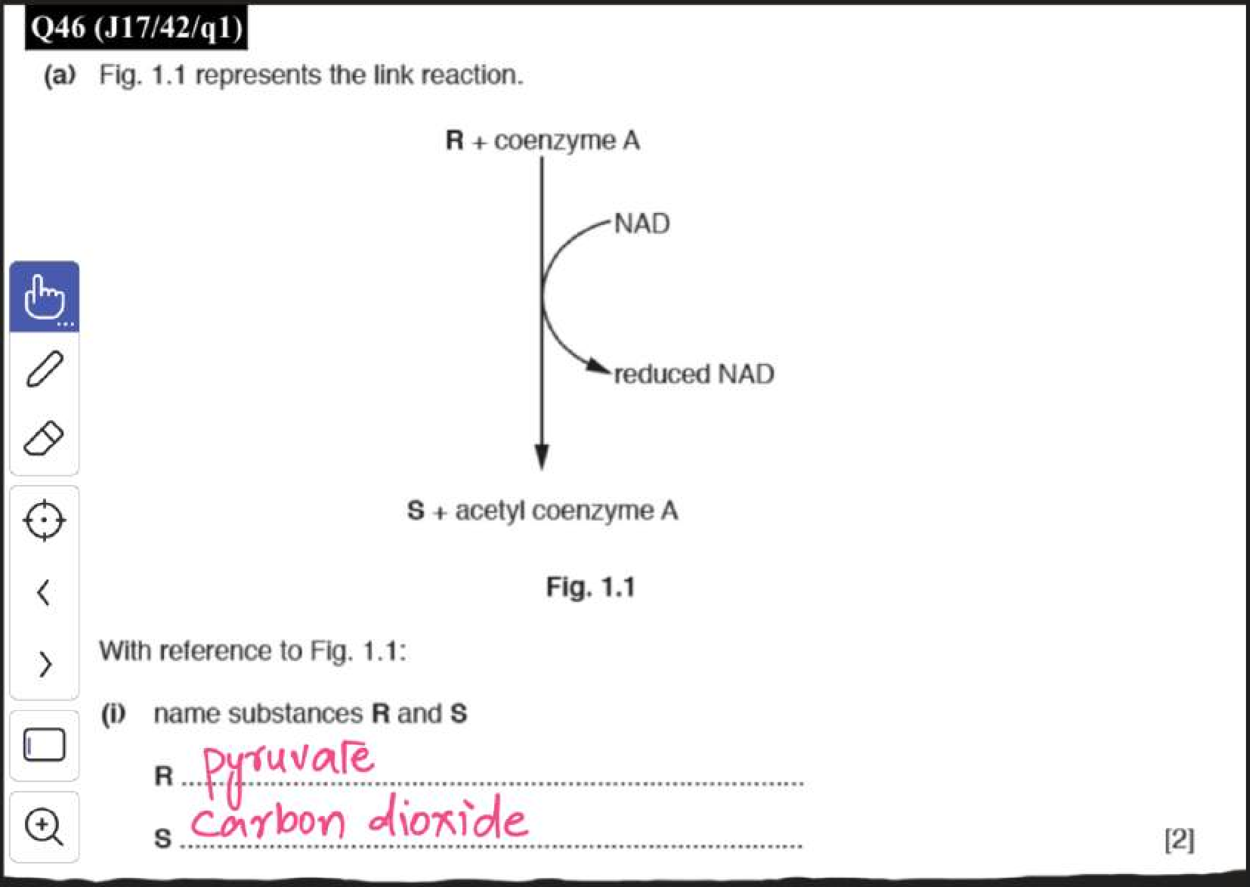
- Kreb Cycle

Video Lecture 3 Slides

Mohammad Hussham Arshad, MD
Biology Department



Summary of glycolysis and Link reaction per molecule of glucose



Q46 (J17/42/q1)

(a) Fig. 1.1 represents the link reaction.

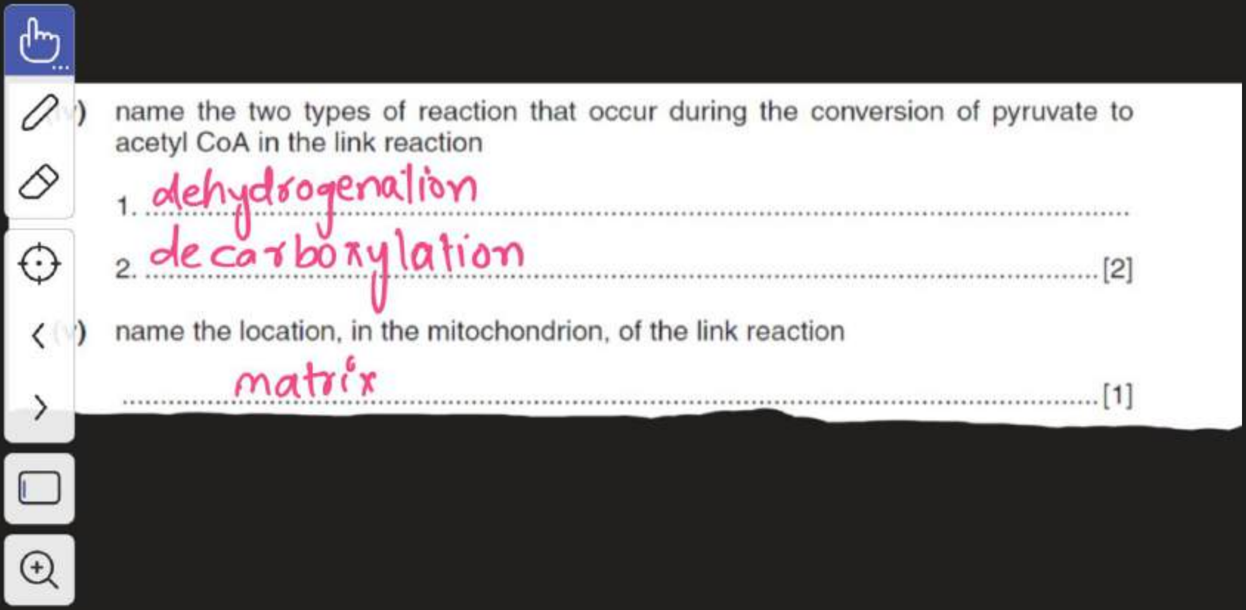
Fig. 1.1

With reference to Fig. 1.1:

(i) name substances **R** and **S**

R pyruvate

S carbon dioxide [2]



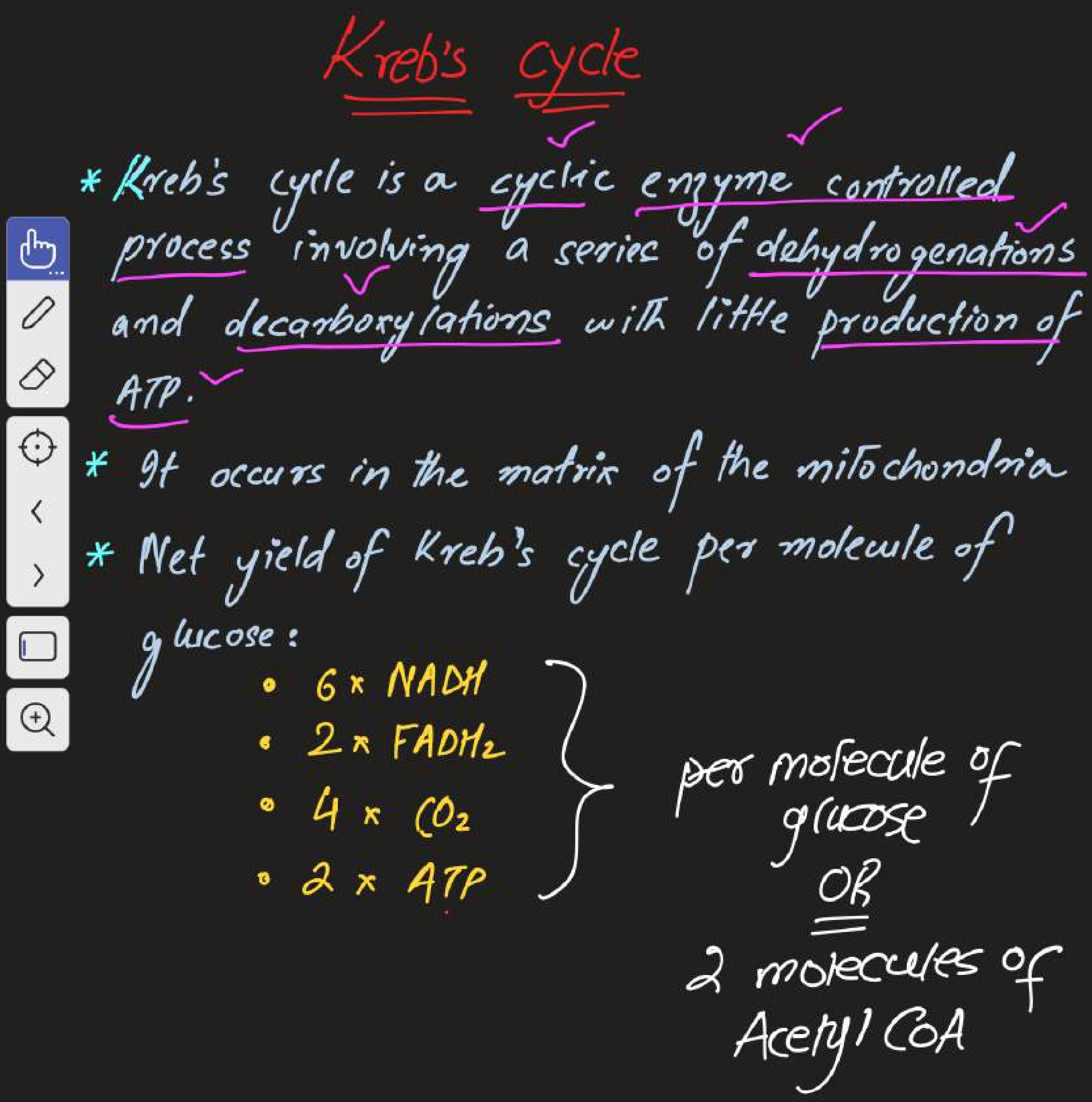
(iv) name the two types of reaction that occur during the conversion of pyruvate to acetyl CoA in the link reaction

1. dehydrogenation

2. decarboxylation [2]

(v) name the location, in the mitochondrion, of the link reaction

matrix [1]



Kreb's cycle

* Kreb's cycle is a cyclic enzyme controlled process involving a series of dehydrogenations and decarboxylations with little production of ATP.
* It occurs in the matrix of the mitochondria
* Net yield of Kreb's cycle per molecule of glucose:
  - 6 × NADH
  - 2 × $FADH_2$
  - 4 × CO_2
  - 2 × ATP

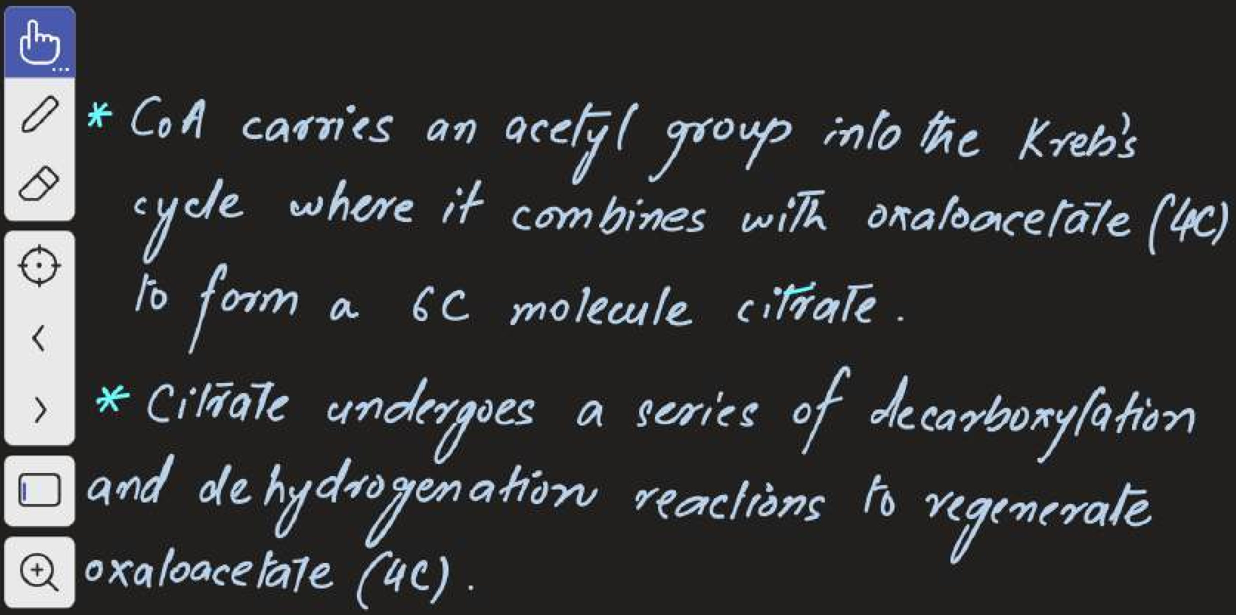
per molecule of glucose

OR

2 molecules of Acetyl CoA

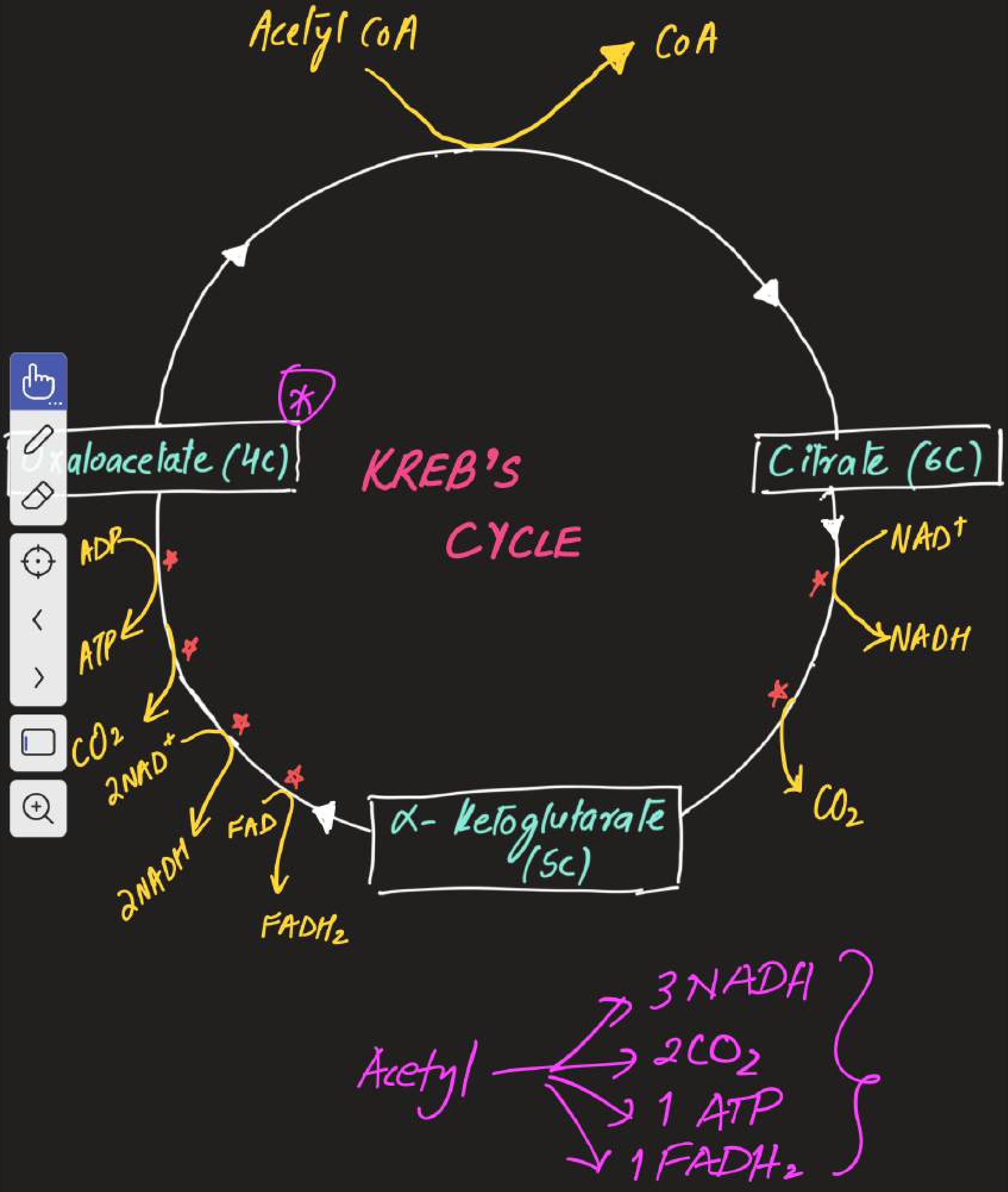
Sir Hans Kreb's

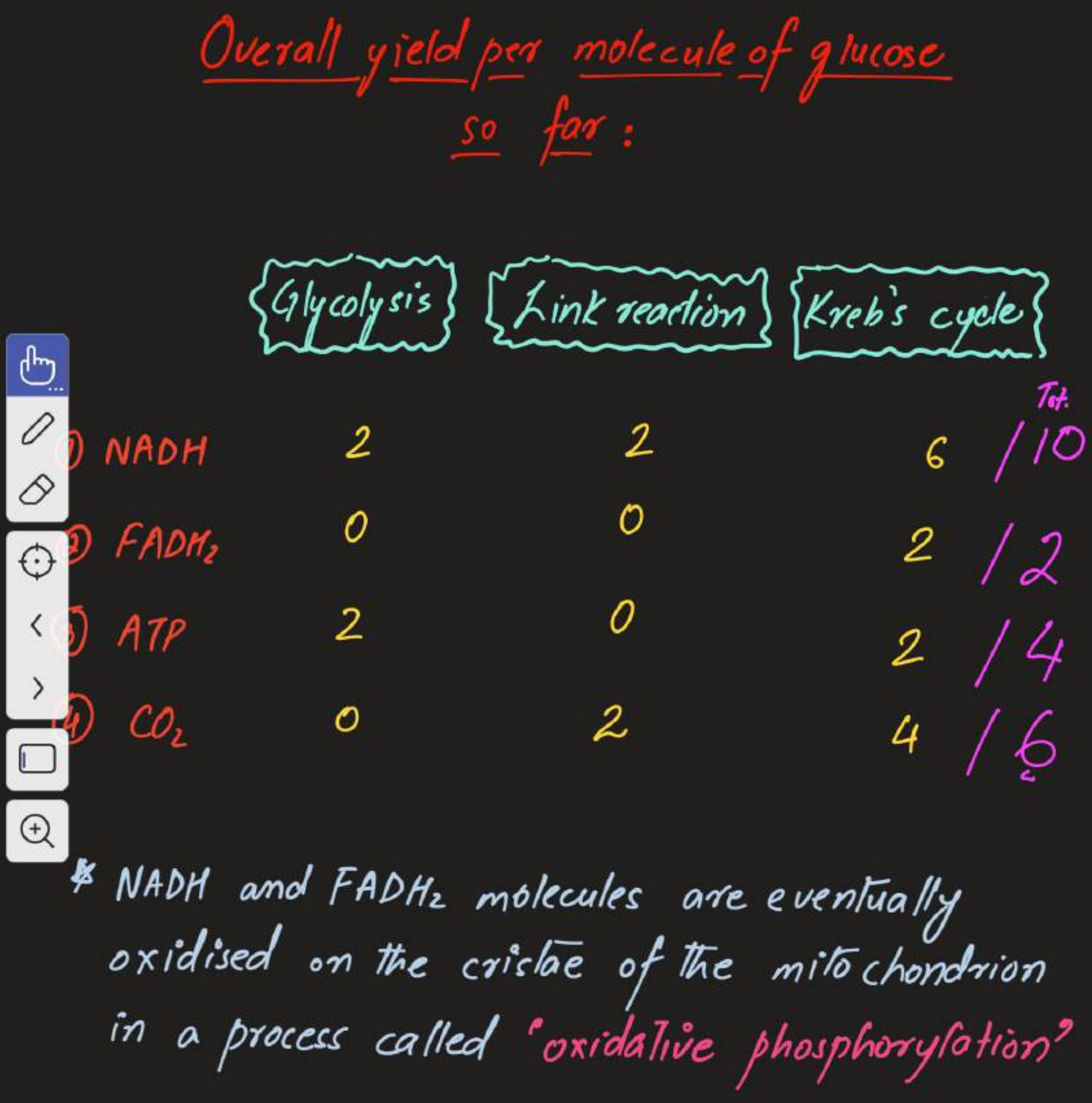
* Kreb's cycle is also known by the following names:
  - Tricarboxylic acid cycle (TCA cycle)
  - Citric acid cycle.



* CoA carries an acetyl group into the Kreb's cycle where it combines with oxaloacetate (4C) to form a 6C molecule citrate.

* Citrate undergoes a series of decarboxylation and dehydrogenation reactions to regenerate oxaloacetate (4C).

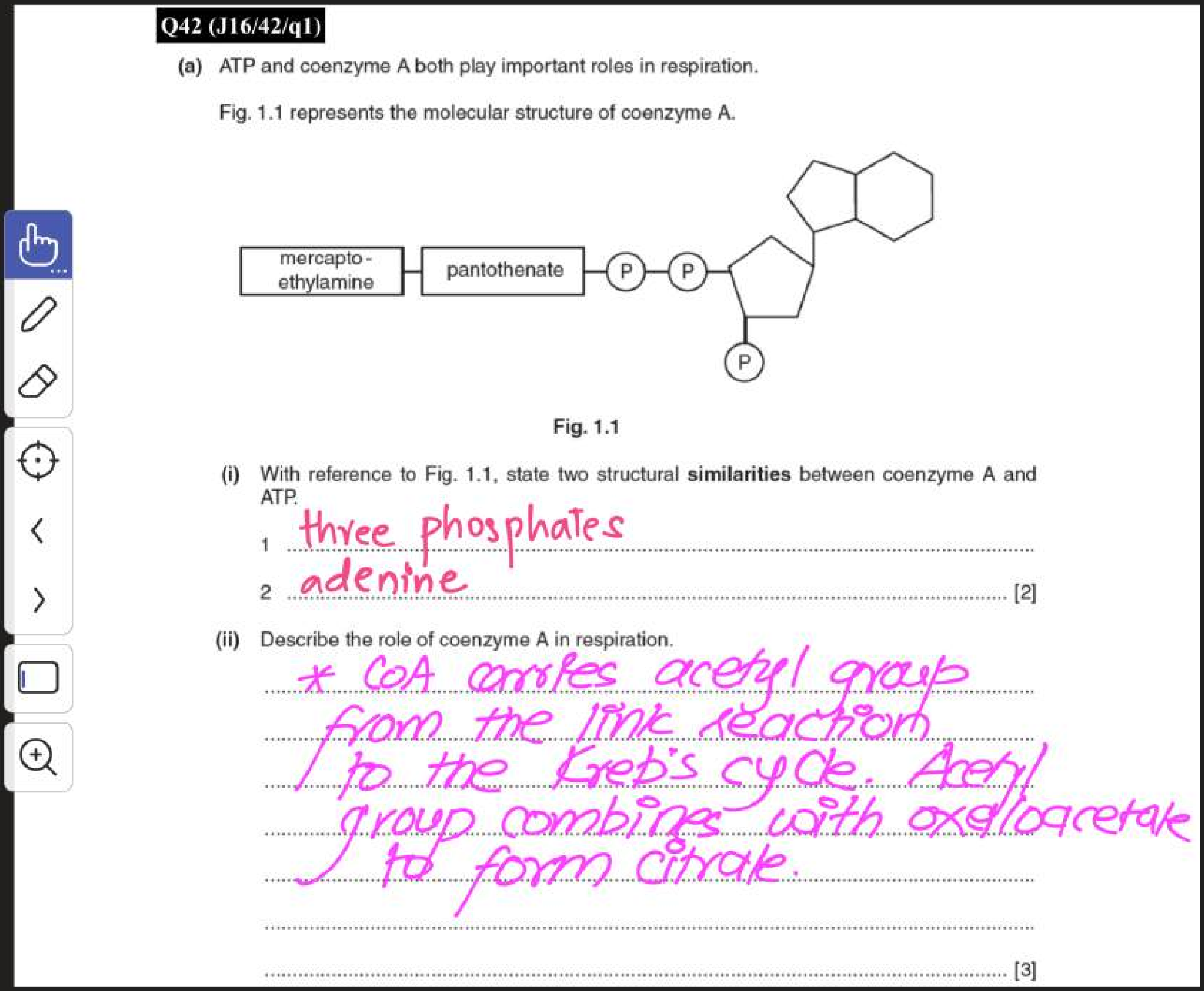

Acetyl CoA
CoA
Oxaloacetate (4C)
KREB's CYCLE
Citrate (6C)
NAD+
NADH
CO2
α- ketoglutarate (5C)
FAD
FADH2
2NAD+
2NADH
CO2
ADP
ATP
Acetyl
3 NADH
2CO2
1 ATP
1 FADH2



Overall yield per molecule of glucose so far:

	Glycolysis	Link reaction	Kreb's cycle	Tot.
① NADH	2	2	6	10
② $FADH_2$	0	0	2	2
③ ATP	2	0	2	4
④ CO_2	0	2	4	6

* NADH and $FADH_2$ molecules are eventually oxidised on the cristae of the mitochondrion in a process called 'oxidative phosphorylation'



Q42 (J16/42/q1)

(a) ATP and coenzyme A both play important roles in respiration.

Fig. 1.1 represents the molecular structure of coenzyme A.

Fig. 1.1

(i) With reference to Fig. 1.1, state two structural **similarities** between coenzyme A and ATP.

1 three phosphates

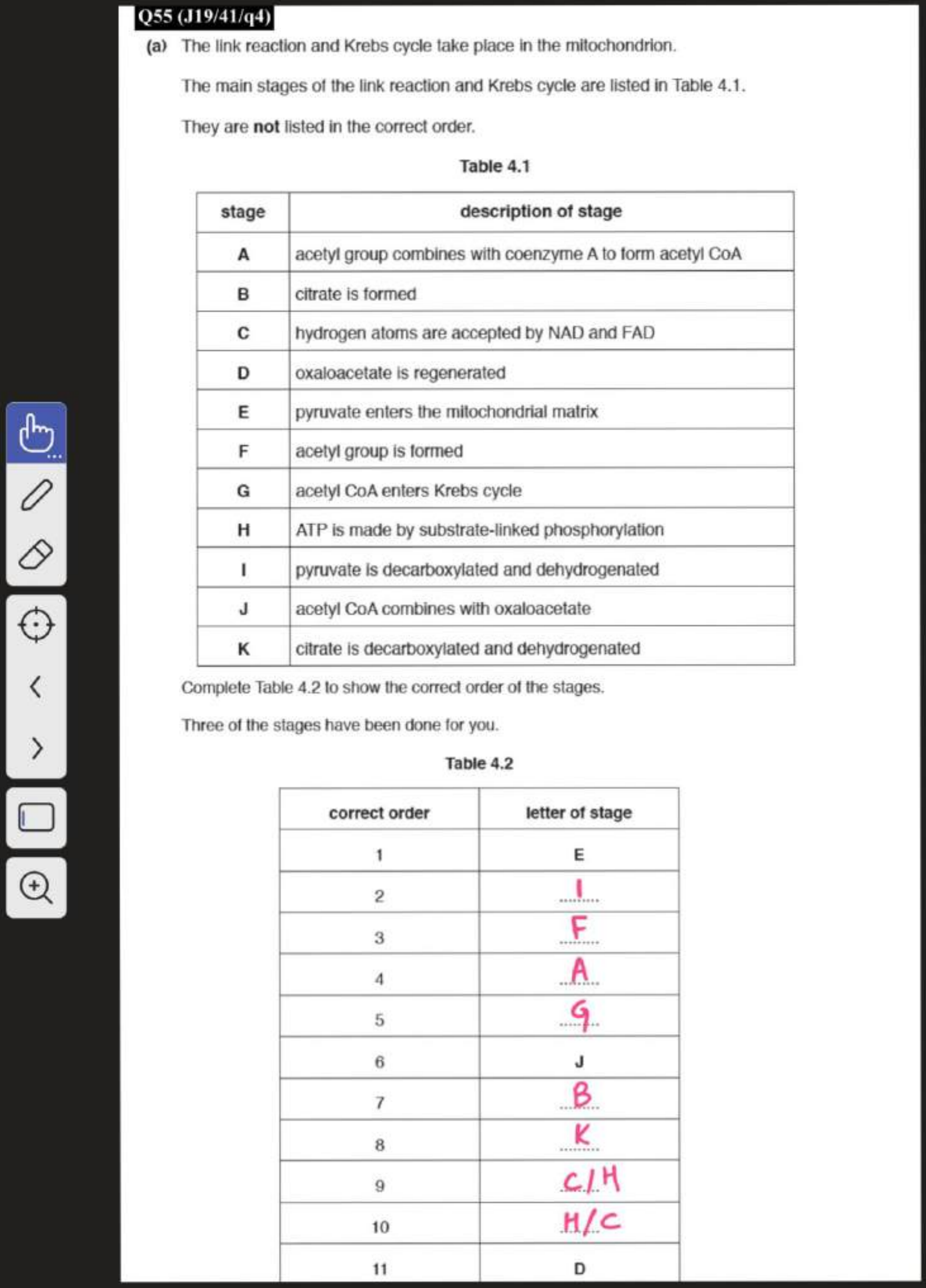
2 adenine [2]

(ii) Describe the role of coenzyme A in respiration.

* CoA carries acetyl group from the link reaction to the Kreb's cycle. Acetyl group combines with oxaloacetate to form citrate.

[3]

$$\underset{(3C)}{\text{Pyruvate}} \xrightarrow[\textcircled{2}]{\textcircled{1}} \underset{(2C)}{\text{Acetyl}} \xrightarrow{\text{CoA}} \text{Acetyl CoA}$$



Q55 (J19/41/q4)

(a) The link reaction and Krebs cycle take place in the mitochondrion.

The main stages of the link reaction and Krebs cycle are listed in Table 4.1.

They are **not** listed in the correct order.

Table 4.1

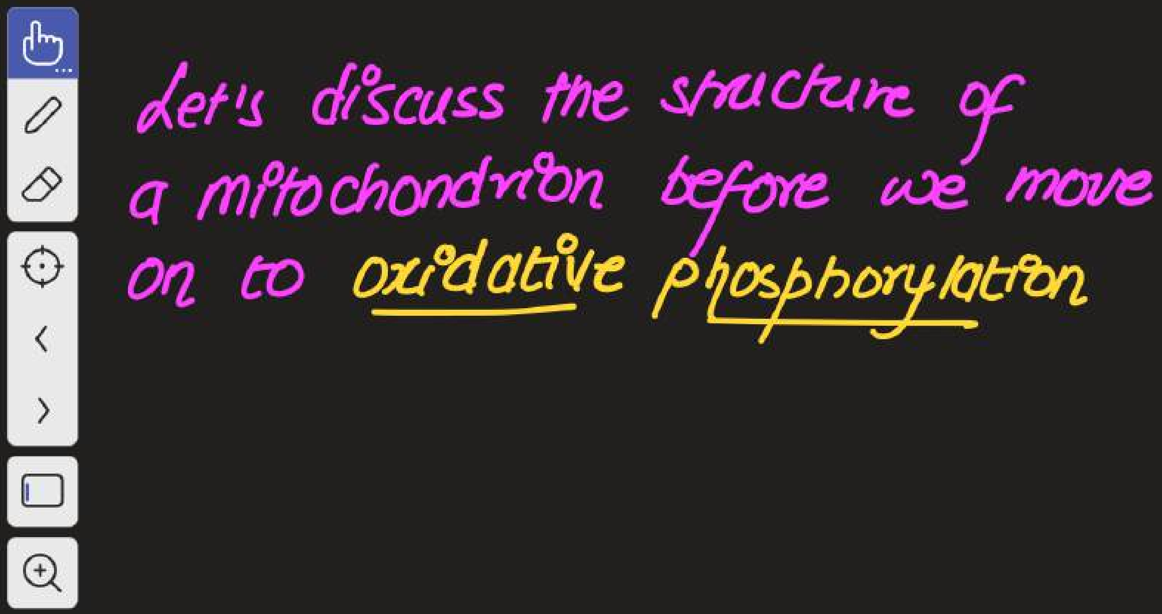
stage	description of stage
A	acetyl group combines with coenzyme A to form acetyl CoA
B	citrate is formed
C	hydrogen atoms are accepted by NAD and FAD
D	oxaloacetate is regenerated
E	pyruvate enters the mitochondrial matrix
F	acetyl group is formed
G	acetyl CoA enters Krebs cycle
H	ATP is made by substrate-linked phosphorylation
I	pyruvate is decarboxylated and dehydrogenated
J	acetyl CoA combines with oxaloacetate
K	citrate is decarboxylated and dehydrogenated

Complete Table 4.2 to show the correct order of the stages.

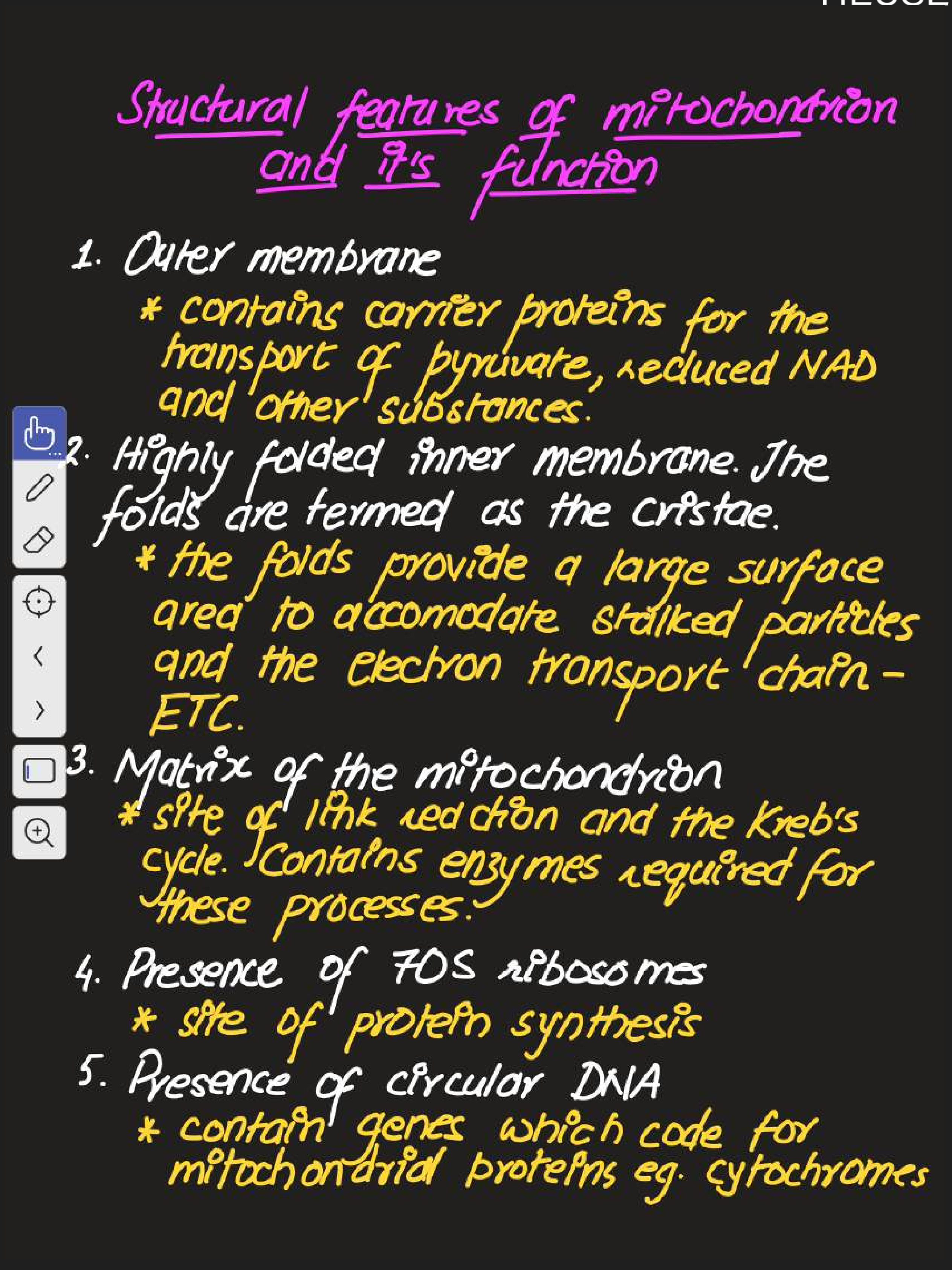
Three of the stages have been done for you.

Table 4.2

correct order	letter of stage
1	E
2	I
3	F
4	A
5	G
6	J
7	B
8	K
9	C/H
10	H/C
11	D



Let's discuss the structure of a mitochondrion before we move on to oxidative phosphorylation



Structural features of mitochondrion and it's function

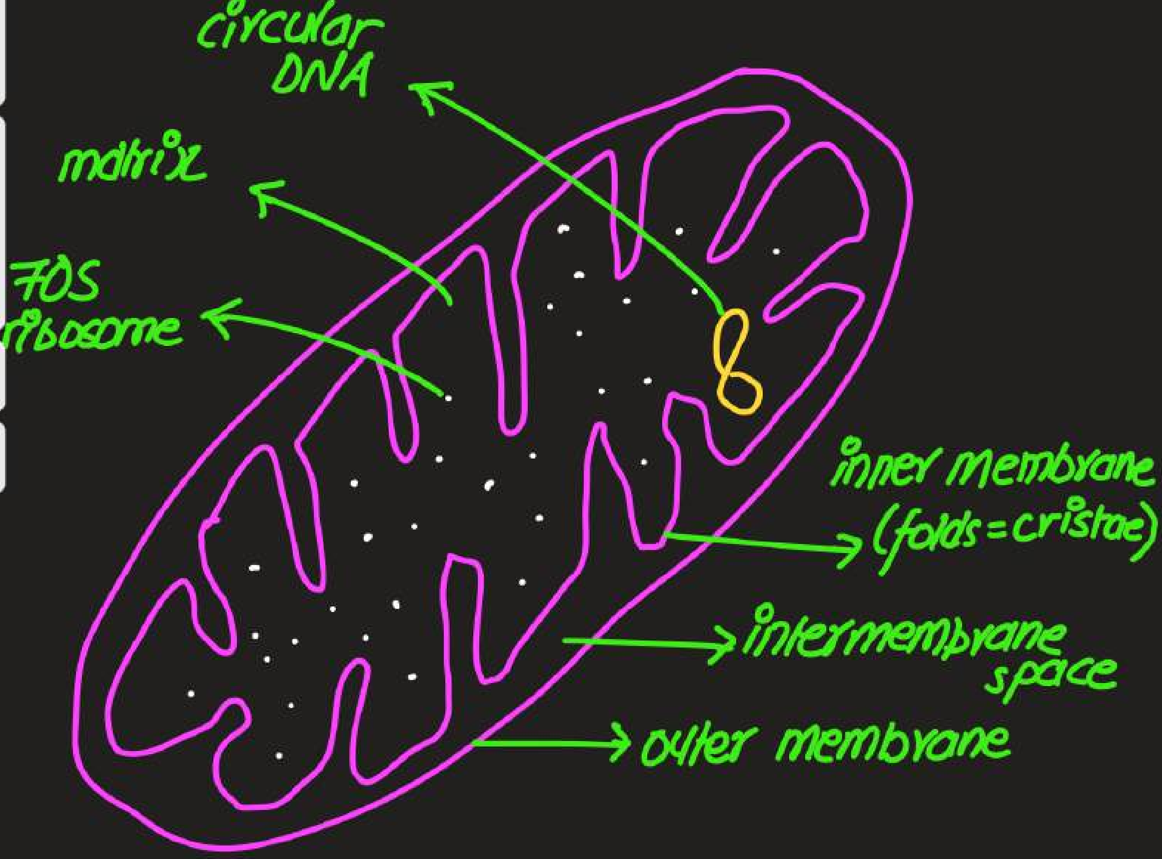
1. Outer membrane
   * contains carrier proteins for the transport of pyruvate, reduced NAD and other substances.
2. Highly folded inner membrane. The folds are termed as the cristae.
   * the folds provide a large surface area to accomodate stalked particles and the electron transport chain - ETC.
3. Matrix of the mitochondrion
   * site of link reaction and the Kreb's cycle. Contains enzymes required for these processes.
4. Presence of 70S ribosomes
   * site of protein synthesis
5. Presence of circular DNA
   * contain genes which code for mitochondrial proteins eg. cytochromes

6. Inner membrane is impermeable to H^+

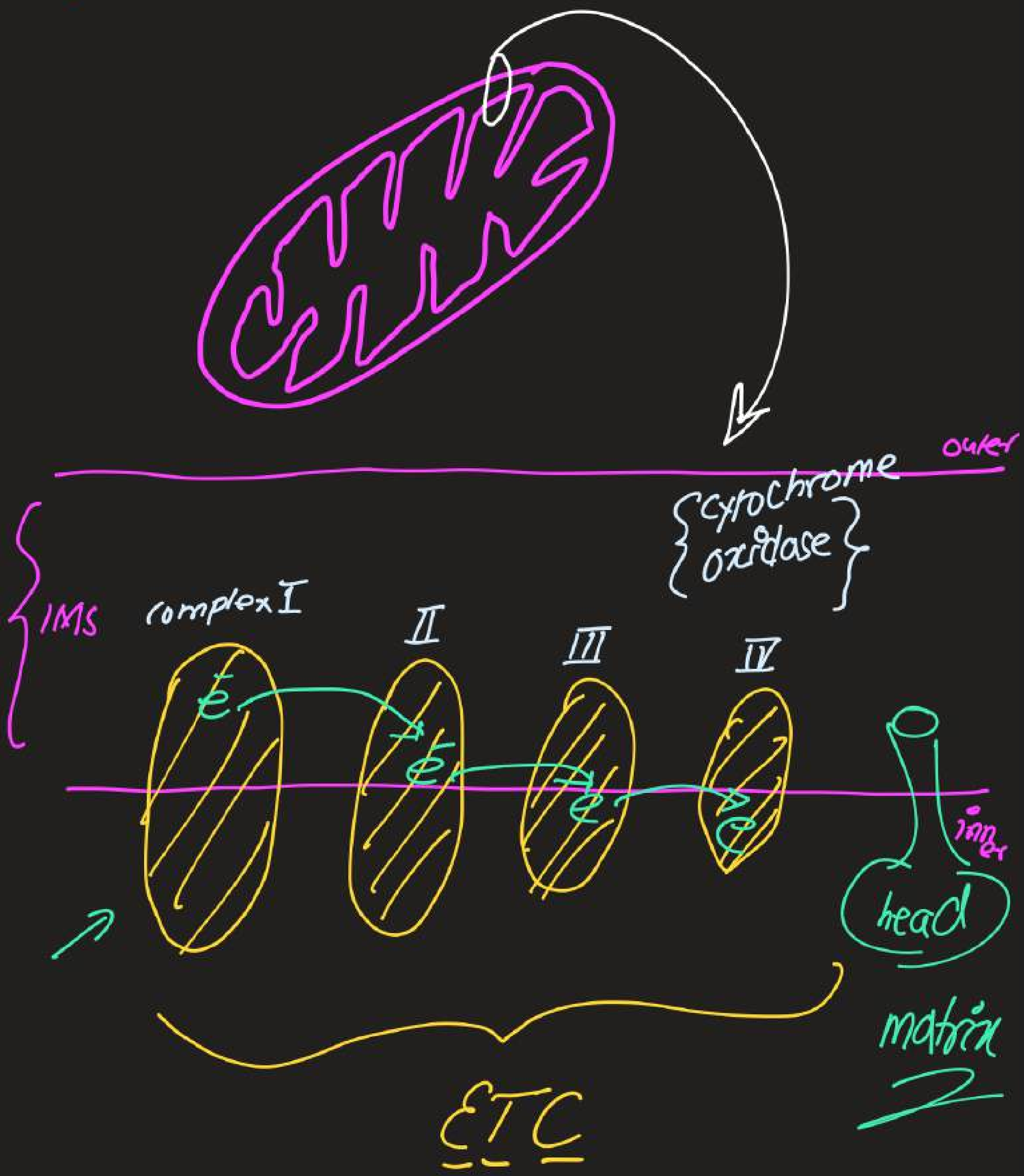
   * enables creation of the proton motive force (pmf).

7. The intermembrane space

   * contains a higher concentration of H^+ relative to the matrix



Arrangement of the ETC & Stalked particles



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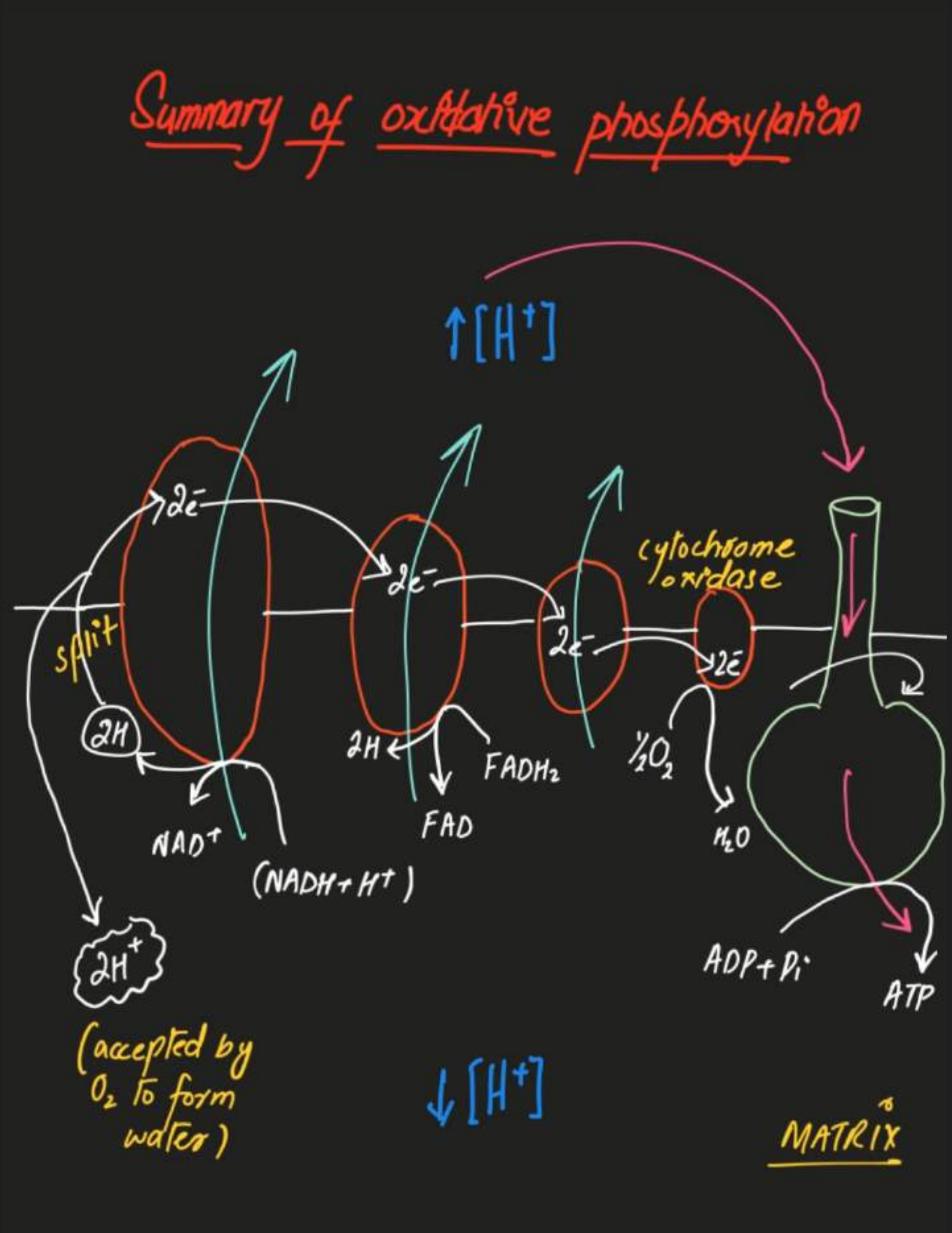
Energy & Respiration



With

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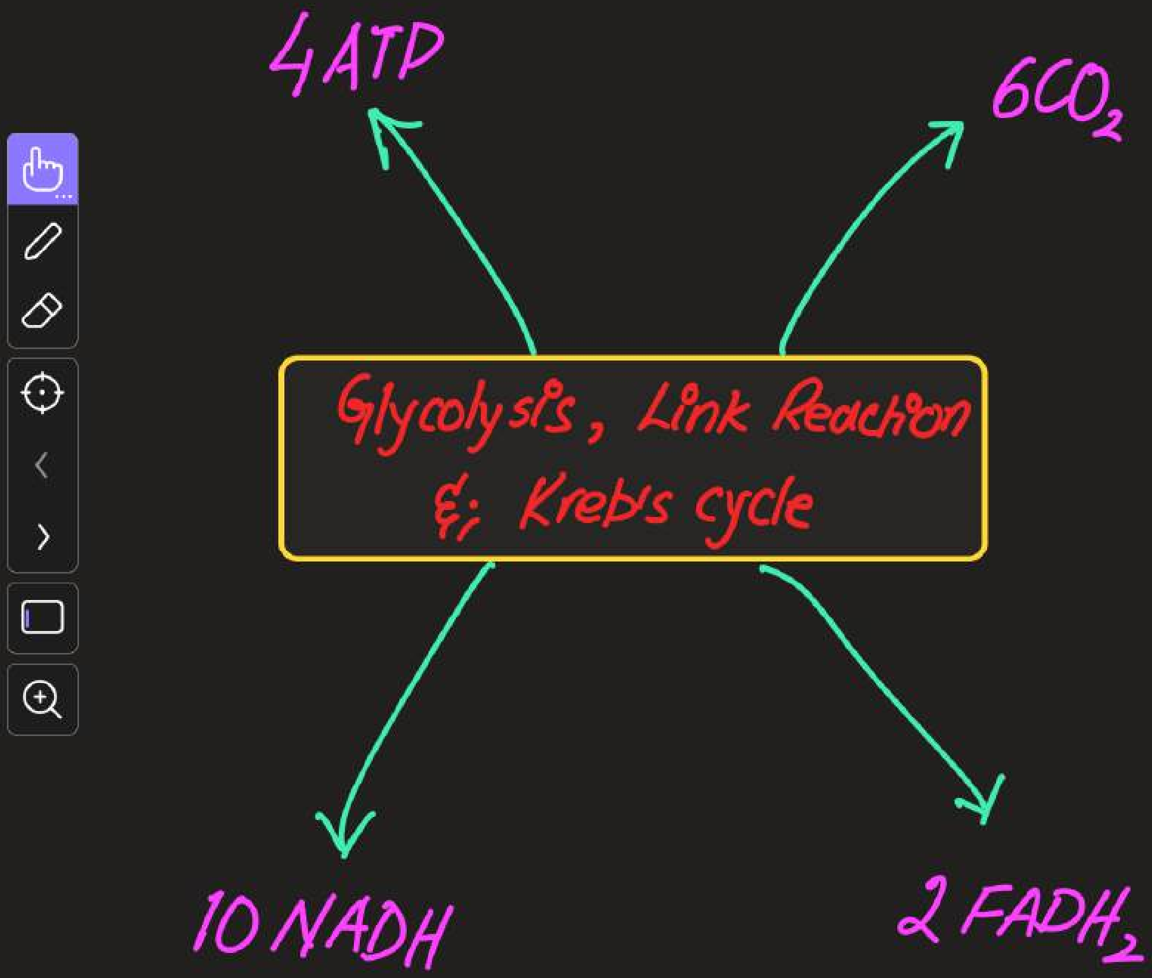
UNIT 12: ENERGY AND RESPIRATION

Learning Objectives:

- Oxidative Phosphorylation

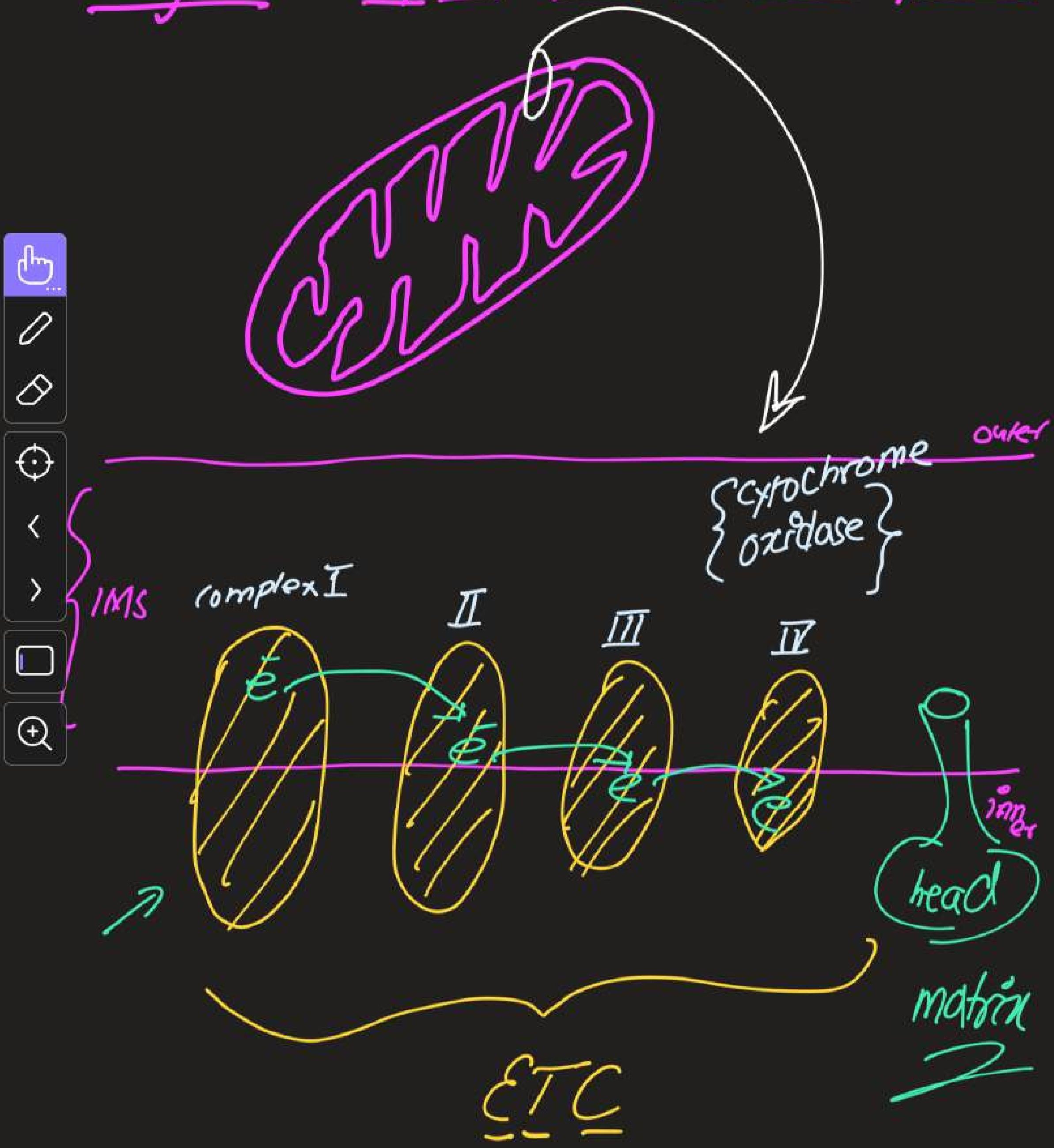
Video Lecture 6 Slides
Mohammad Hussham Arshad, MD
Biology Department

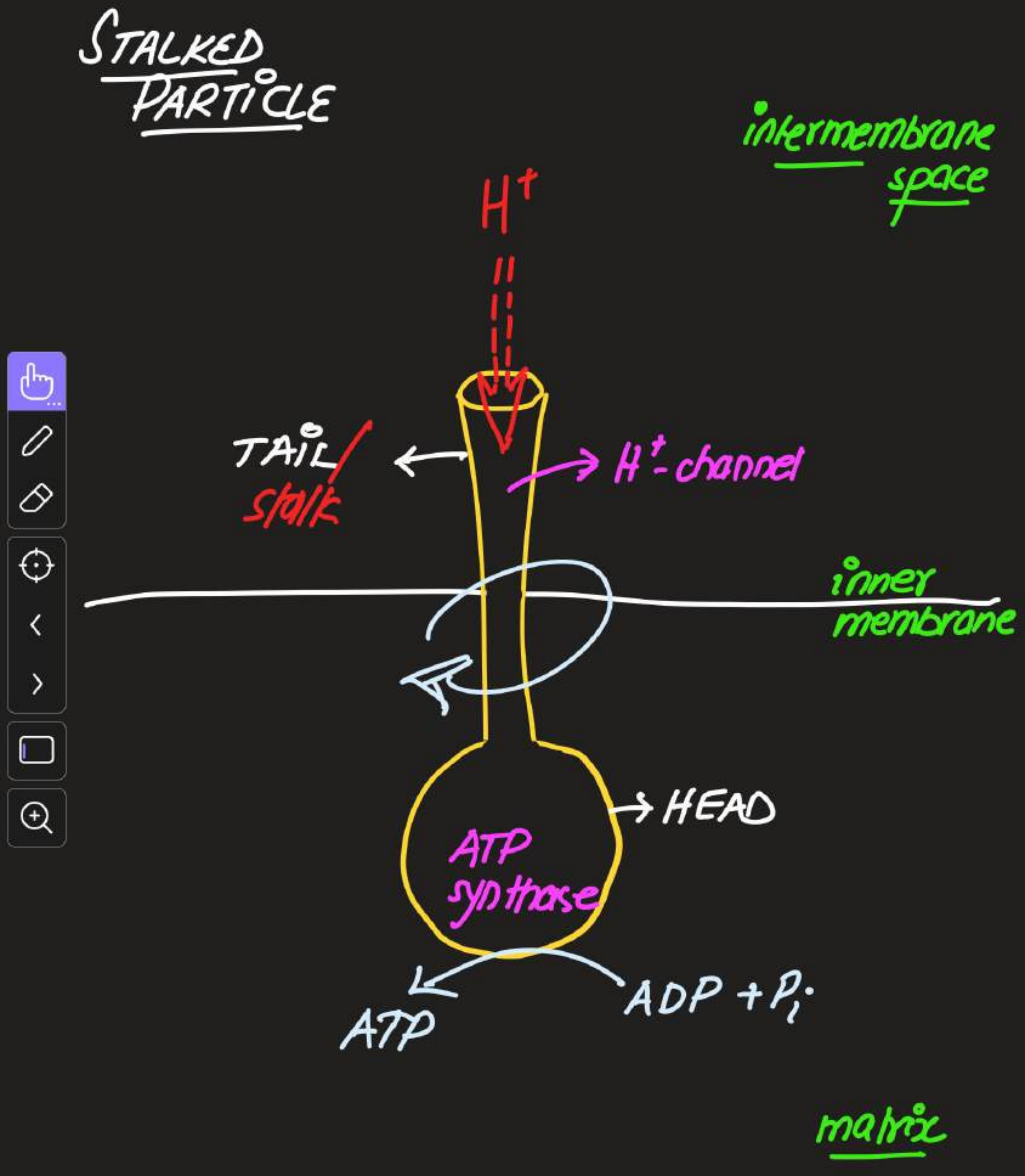
Previously .....


4 ATP
6CO2
Glycolysis, Link Reaction &; Krebs cycle
10 NADH
2 FADH2

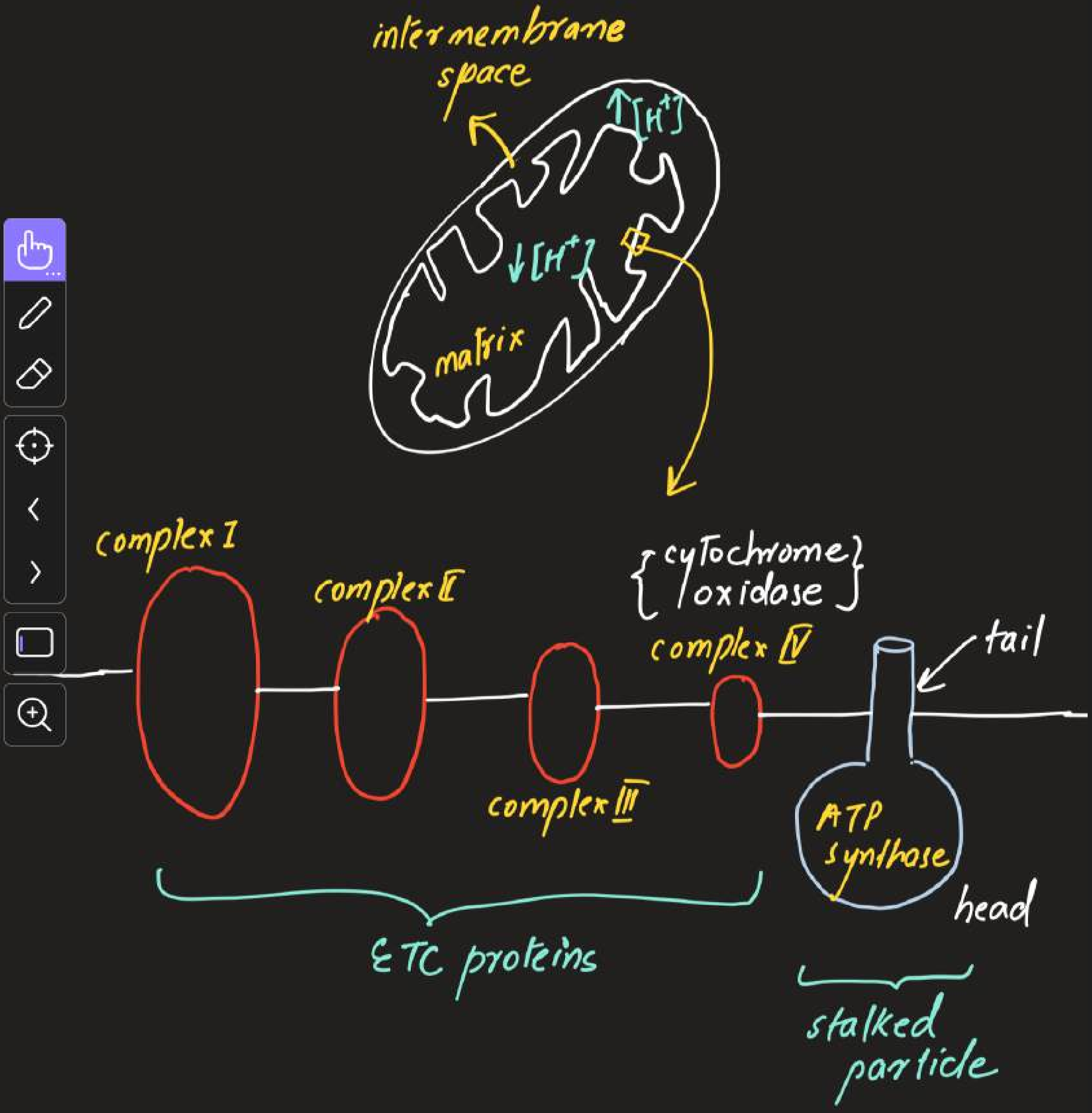
Previously ......

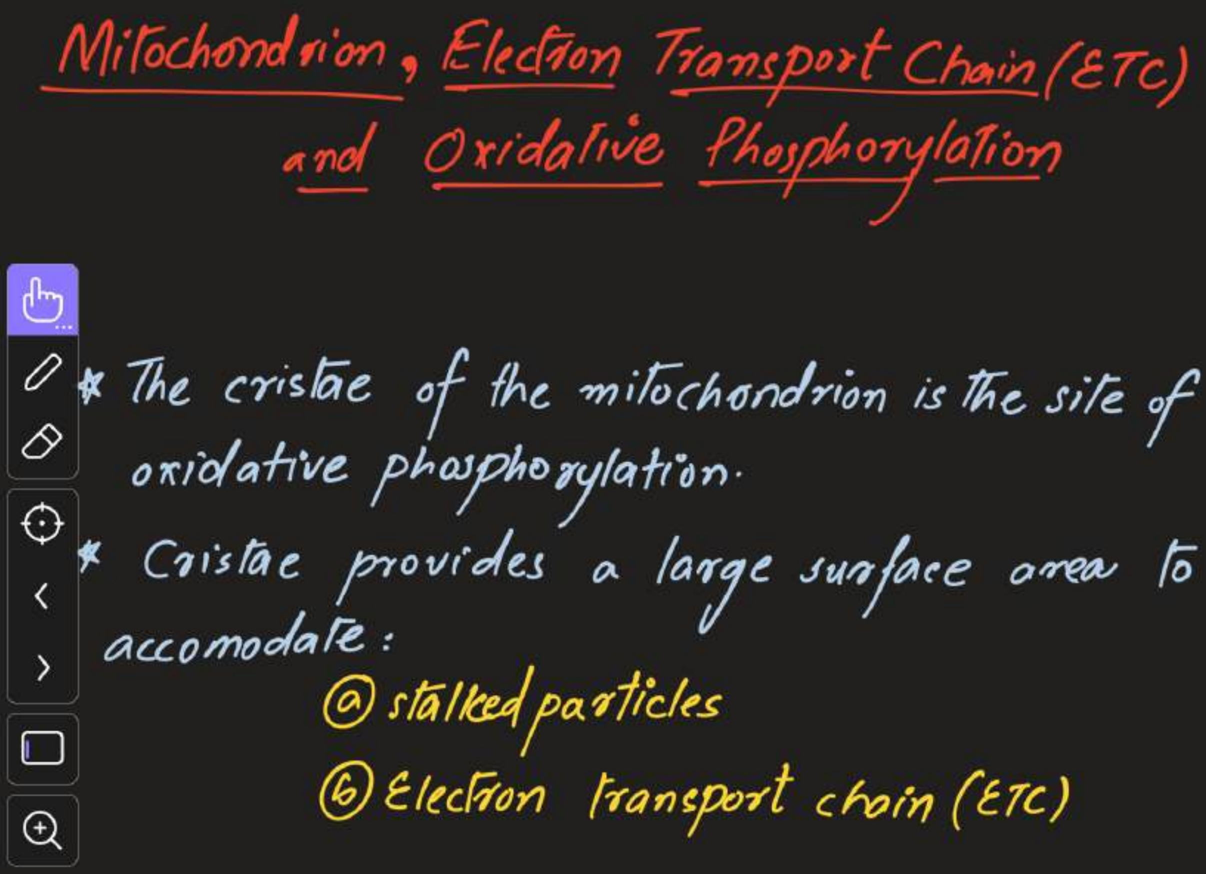
Arrangement of the ETC & Stalked particles




STALKED PARTICLE
intermembrane space
H+
TAIL/stalk
H+-channel
inner membrane
HEAD
ATP synthase
ATP
ADP + Pi
matrix

Arrangement of the ETC & Stalked particles





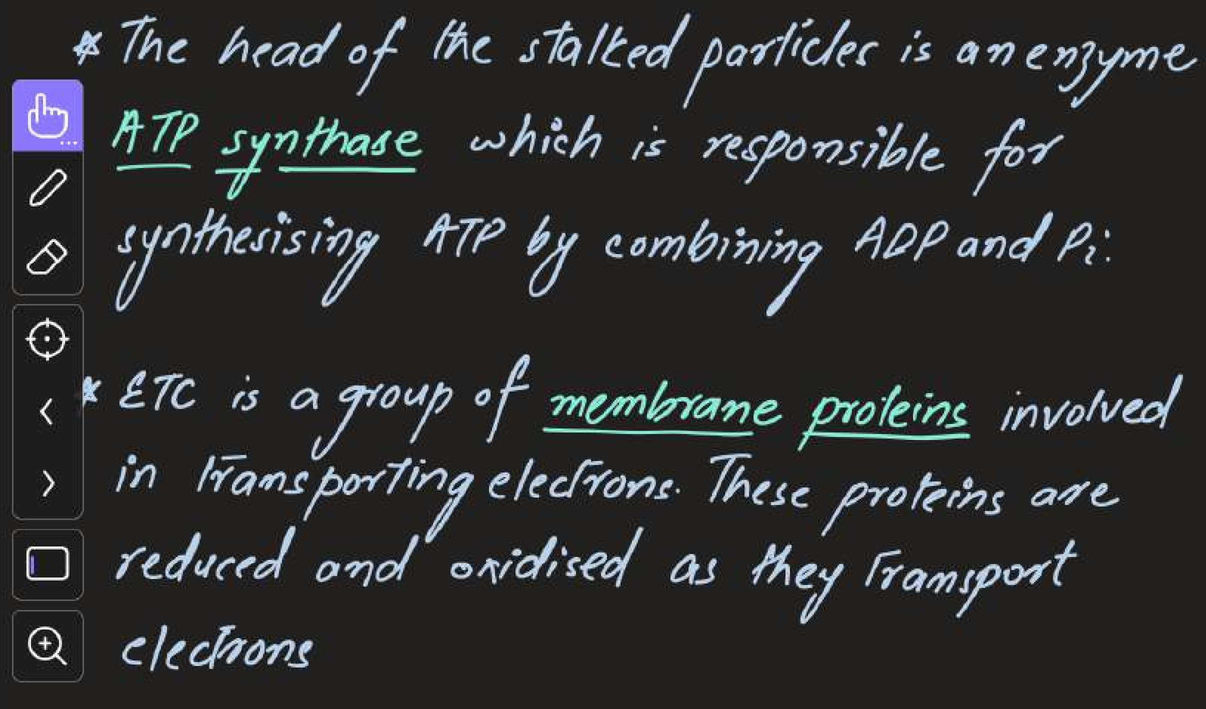
Mitochondrion, Electron Transport Chain (ETC) and Oxidative Phosphorylation

* The cristae of the mitochondrion is the site of oxidative phosphorylation.

* Cristae provides a large surface area to accomodate:

ⓐ stalked particles

ⓑ Electron transport chain (ETC)



* The head of the stalked particles is an enzyme ATP synthase which is responsible for synthesising ATP by combining ADP and P_i:

* ETC is a group of membrane proteins involved in transporting electrons. These proteins are reduced and oxidised as they transport electrons

10 NADH = 30 = ATP

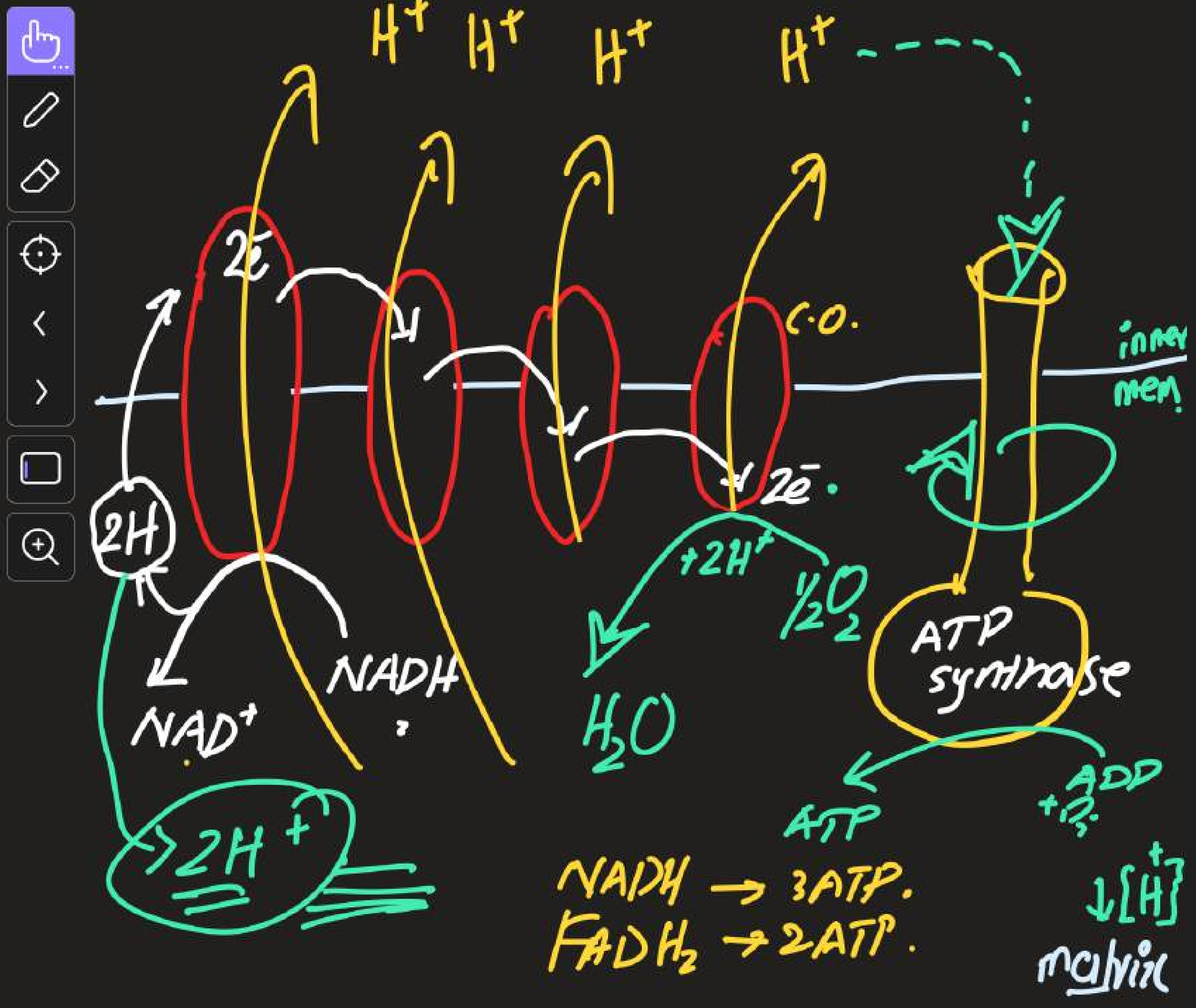
2FADH$_2$ = 4ATP

Oxidative Phosphorylation

↑[H$^+$]

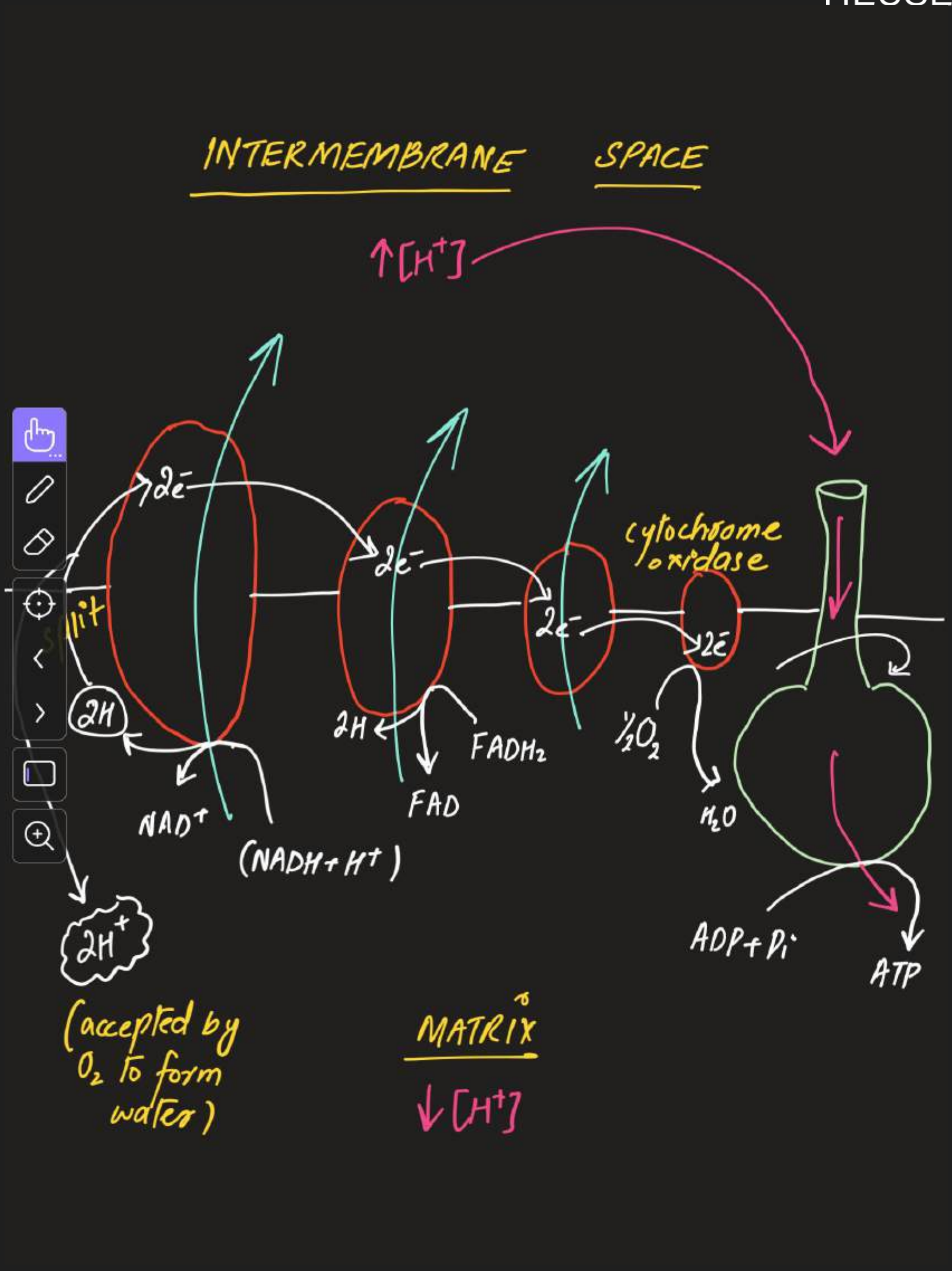
IMS

* production of ATP in the presence of the proton motive force.



NADH → 3ATP.

FADH$_2$ → 2ATP.

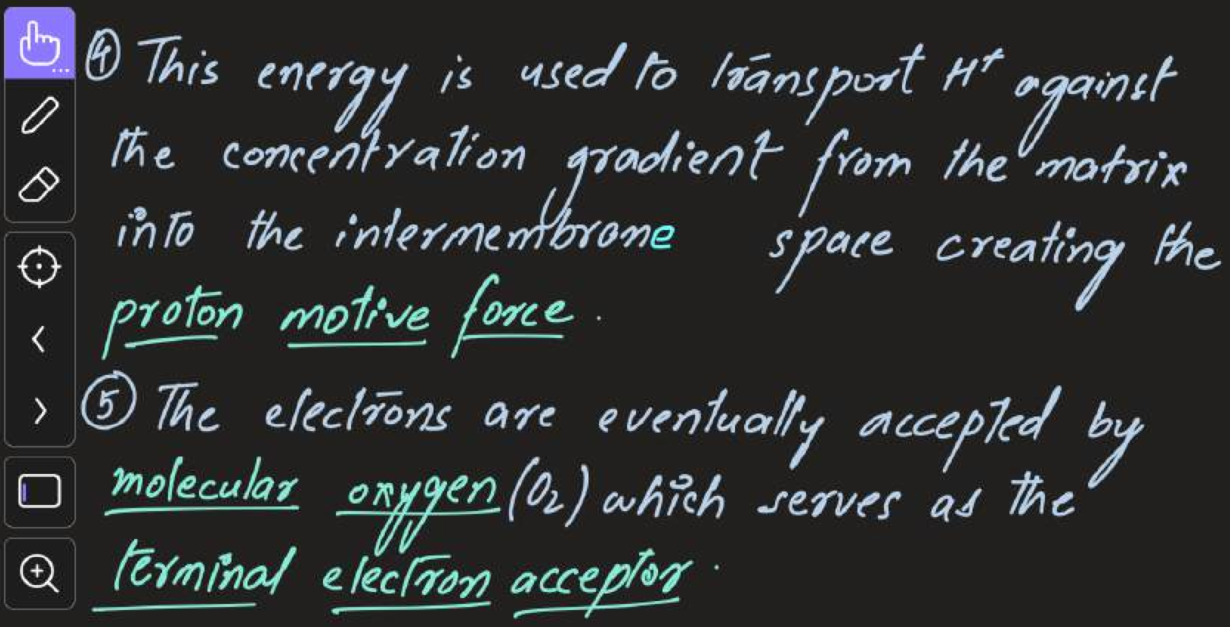

INTERMEMBRANE SPACE
↑[H⁺]
2e⁻
2e⁻
2e⁻
2e⁻
cytochrome oxidase
split
2H
NAD⁺
(NADH+H⁺)
2H
FADH₂
FAD
½O₂
H₂O
ADP+Pi
ATP
2H⁺
(accepted by O₂ to form water)
MATRIX
↓[H⁺]

Oxidative Phosphorylation

① NADH gets oxidised at the ETC releasing hydrogen atoms.

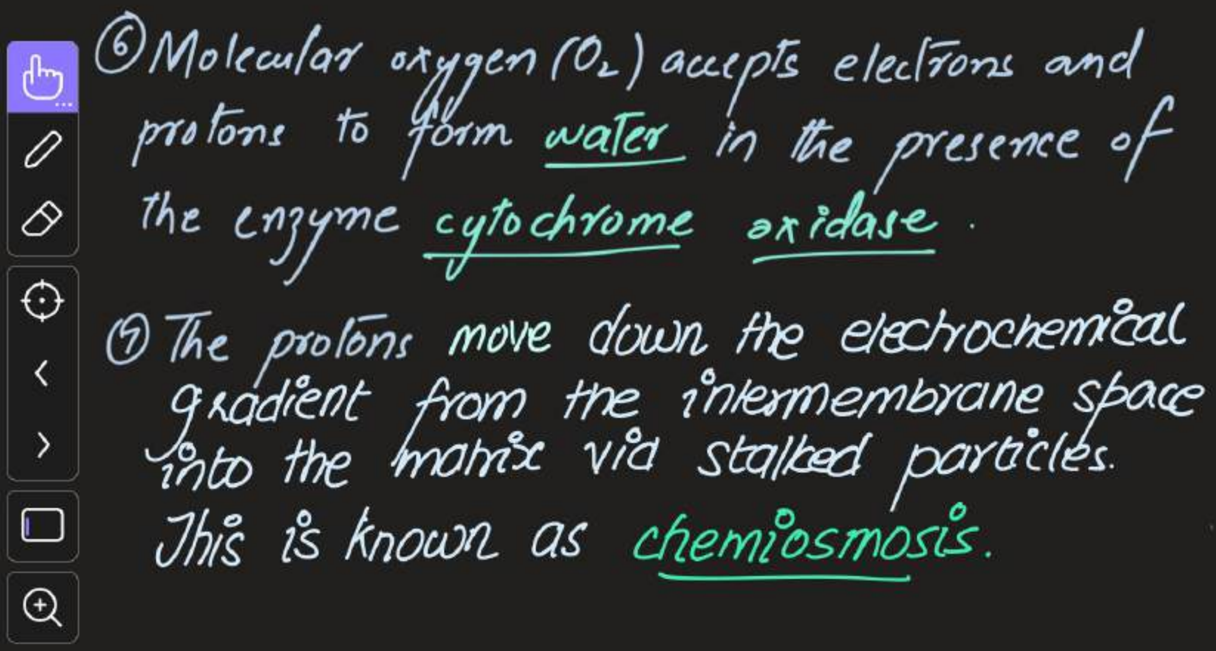
② Hydrogen atoms split to form protons and high energy electrons. The electrons are picked up by the electron transport chain.

③ The electrons lose energy as they move from one ETC protein to another.



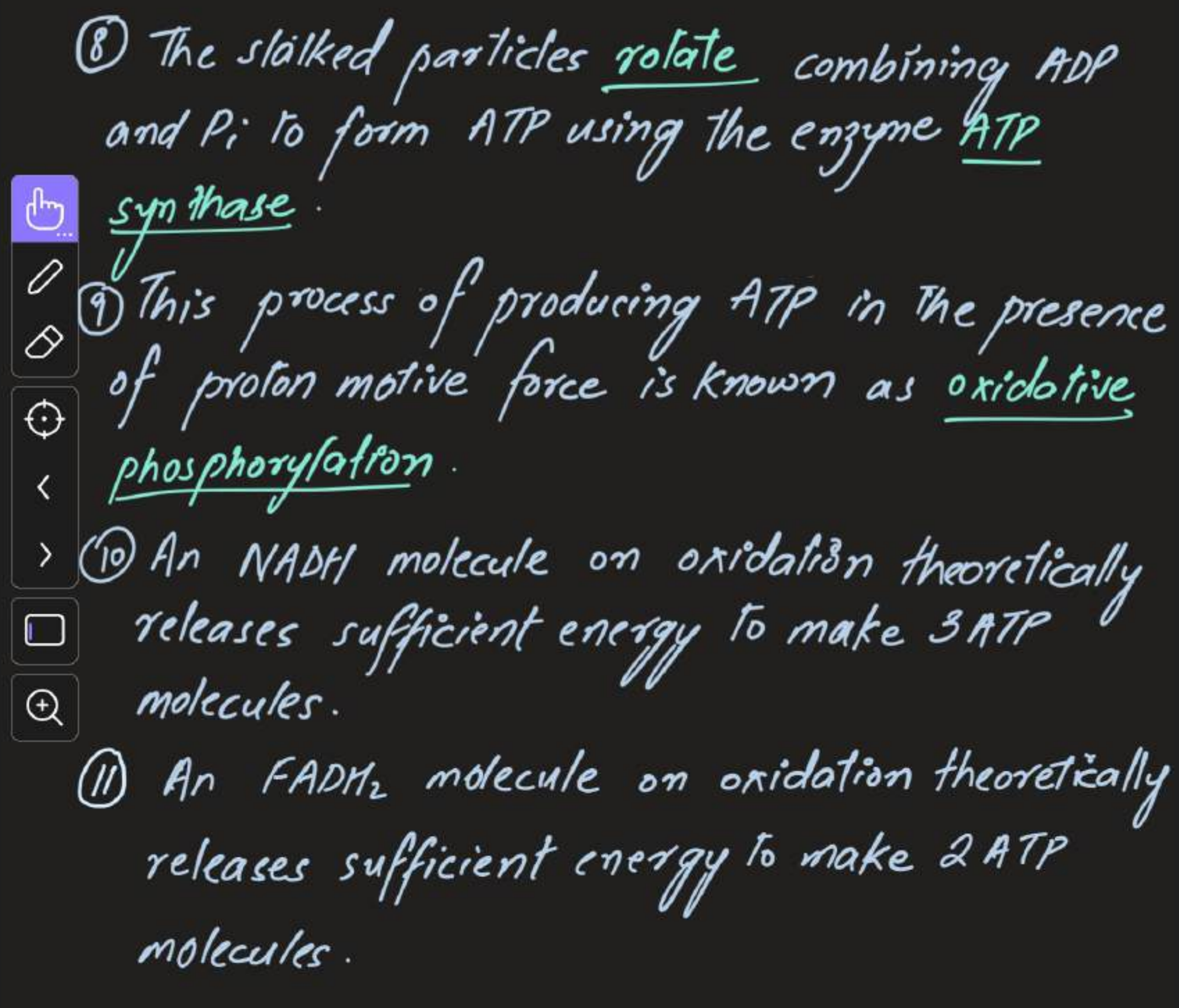
④ This energy is used to transport H^+ against the concentration gradient from the matrix into the intermembrane space creating the proton motive force.

⑤ The electrons are eventually accepted by molecular oxygen (O_2) which serves as the terminal electron acceptor.



⑥ Molecular oxygen (O_2) accepts electrons and protons to form water in the presence of the enzyme cytochrome oxidase.

⑦ The protons move down the electrochemical gradient from the intermembrane space into the matrix via stalked particles. This is known as chemiosmosis.

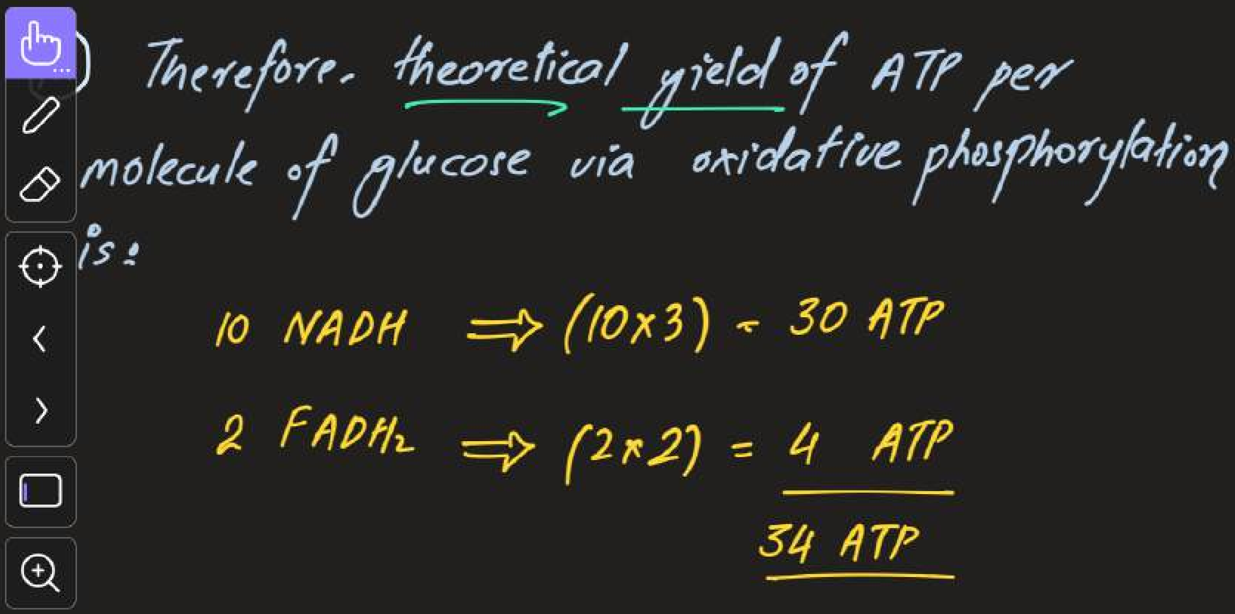


⑧ The stalked particles rotate combining ADP and P_i to form ATP using the enzyme ATP synthase.

⑨ This process of producing ATP in the presence of proton motive force is known as oxidative phosphorylation.

⑩ An NADH molecule on oxidation theoretically releases sufficient energy to make 3 ATP molecules.

⑪ An $FADH_2$ molecule on oxidation theoretically releases sufficient energy to make 2 ATP molecules.

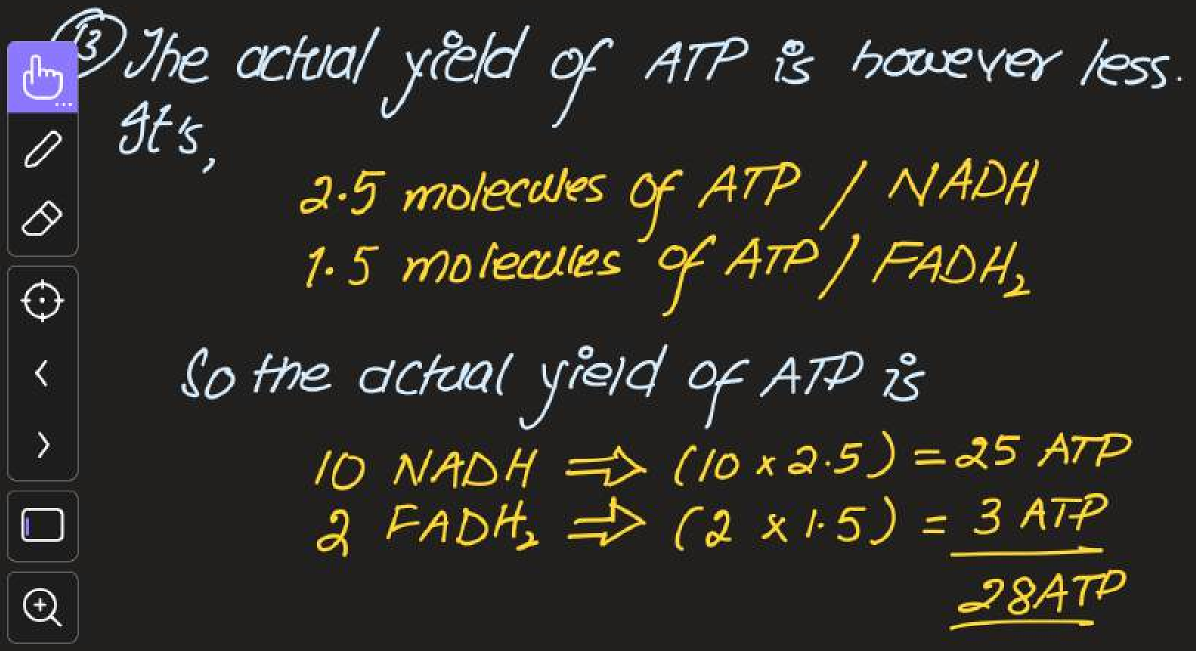


Therefore. theoretical yield of ATP per molecule of glucose via oxidative phosphorylation is:

$10\ NADH \Rightarrow (10 \times 3) = 30\ ATP$

$2\ FADH_2 \Rightarrow (2 \times 2) = 4\ ATP$

$\underline{34\ ATP}$



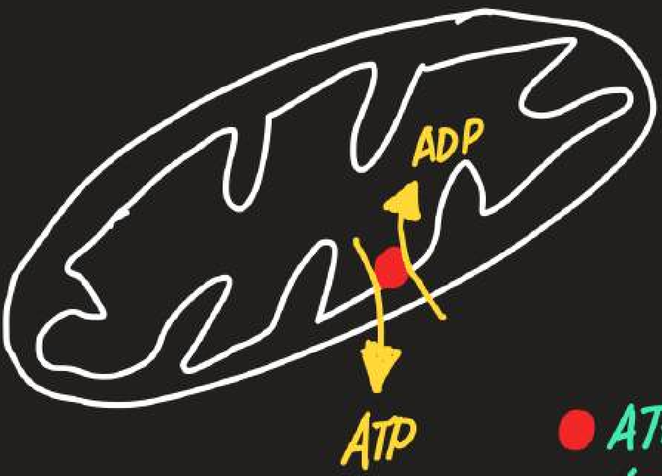
⑬ The actual yield of ATP is however less.
It's,

2.5 molecules of ATP / NADH
1.5 molecules of ATP / $FADH_2$

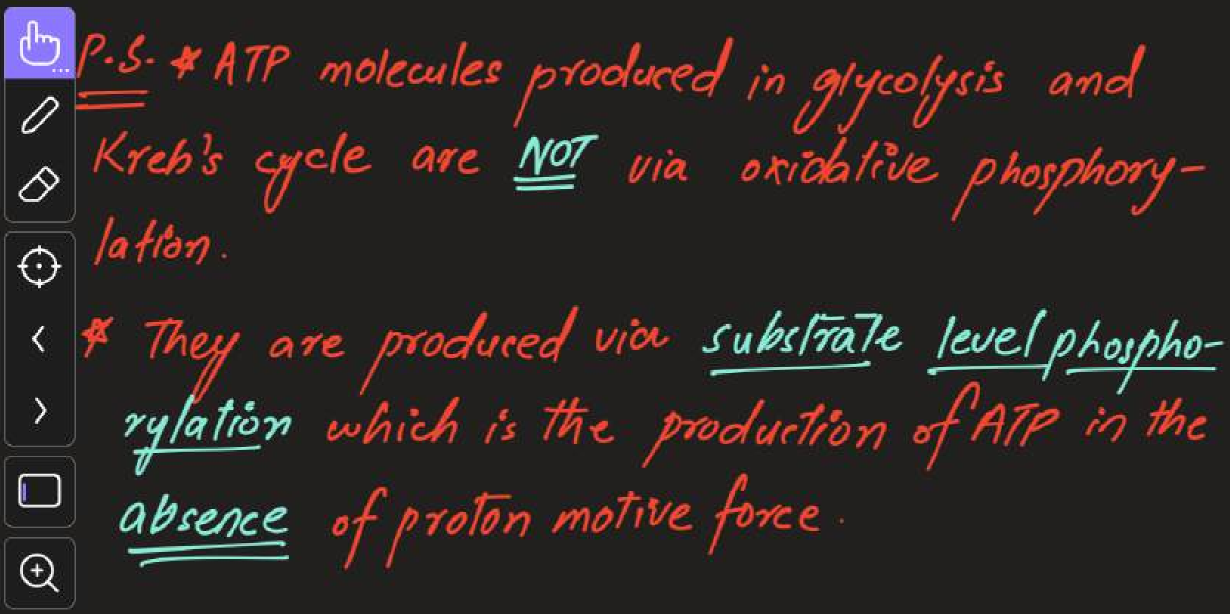
So the actual yield of ATP is

$$10\ NADH \Rightarrow (10 \times 2.5) = 25\ ATP$$
$$2\ FADH_2 \Rightarrow (2 \times 1.5) = \underline{3\ ATP}$$
$$\underline{28ATP}$$

Q. Why is the actual yield of ATP less than the theoretical yield?

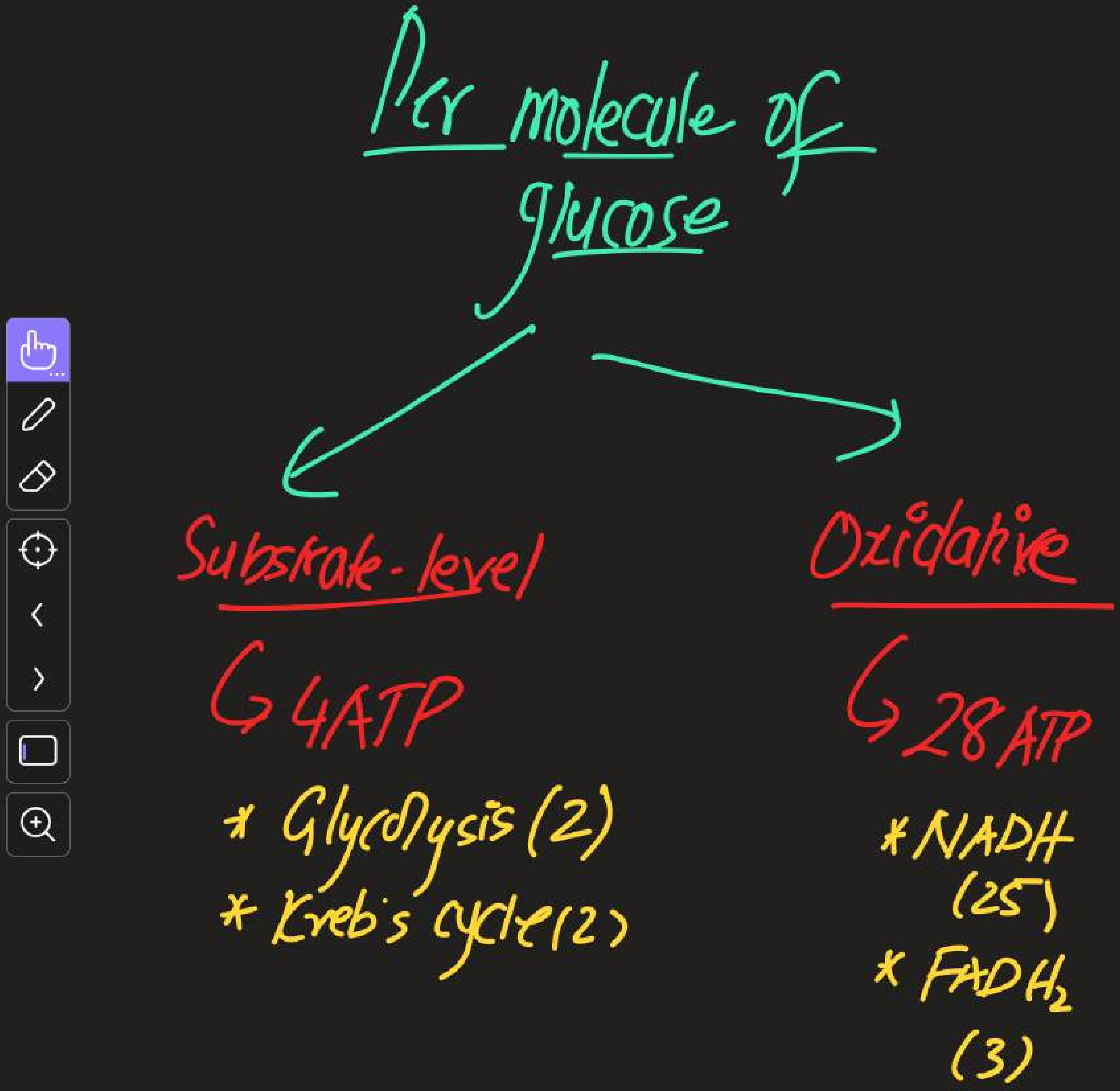


* b/c some energy is used to transport ADP into and ATP out of the mitochondrion. The carrier pump used is ATP-ADP translocase



P.S. * ATP molecules produced in glycolysis and Kreb's cycle are NOT via oxidative phosphorylation.

* They are produced via substrate level phosphorylation which is the production of ATP in the absence of proton motive force.



Per molecule of glucose

Substrate-level

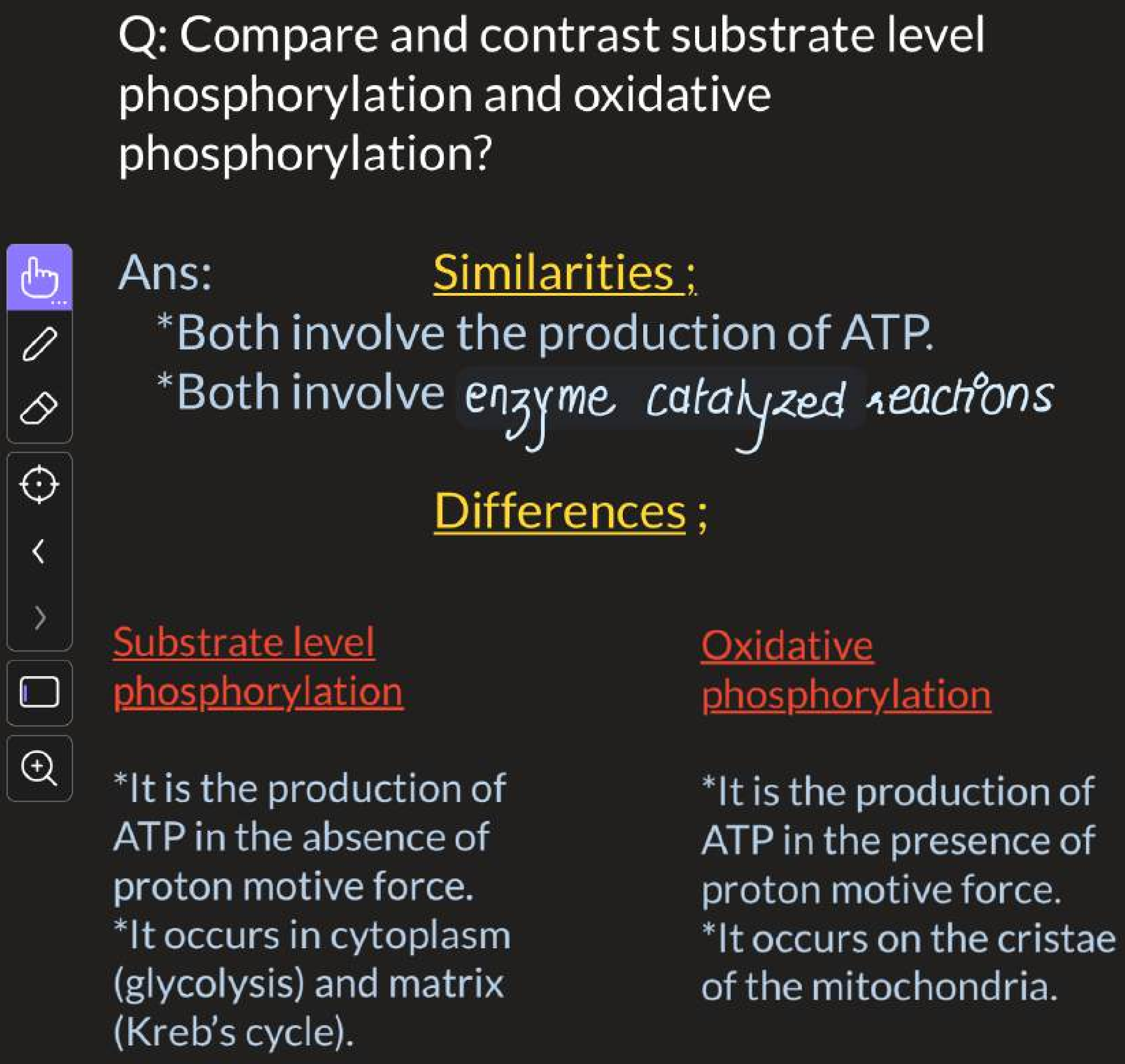
↳ 4ATP

- * Glycolysis (2)
- * Kreb's cycle (2)

Oxidative

↳ 28 ATP

- * NADH (25)
- * $FADH_2$ (3)



Q: Compare and contrast substrate level phosphorylation and oxidative phosphorylation?

Ans: **Similarities ;**

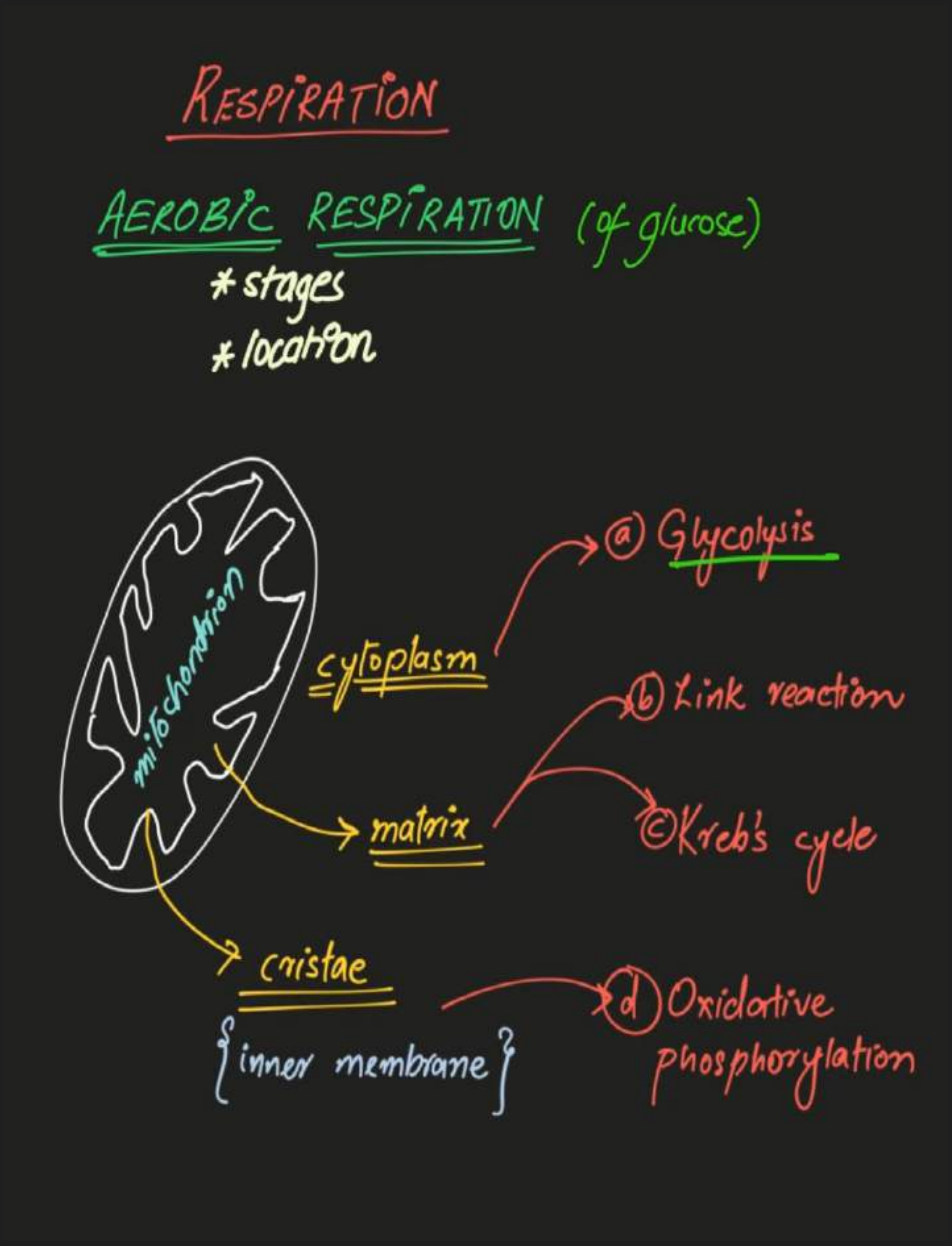
*Both involve the production of ATP.

*Both involve enzyme catalyzed reactions

Differences ;

Substrate level phosphorylation	Oxidative phosphorylation
*It is the production of ATP in the absence of proton motive force.	*It is the production of ATP in the presence of proton motive force.
*It occurs in cytoplasm (glycolysis) and matrix (Kreb's cycle).	*It occurs on the cristae of the mitochondria.

Energy & Respiration



With

Mohammad Hussham Arshad, MD

HEUSER

ADVANCED LEVEL BIOLOGY 9700

UNIT 12: ENERGY AND RESPIRATION

Learning Objectives:

- Review of Aerobic Respiration

Video Lecture 7 Slides
Mohammad Hussham Arshad, MD
Biology Department

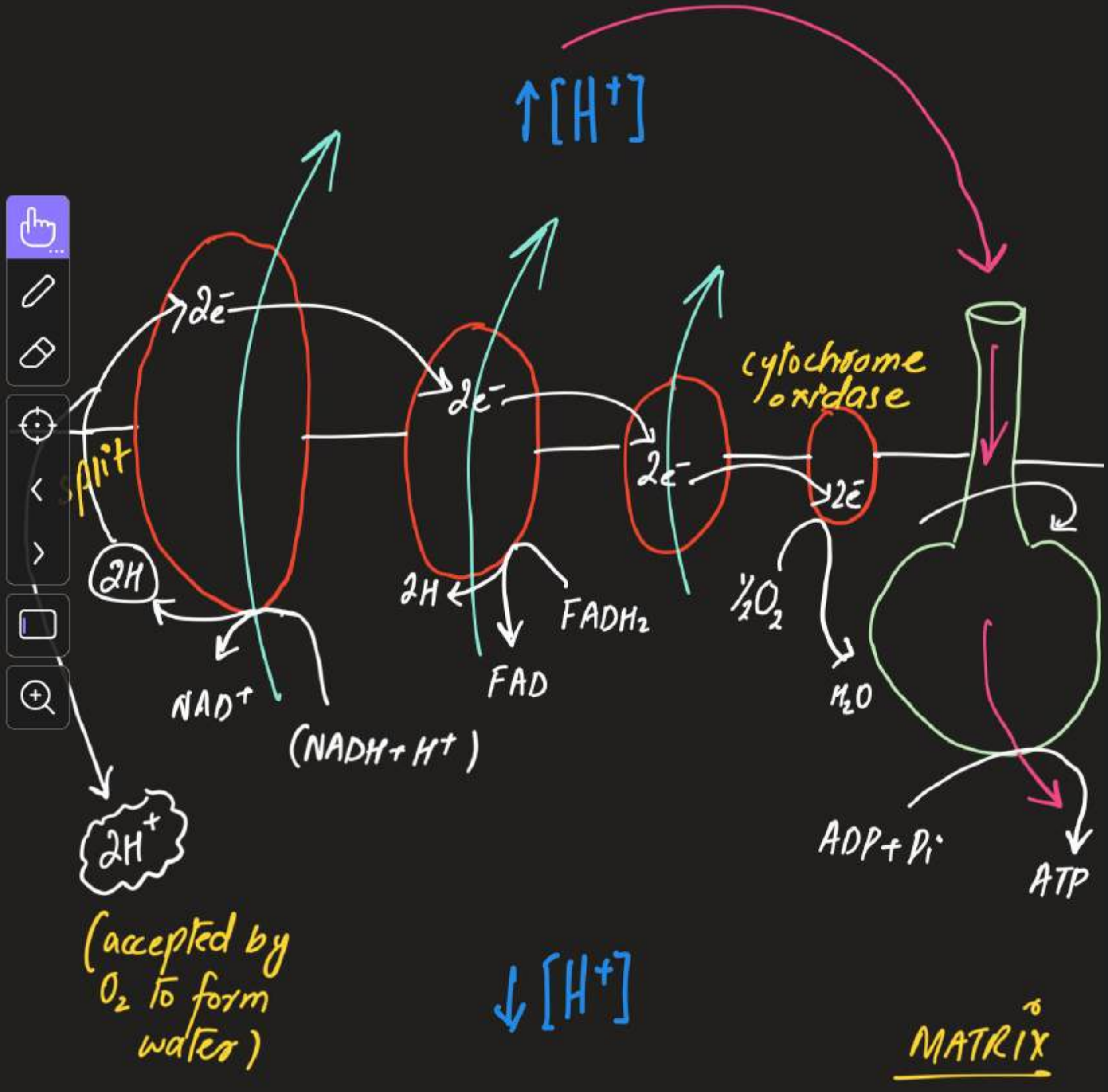
Previously .....

* we discussed oxidative phosphorylation
* differentiated between oxidative and substrate level phosphorylation

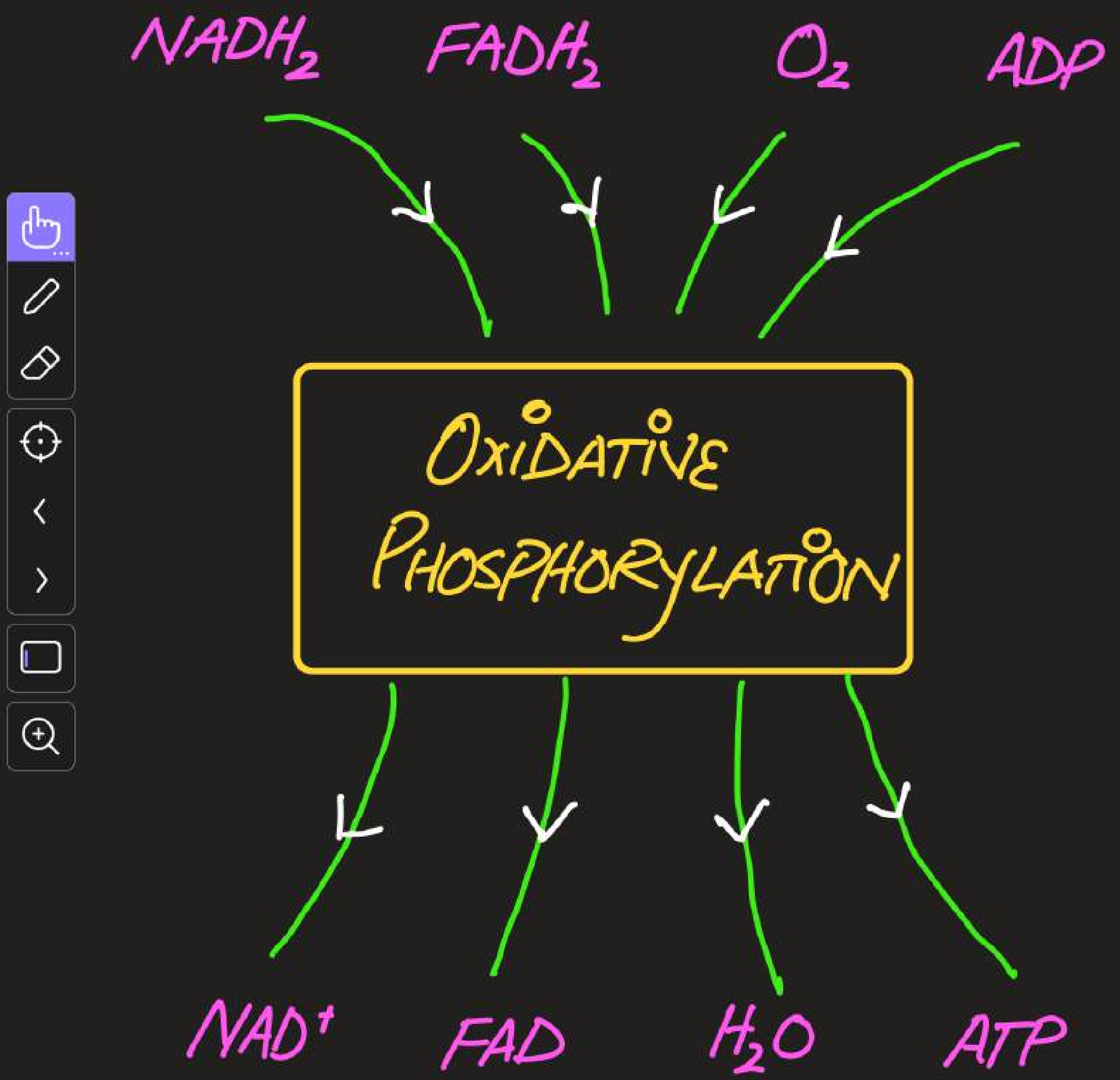
and ....

* the theoretical and actual yield of ATP

Summary of oxidative phosphorylation

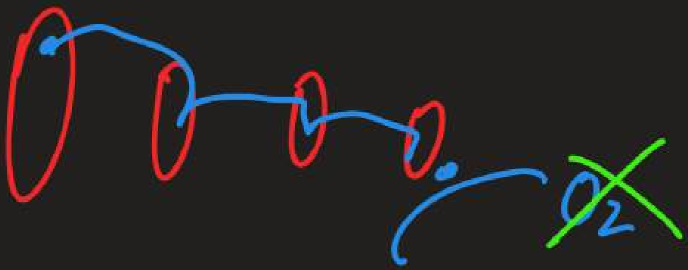


Summary of Oxidative Phosphorylation



Role of O_2 in aerobic respiration

* O_2 is used in oxidative phosphorylation as the final electron acceptor
* accepts electrons and protons in the presence of the enzyme cytochrome oxidase to form water.
* Presence of O_2 allows ETC to continue
* ATP is produced via oxidative phosphorylation.



Q. Explain how aerobic respiration is affected by decrease in oxygen availability.

A. * O_2 serves as the final electron acceptor

* It is required to ensure that the ETC functions properly

* decrease in O_2 decreases the efficiency of ETC which reduces the rate of oxidative phosphorylation

* regeneration of oxidised NAD is reduced

* rate of link reaction and Kreb's cycle decreases

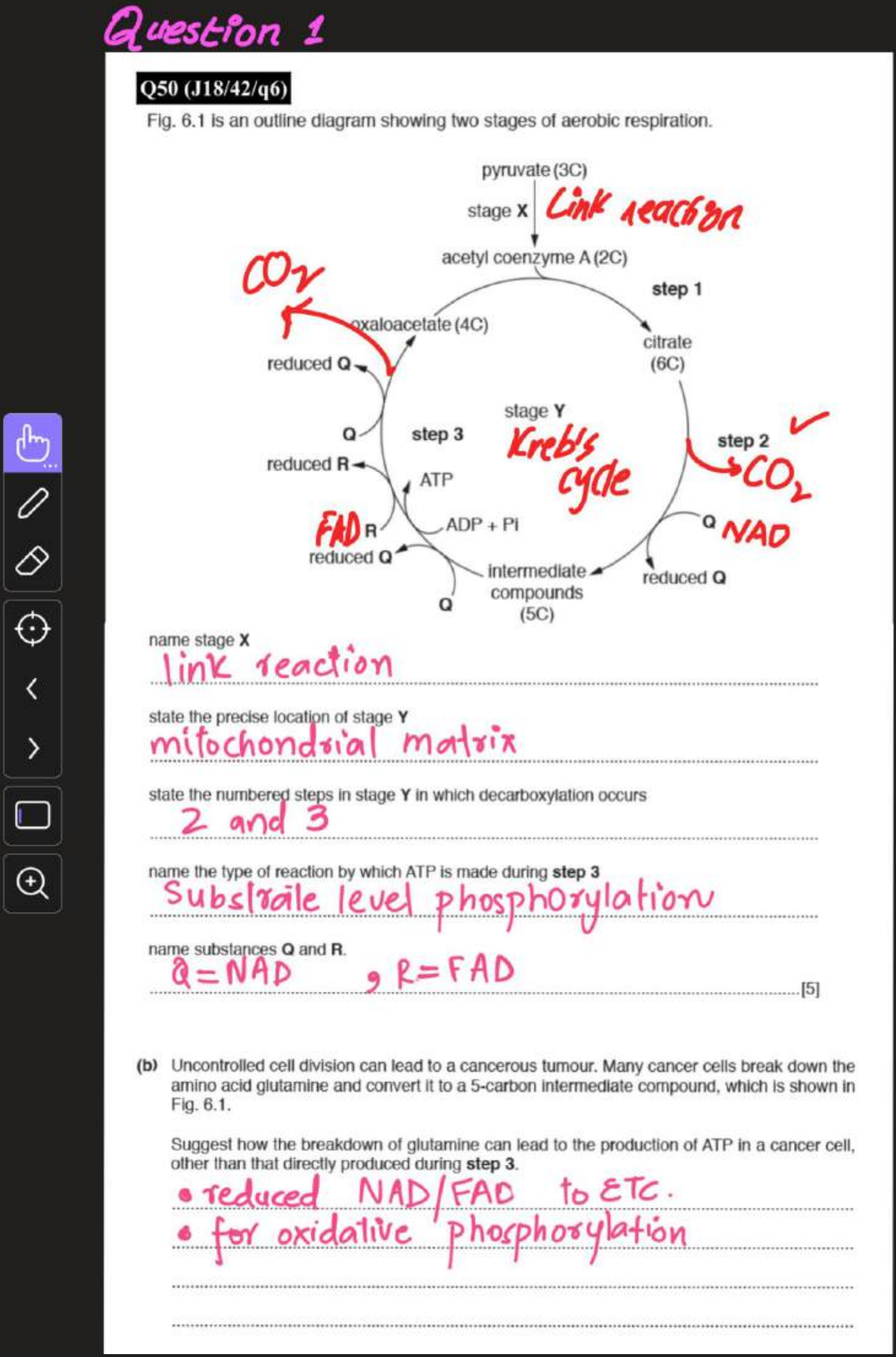
* overall rate of aerobic respiration decreases.

Role of NAD$^+$ in respiration

- coenzymes used in respiration
- coenzymes for dehydrogenases
- Carry electrons and protons to form reduced NAD (NADH)

$$NAD^+ + 2H^+ + 2e^- \rightleftharpoons NADH + H^+$$

- reduced NAD carries electrons and protons from glycolysis, link reaction and Kreb's cycle
- to the electron transport chain for oxidative phosphorylation
- Oxidised NAD (NAD$^+$) is regenerated in the process
- 2.5 ATP molecules are produced per molecule of reduced NAD.



Question 1

Q50 (J18/42/q6)

Fig. 6.1 is an outline diagram showing two stages of aerobic respiration.

name stage **X**

link reaction

state the precise location of stage **Y**

mitochondrial matrix

state the numbered steps in stage **Y** in which decarboxylation occurs

2 and 3

name the type of reaction by which ATP is made during **step 3**

Substrate level phosphorylation

name substances **Q** and **R**.

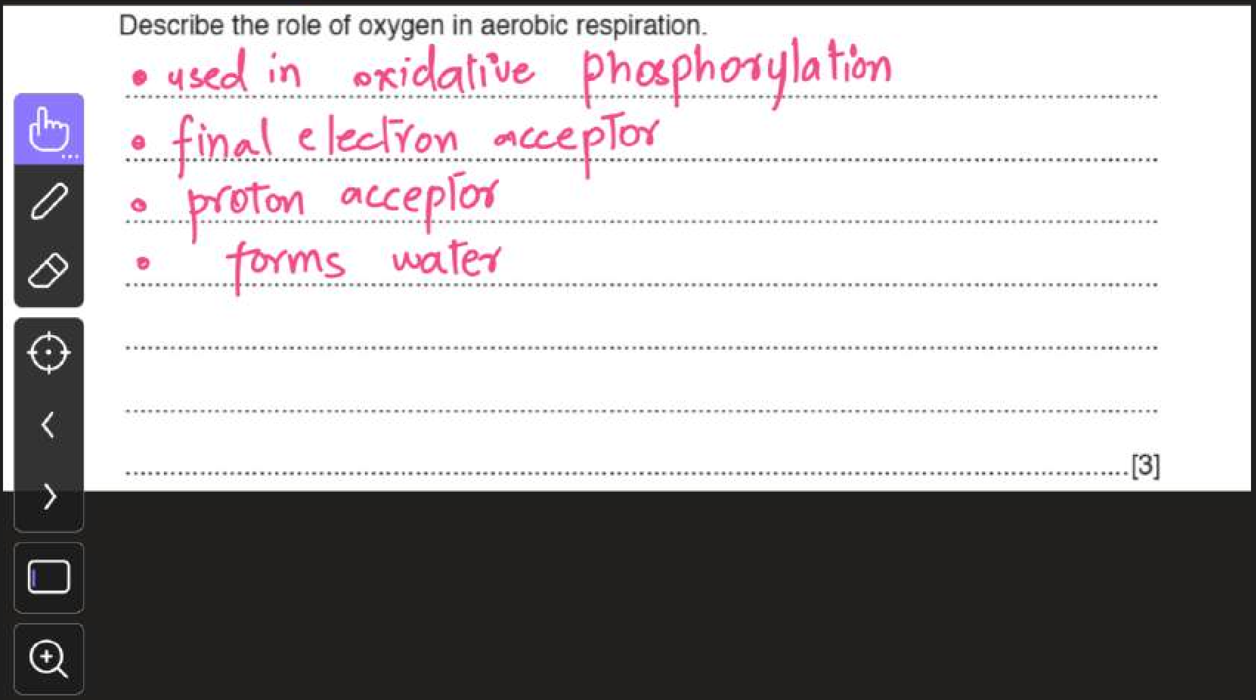
Q = NAD , R = FAD [5]

(b) Uncontrolled cell division can lead to a cancerous tumour. Many cancer cells break down the amino acid glutamine and convert it to a 5-carbon intermediate compound, which is shown in Fig. 6.1.

Suggest how the breakdown of glutamine can lead to the production of ATP in a cancer cell, other than that directly produced during **step 3**.

- reduced NAD/FAD to ETC.
- for oxidative phosphorylation

Question 2

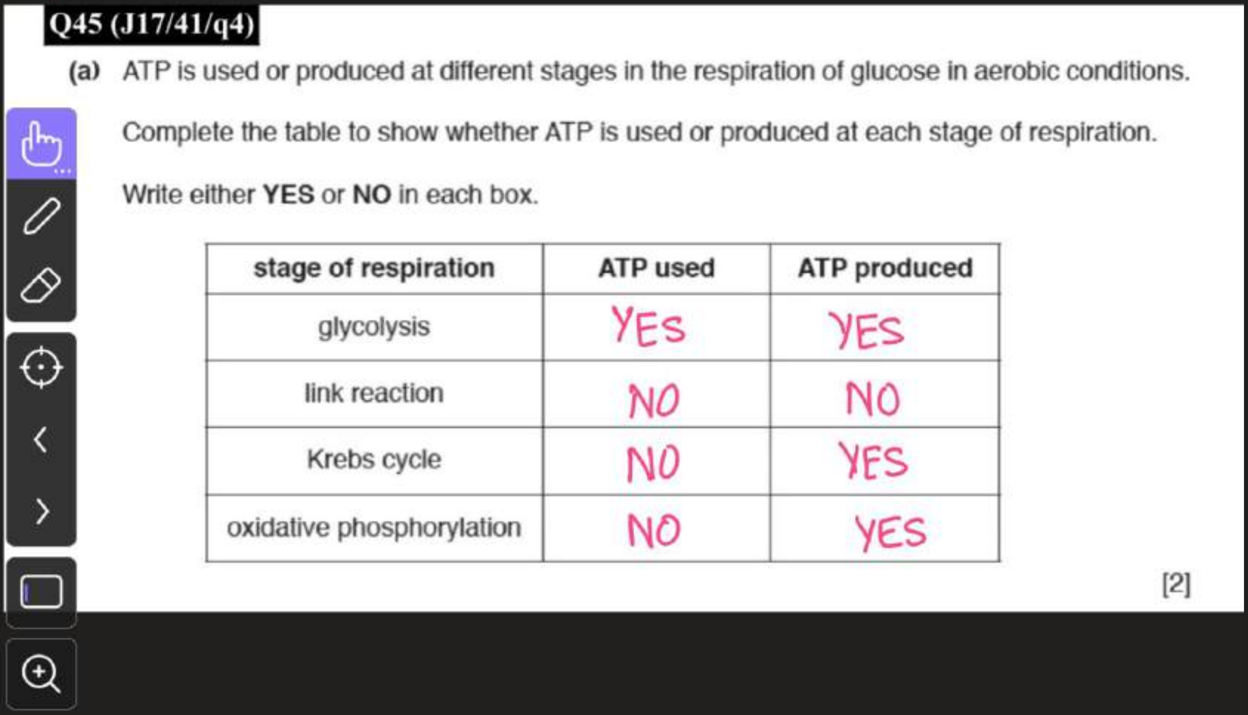


Describe the role of oxygen in aerobic respiration.

- used in oxidative phosphorylation
- final electron acceptor
- proton acceptor
- forms water

[3]

Question 3



Q45 (J17/41/q4)

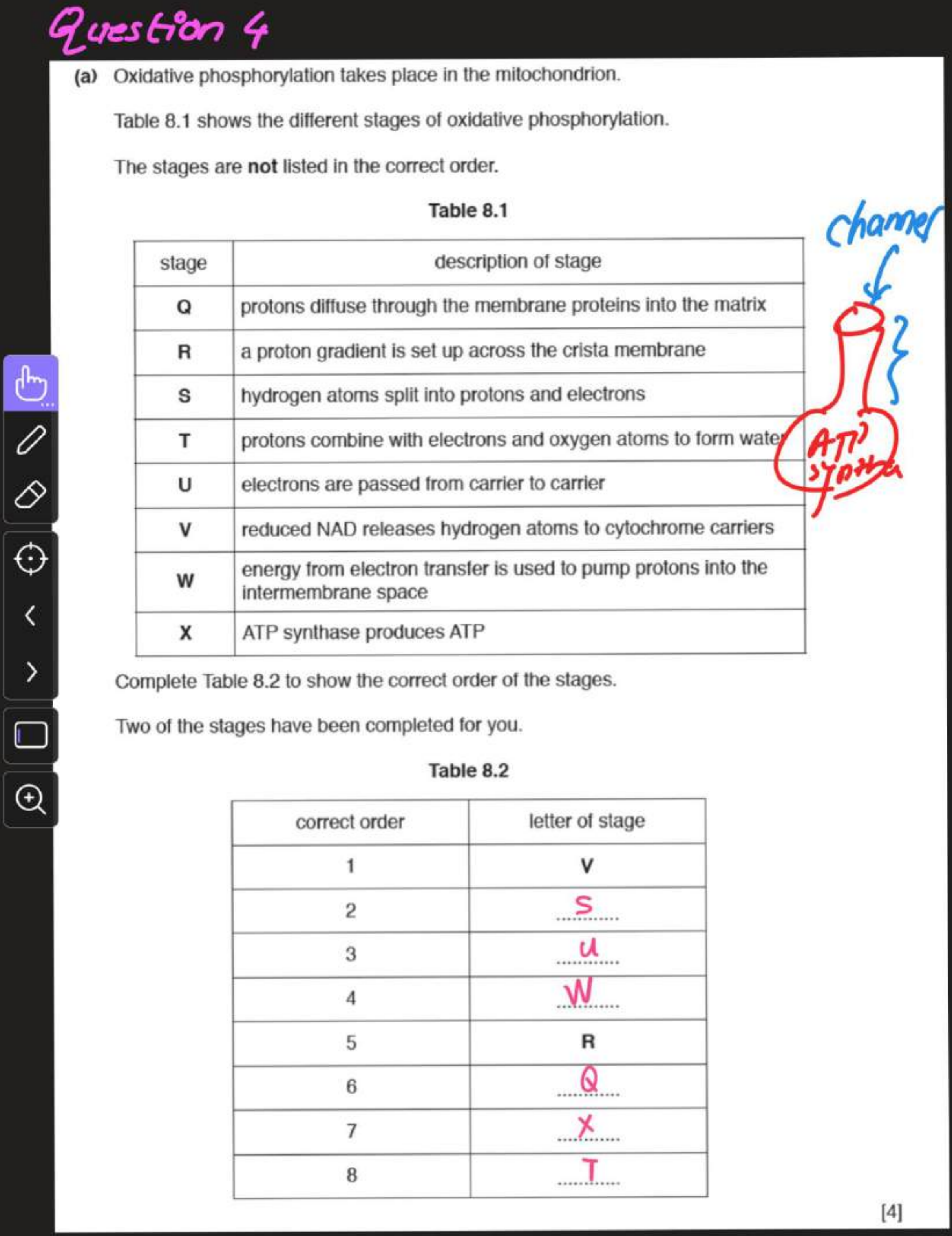
(a) ATP is used or produced at different stages in the respiration of glucose in aerobic conditions.

Complete the table to show whether ATP is used or produced at each stage of respiration.

Write either **YES** or **NO** in each box.

stage of respiration	ATP used	ATP produced
glycolysis	YES	YES
link reaction	NO	NO
Krebs cycle	NO	YES
oxidative phosphorylation	NO	YES

[2]



Question 4

(a) Oxidative phosphorylation takes place in the mitochondrion.

Table 8.1 shows the different stages of oxidative phosphorylation.

The stages are **not** listed in the correct order.

Table 8.1

stage	description of stage
Q	protons diffuse through the membrane proteins into the matrix
R	a proton gradient is set up across the crista membrane
S	hydrogen atoms split into protons and electrons
T	protons combine with electrons and oxygen atoms to form water
U	electrons are passed from carrier to carrier
V	reduced NAD releases hydrogen atoms to cytochrome carriers
W	energy from electron transfer is used to pump protons into the intermembrane space
X	ATP synthase produces ATP

Complete Table 8.2 to show the correct order of the stages.

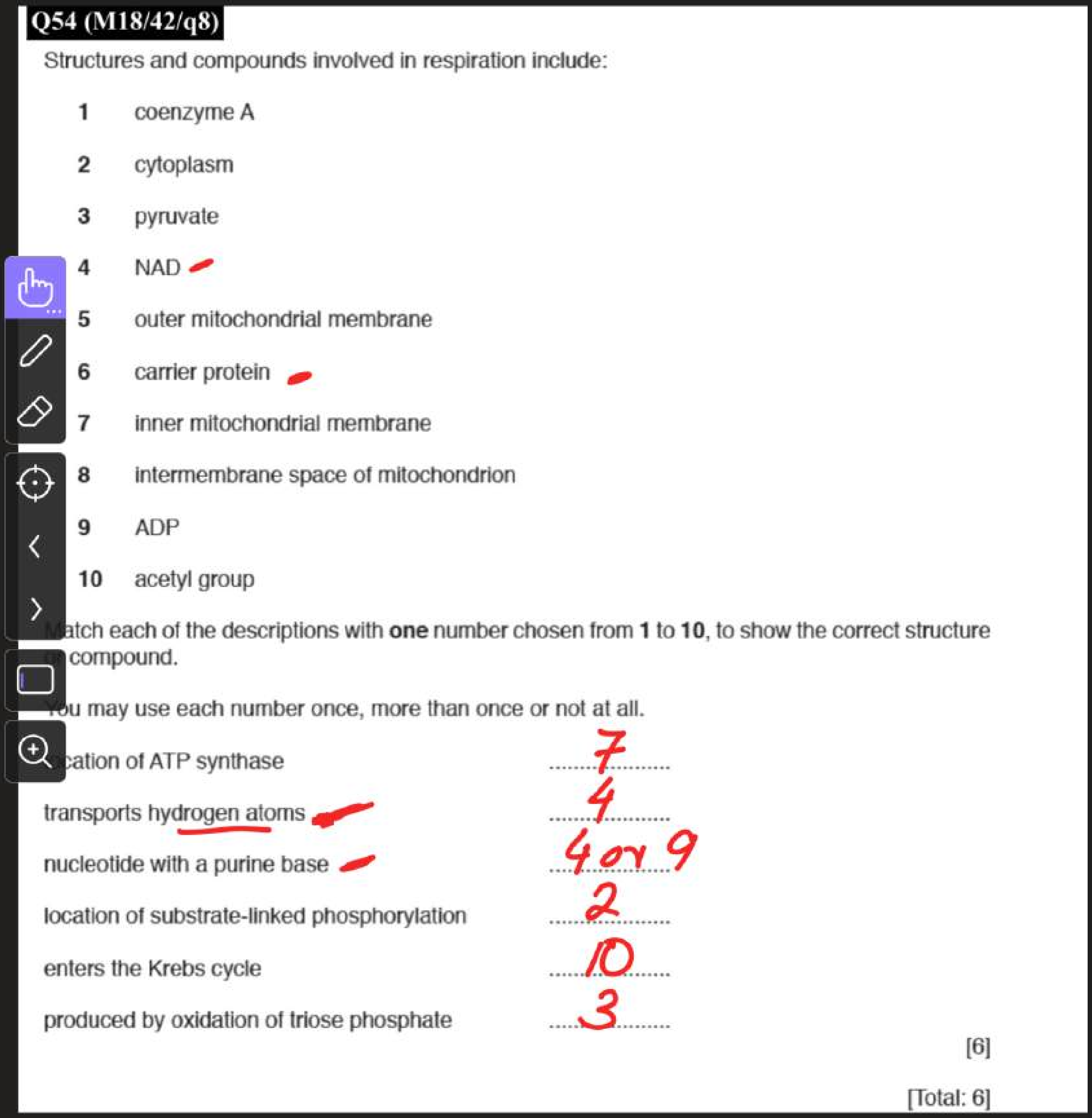
Two of the stages have been completed for you.

Table 8.2

correct order	letter of stage
1	**V**
2	S
3	U
4	W
5	**R**
6	Q
7	X
8	T

[4]

Question 5



Q54 (M18/42/q8)

Structures and compounds involved in respiration include:

1 coenzyme A

2 cytoplasm

3 pyruvate

4 NAD

5 outer mitochondrial membrane

6 carrier protein

7 inner mitochondrial membrane

8 intermembrane space of mitochondrion

9 ADP

10 acetyl group

Match each of the descriptions with **one** number chosen from **1** to **10**, to show the correct structure or compound.

You may use each number once, more than once or not at all.

location of ATP synthase ....7..........

transports hydrogen atoms ....4..........

nucleotide with a purine base ....4 or 9..........

location of substrate-linked phosphorylation ....2..........

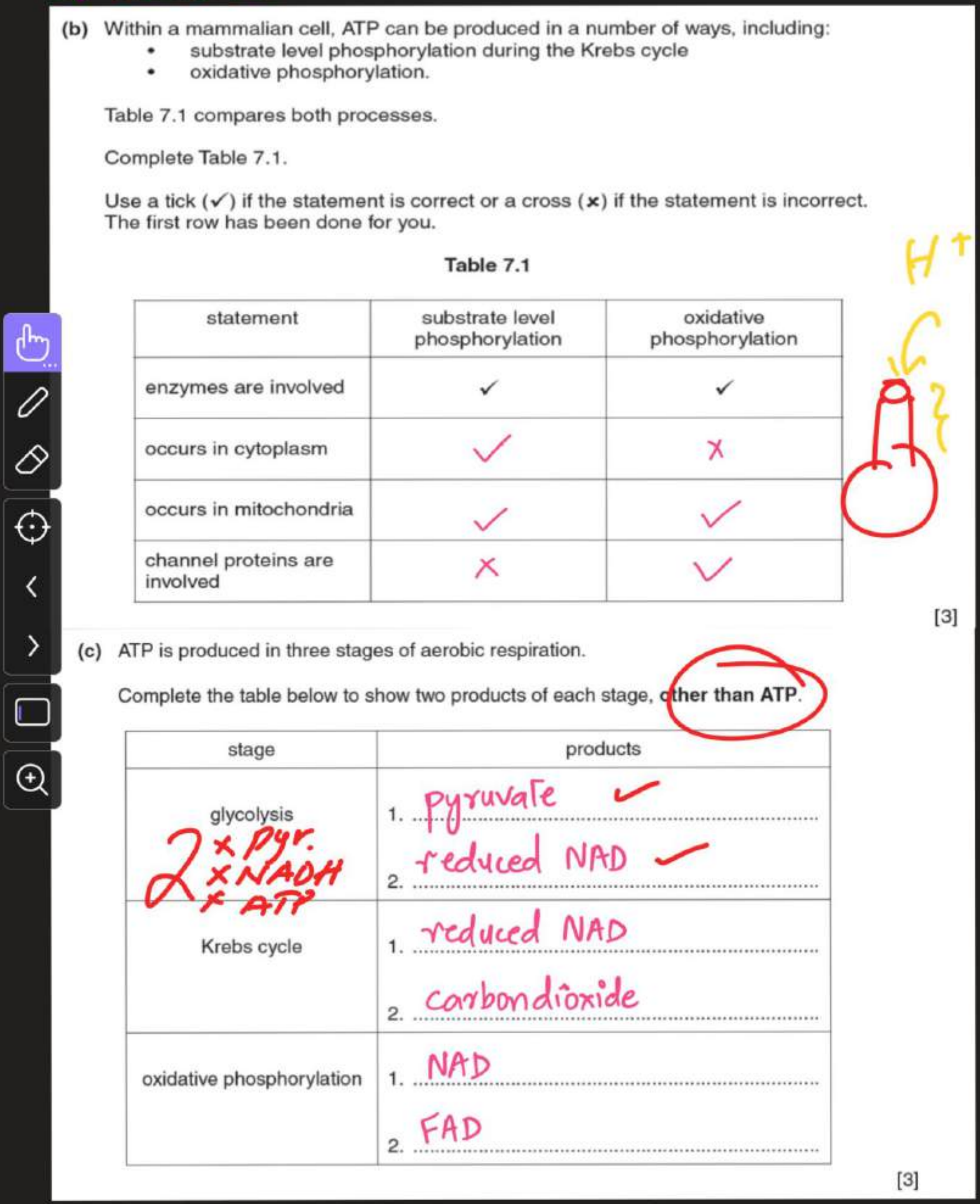
enters the Krebs cycle ....10..........

produced by oxidation of triose phosphate ....3..........

[6]

[Total: 6]

Question 6



(b) Within a mammalian cell, ATP can be produced in a number of ways, including:

- substrate level phosphorylation during the Krebs cycle
- oxidative phosphorylation.

Table 7.1 compares both processes.

Complete Table 7.1.

Use a tick (✓) if the statement is correct or a cross (✗) if the statement is incorrect. The first row has been done for you.

Table 7.1

statement	substrate level phosphorylation	oxidative phosphorylation
enzymes are involved	✓	✓
occurs in cytoplasm	✓	✗
occurs in mitochondria	✓	✓
channel proteins are involved	✗	✓

[3]

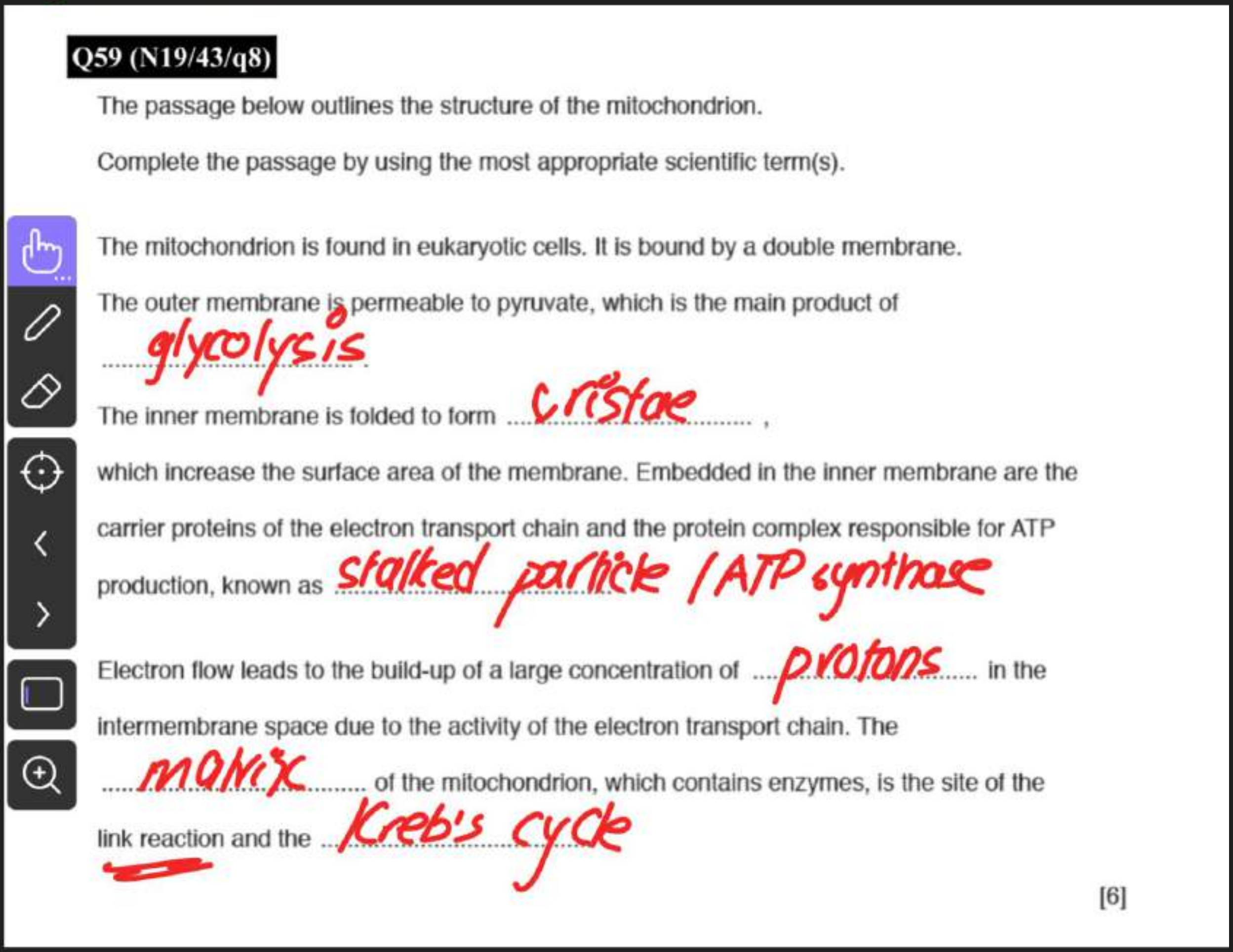
(c) ATP is produced in three stages of aerobic respiration.

Complete the table below to show two products of each stage, **other than ATP**.

stage	products
glycolysis 2 × Pyr. × NADH × ATP	1. pyruvate ✓ 2. reduced NAD ✓
Krebs cycle	1. reduced NAD 2. carbondioxide
oxidative phosphorylation	1. NAD 2. FAD

[3]

Question 7



Q59 (N19/43/q8)

The passage below outlines the structure of the mitochondrion.

Complete the passage by using the most appropriate scientific term(s).

The mitochondrion is found in eukaryotic cells. It is bound by a double membrane.

The outer membrane is permeable to pyruvate, which is the main product of glycolysis

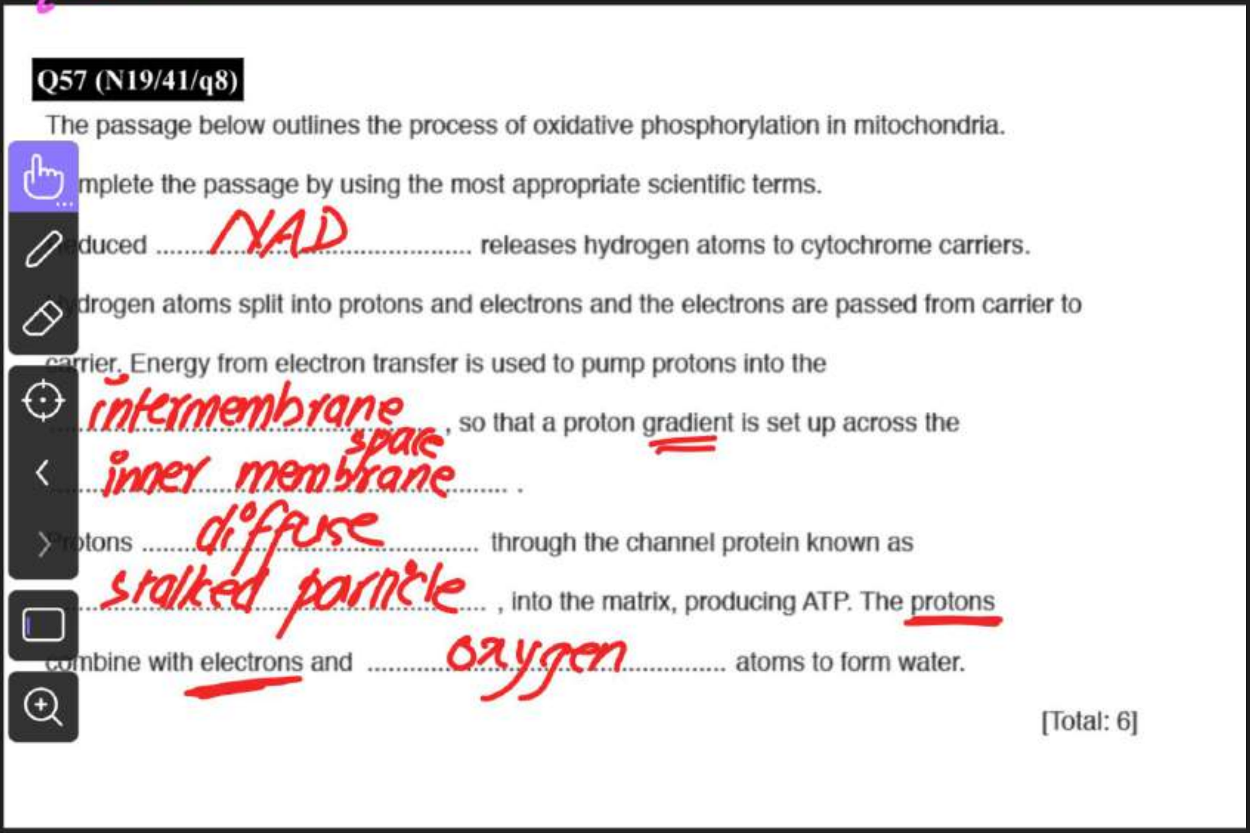
The inner membrane is folded to form cristae ,

which increase the surface area of the membrane. Embedded in the inner membrane are the carrier proteins of the electron transport chain and the protein complex responsible for ATP production, known as stalked particle / ATP synthase

Electron flow leads to the build-up of a large concentration of protons in the intermembrane space due to the activity of the electron transport chain. The matrix of the mitochondrion, which contains enzymes, is the site of the link reaction and the Kreb's cycle

[6]

Question 8



Q57 (N19/41/q8)

The passage below outlines the process of oxidative phosphorylation in mitochondria.

mplete the passage by using the most appropriate scientific terms.

duced ....NAD........ releases hydrogen atoms to cytochrome carriers.

drogen atoms split into protons and electrons and the electrons are passed from carrier to carrier. Energy from electron transfer is used to pump protons into the ....intermembrane space.... , so that a proton gradient is set up across the ....inner membrane.... .

otons ....diffuse.... through the channel protein known as ....stalked particle.... , into the matrix, producing ATP. The protons combine with electrons and ....oxygen.... atoms to form water.

[Total: 6]

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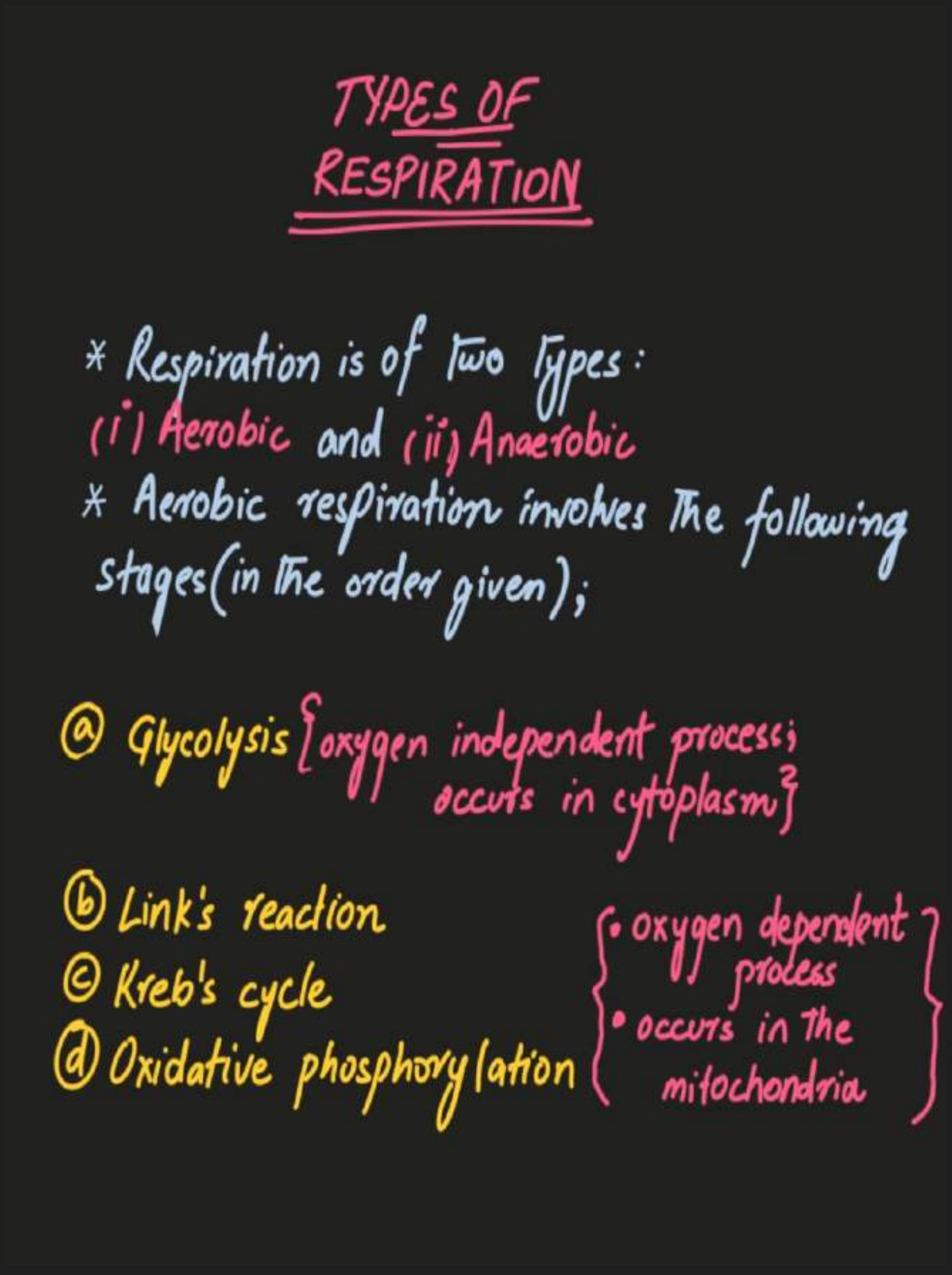
Energy & Respiration



TYPES OF RESPIRATION

* Respiration is of two types:
(i) Aerobic and (ii) Anaerobic
* Aerobic respiration involves the following stages (in the order given);

ⓐ Glycolysis {oxygen independent process; occurs in cytoplasm}

ⓑ Link's reaction
ⓒ Kreb's cycle
ⓓ Oxidative phosphorylation
{• oxygen dependent process
• occurs in the mitochondria}

With

Mohammad Hussham Arshad, MD

ADVANCED LEVEL BIOLOGY 9700

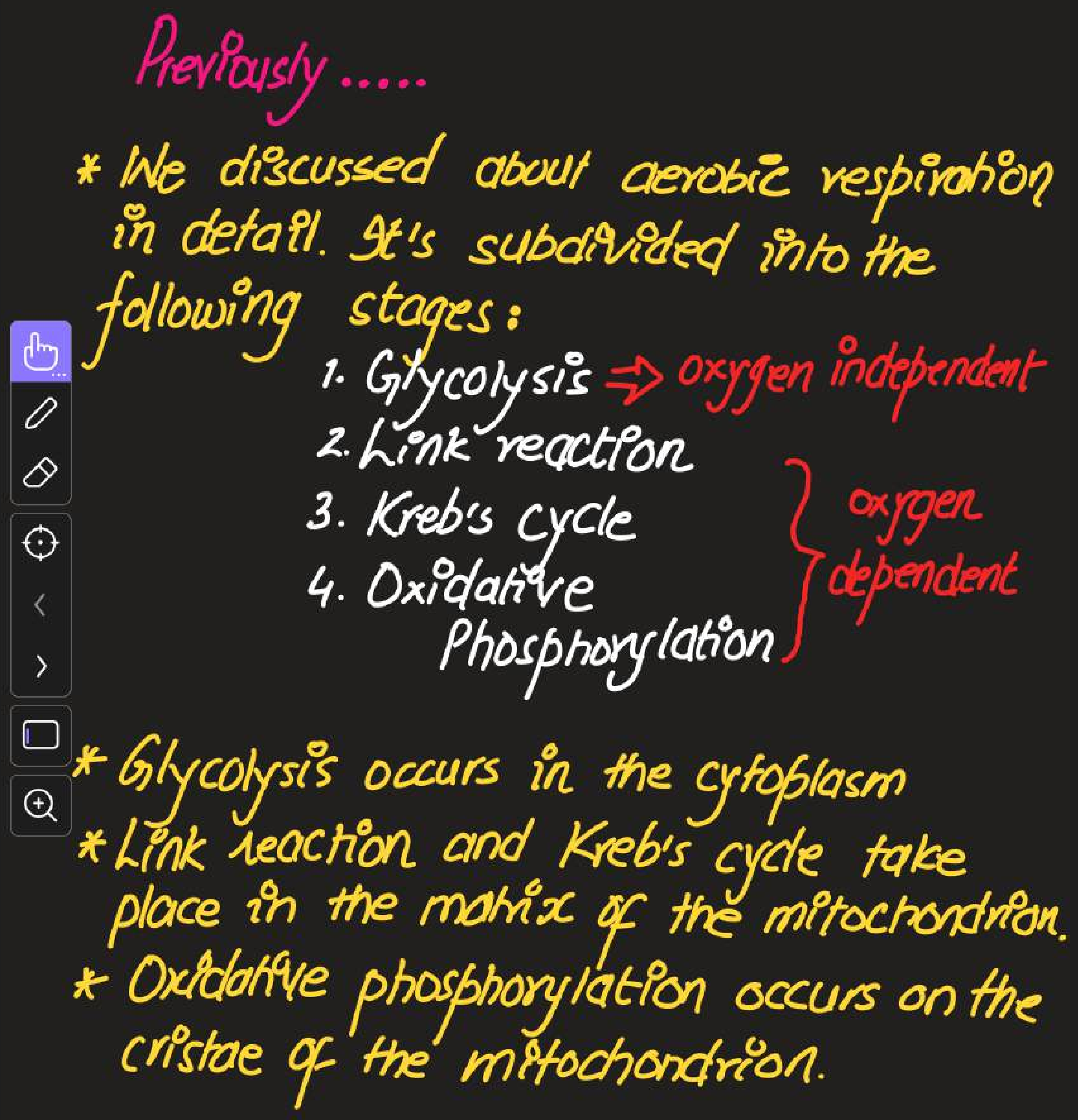
UNIT 12: ENERGY AND RESPIRATION

Learning Objectives:

- Anaerobic Respiration

Video Lecture 8 Slides

Mohammad Hussham Arshad, MD
Biology Department



Previously .....

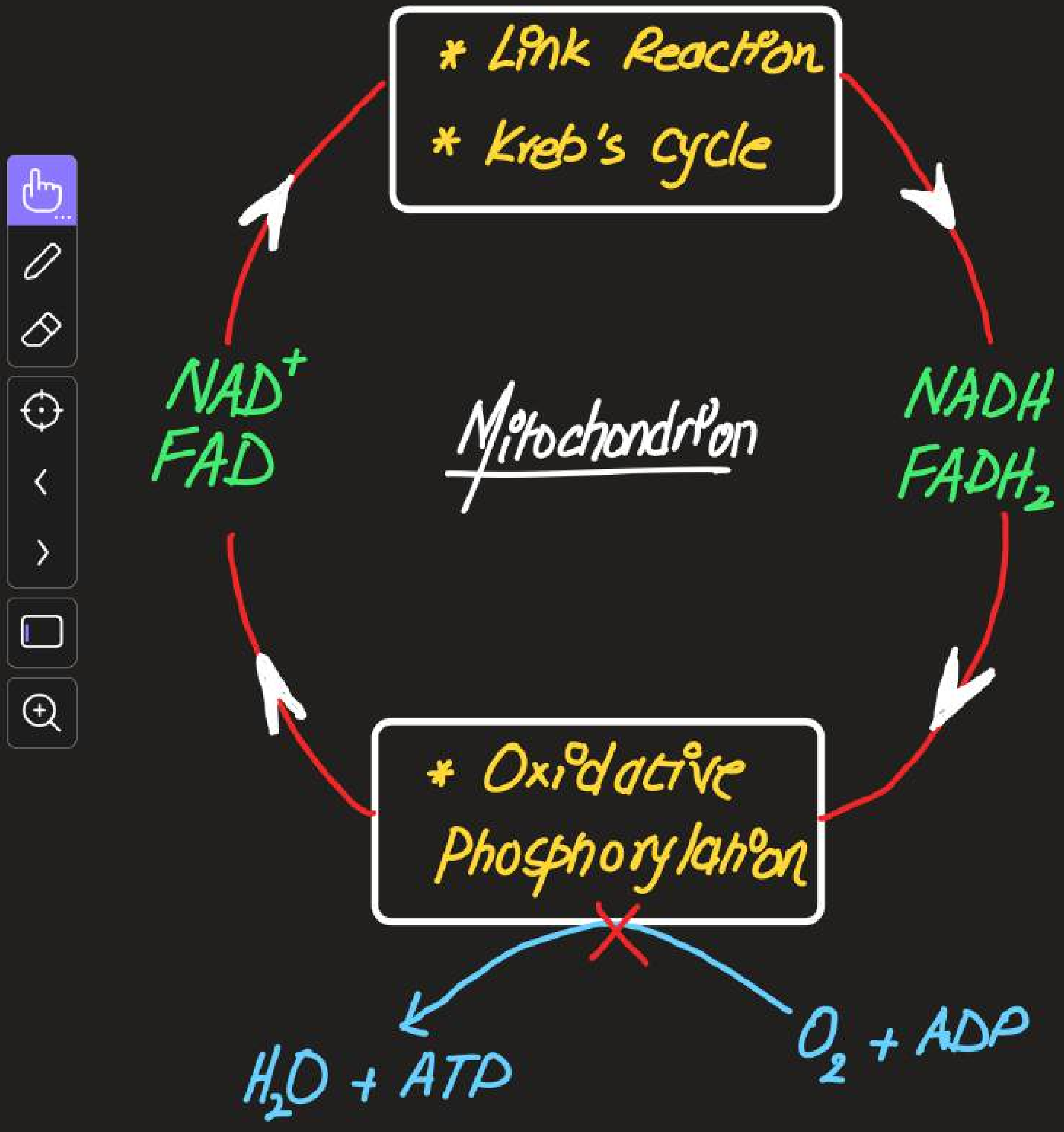
* We discussed about aerobic respiration in detail. It's subdivided into the following stages:

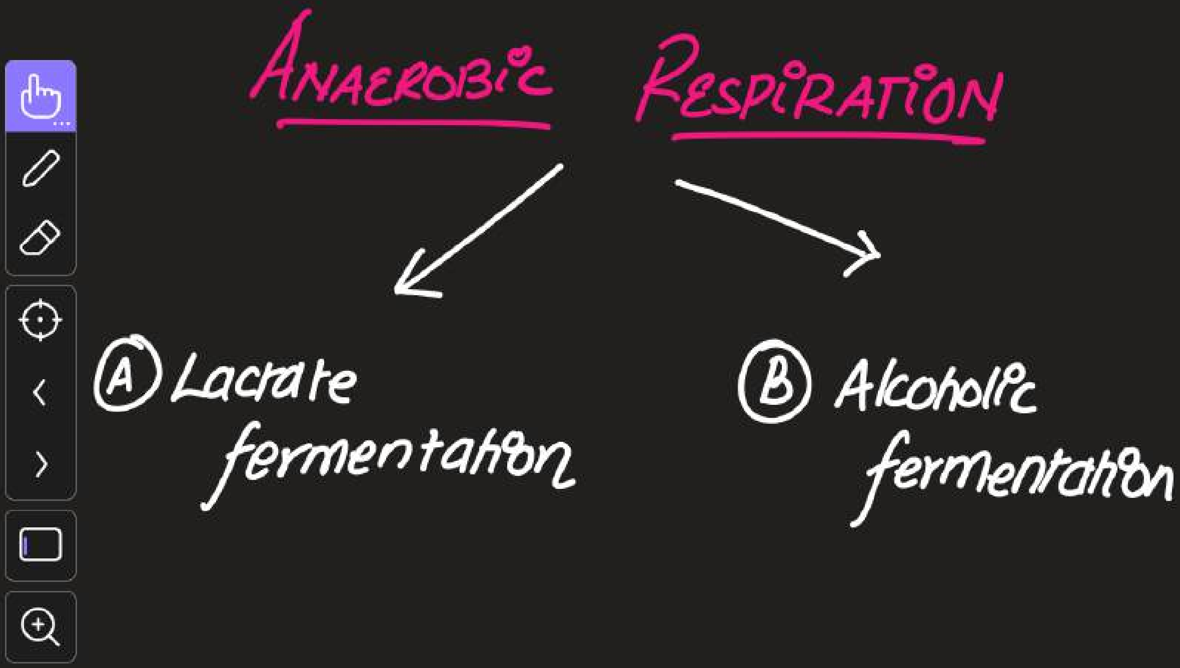
1. Glycolysis ⇒ oxygen independent
2. Link reaction
3. Kreb's cycle
4. Oxidative Phosphorylation

} oxygen dependent

* Glycolysis occurs in the cytoplasm
* Link reaction and Kreb's cycle take place in the matrix of the mitochondrion.
* Oxidative phosphorylation occurs on the cristae of the mitochondrion.

Association between link reaction, Kreb's cycle and oxidative phosphorylation



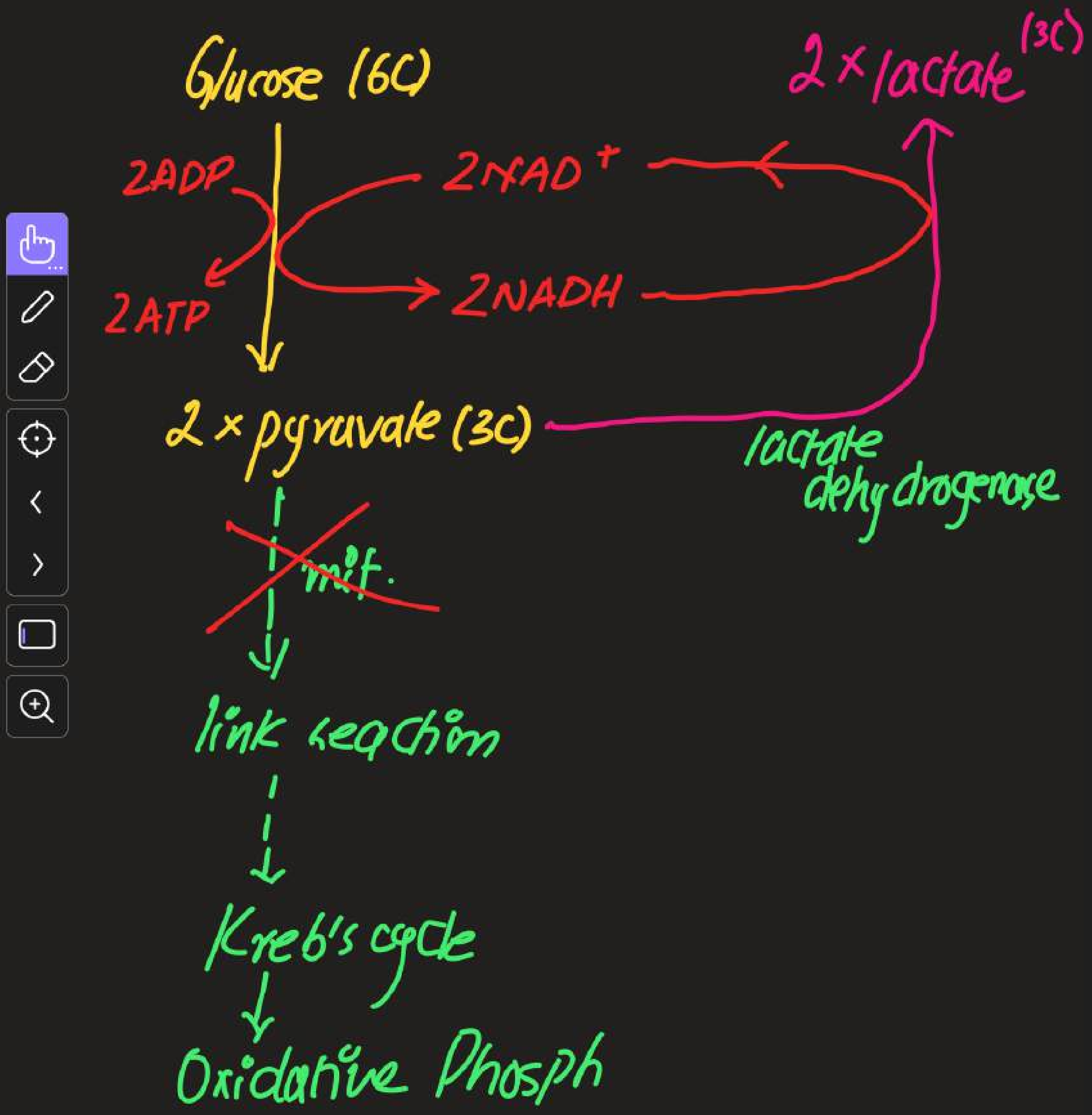


ANAEROBIC RESPIRATION

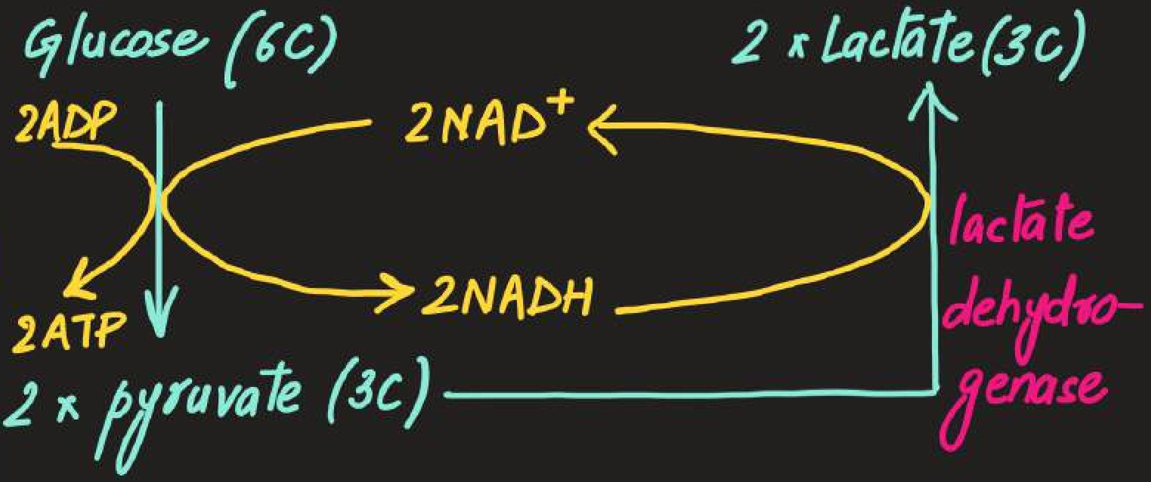
Ⓐ Lactate fermentation

Ⓑ Alcoholic fermentation

Ⓐ Lactate Fermentation

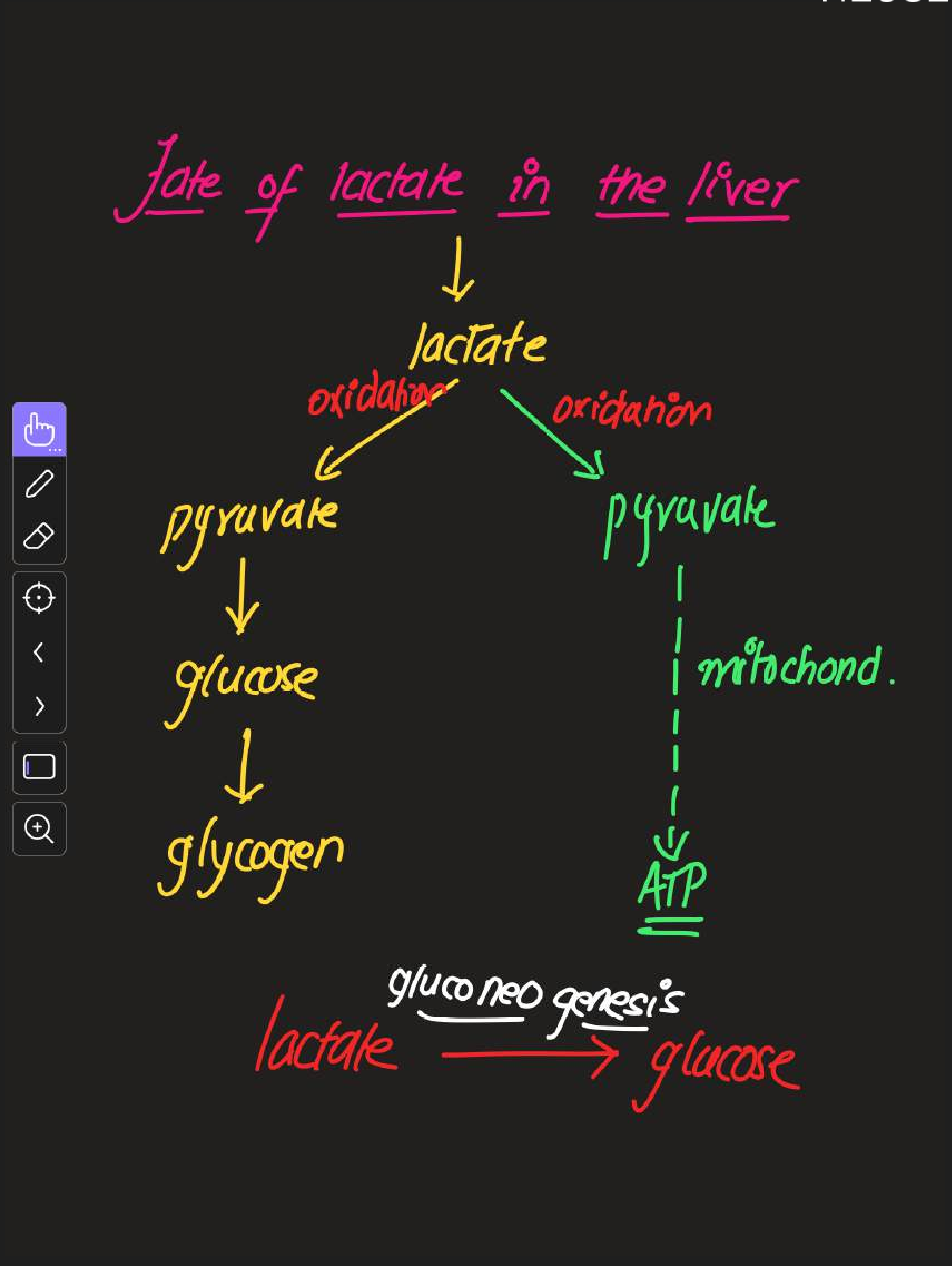


Ⓐ Lactate fermentation



MAIN FEATURES

* occurs in mammals
* single step reaction
* No decarboxylation
* reversible reaction (lactate can be oxidised in the liver)
* enzyme → lactate dehydrogenase



Fate of lactate in the liver

$$\text{lactate} \xrightarrow{\text{gluconeogenesis}} \text{glucose}$$

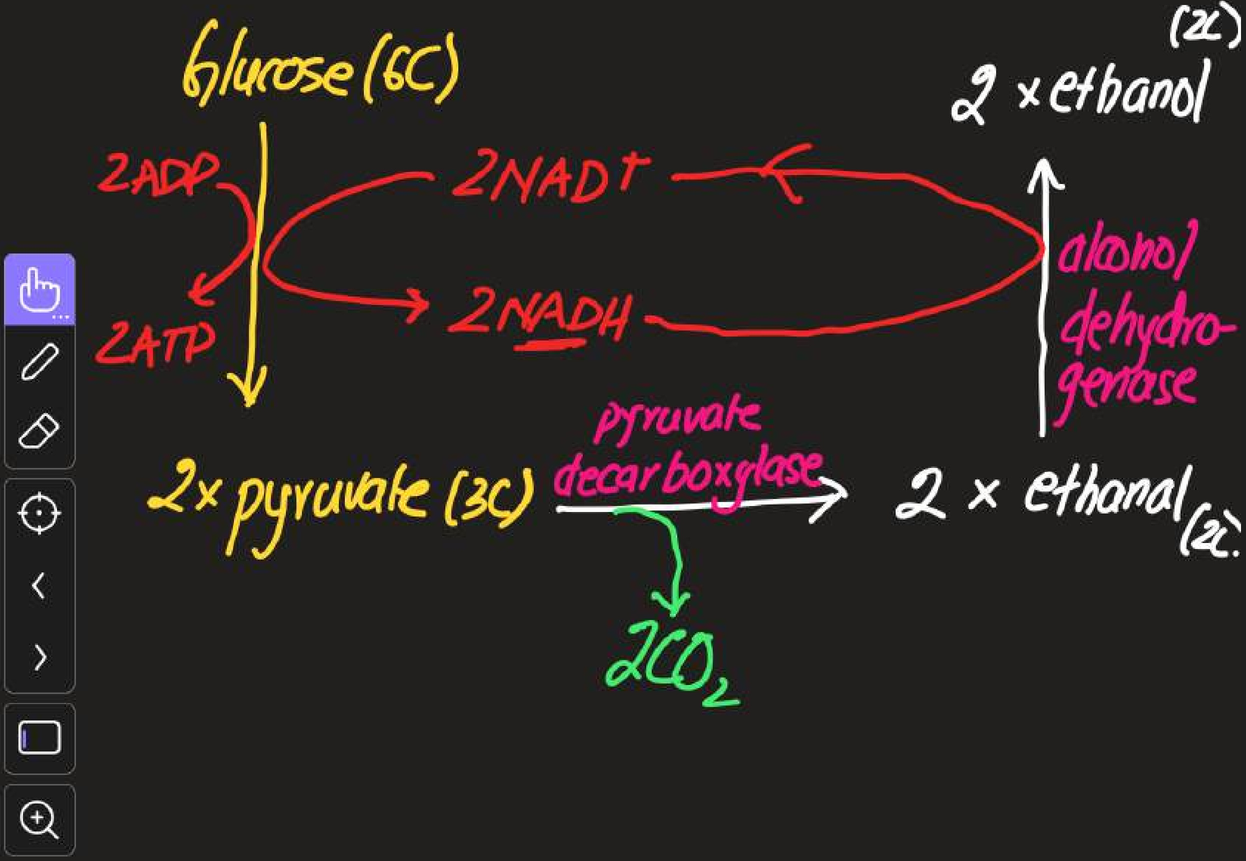
Q. Why is it necessary to convert pyruvate into lactate in the absence of O_2?

* allows NAD^+ to be regenerated
* which enables glycolysis to continue
* some ATP formed via substrate level phosphorylation

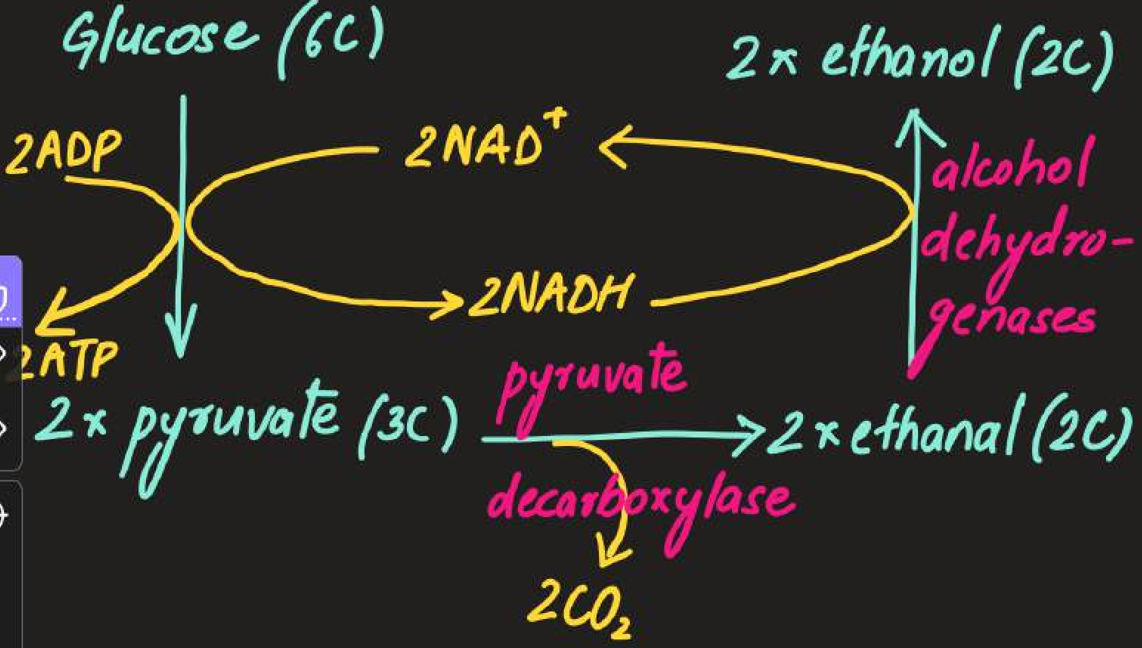
Q. State and explain the amount of energy released via aerobic and anaerobic respiration.

* anaerobic <<< aerobic
* anaerobic → SLP ONLY
* anaerobic → ∅ proton motive force → ∅ oxid. phosph
* product of anaerobic (lactate)
  ↳ energy rich

(B) Alcoholic fermentation



Ⓑ Alcoholic fermentation



MAIN FEATURES

- occurs in yeast and plants
- Two step reaction
- Involves a decarboxylation step.
- Irreversible process
- enzyme → alcohol dehydrogenase

Q. Differentiate between lactate fermentation and alcoholic fermentation.

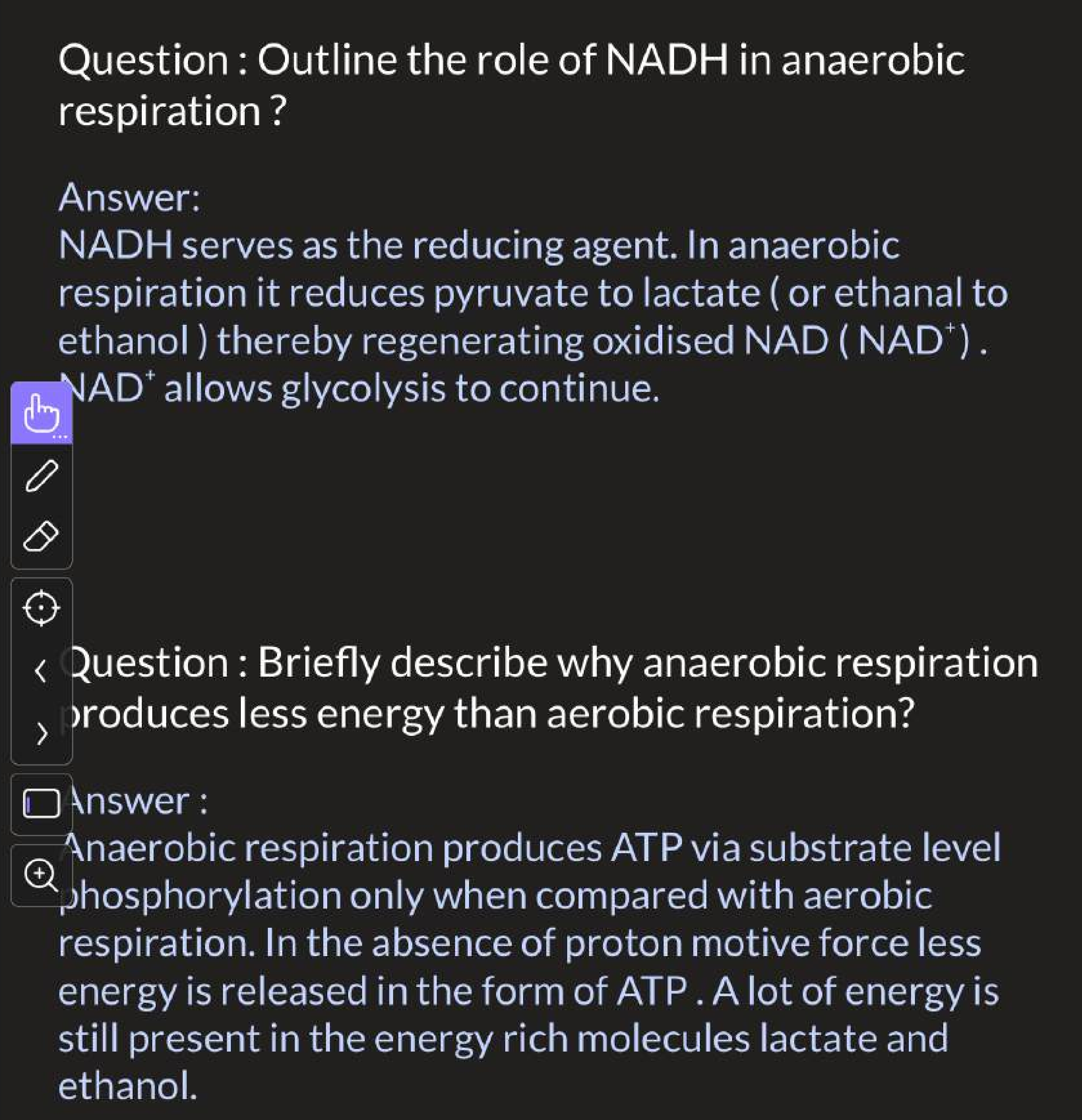
1. Number of steps?
2. Decarboxylation?
3. Reversibility?
4. Enzyme involved?
5. Products?
6. Organisms?

Q. Briefly describe the role of NADH (reduced NAD) in anaerobic respiration.

- NADH serves as the reducing agent
- it converts → pyruvate → lactate
  → pyruvate → ethanol
- this regenerates NAD^+ → glycolysis continues

Q. State the terminal electron acceptor in anaerobic respiration.

- lactate ferm → pyruvate
- alcoholic ferm → ethanal

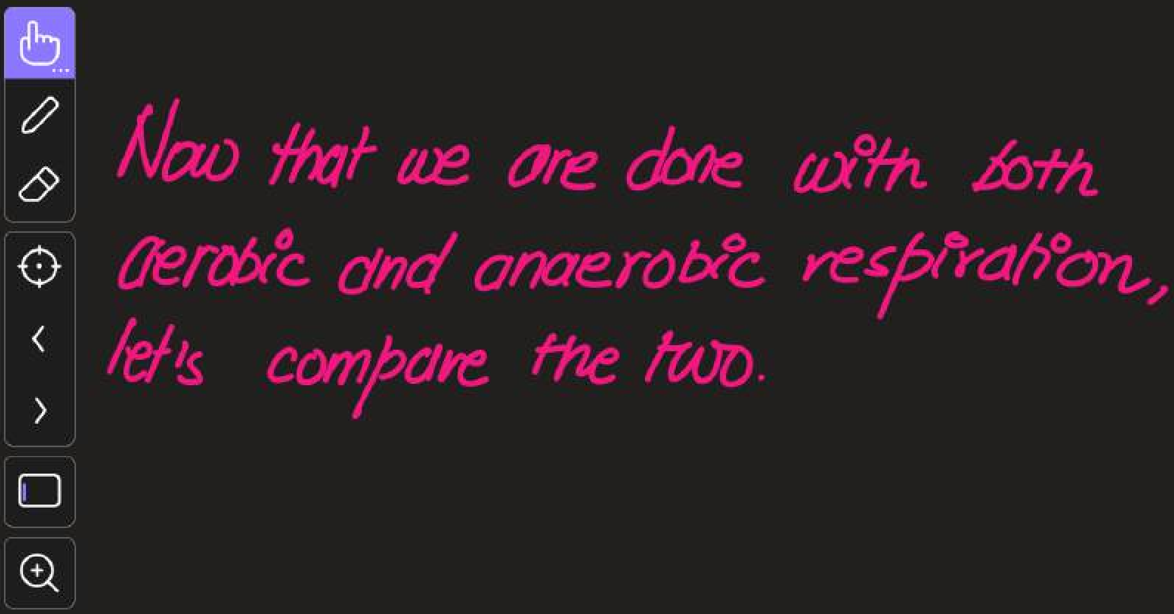


Question : Outline the role of NADH in anaerobic respiration ?

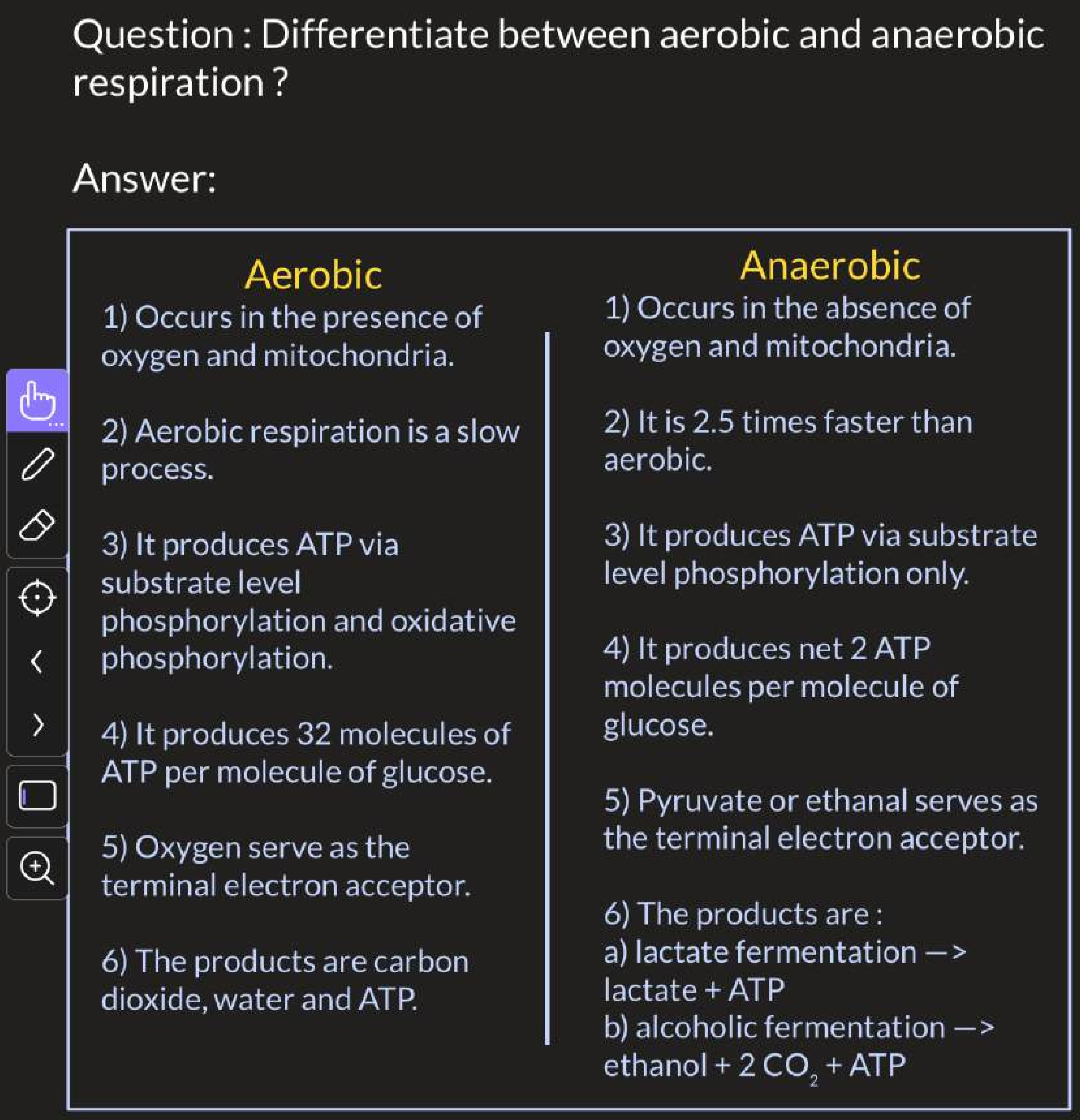
Answer:
NADH serves as the reducing agent. In anaerobic respiration it reduces pyruvate to lactate (or ethanal to ethanol) thereby regenerating oxidised NAD (NAD^+) . NAD^+ allows glycolysis to continue.

Question : Briefly describe why anaerobic respiration produces less energy than aerobic respiration?

Answer :
Anaerobic respiration produces ATP via substrate level phosphorylation only when compared with aerobic respiration. In the absence of proton motive force less energy is released in the form of ATP . A lot of energy is still present in the energy rich molecules lactate and ethanol.



Now that we are done with both aerobic and anaerobic respiration, let's compare the two.

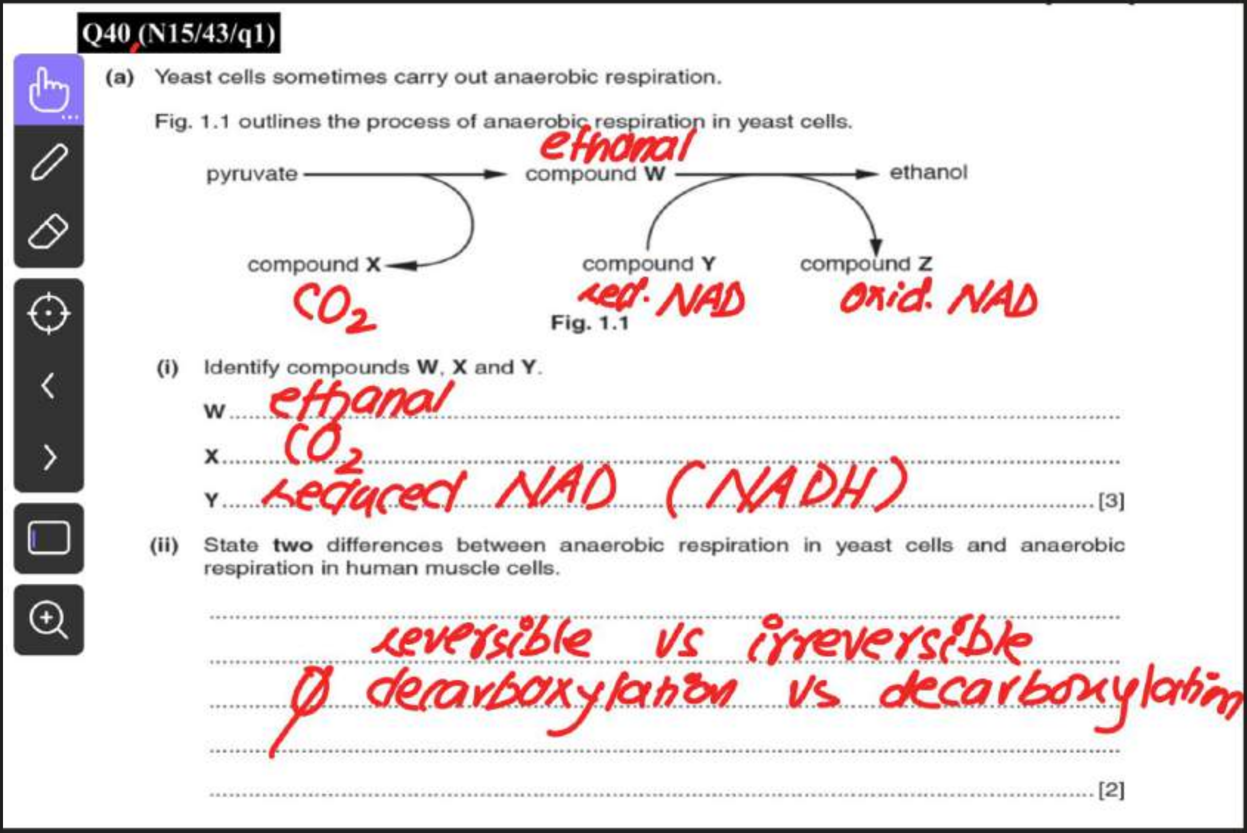


Question : Differentiate between aerobic and anaerobic respiration ?

Answer:

Aerobic	Anaerobic
1) Occurs in the presence of oxygen and mitochondria.	1) Occurs in the absence of oxygen and mitochondria.
2) Aerobic respiration is a slow process.	2) It is 2.5 times faster than aerobic.
3) It produces ATP via substrate level phosphorylation and oxidative phosphorylation.	3) It produces ATP via substrate level phosphorylation only.
4) It produces 32 molecules of ATP per molecule of glucose.	4) It produces net 2 ATP molecules per molecule of glucose.
5) Oxygen serve as the terminal electron acceptor.	5) Pyruvate or ethanal serves as the terminal electron acceptor.
6) The products are carbon dioxide, water and ATP.	6) The products are : a) lactate fermentation —> lactate + ATP b) alcoholic fermentation —> ethanol + 2 CO_2 + ATP

Question 1



Q40 (N15/43/q1)

(a) Yeast cells sometimes carry out anaerobic respiration.

Fig. 1.1 outlines the process of anaerobic respiration in yeast cells.

Fig. 1.1

(i) Identify compounds **W**, **X** and **Y**.

W ethanal

X CO_2

Y reduced NAD (NADH) [3]

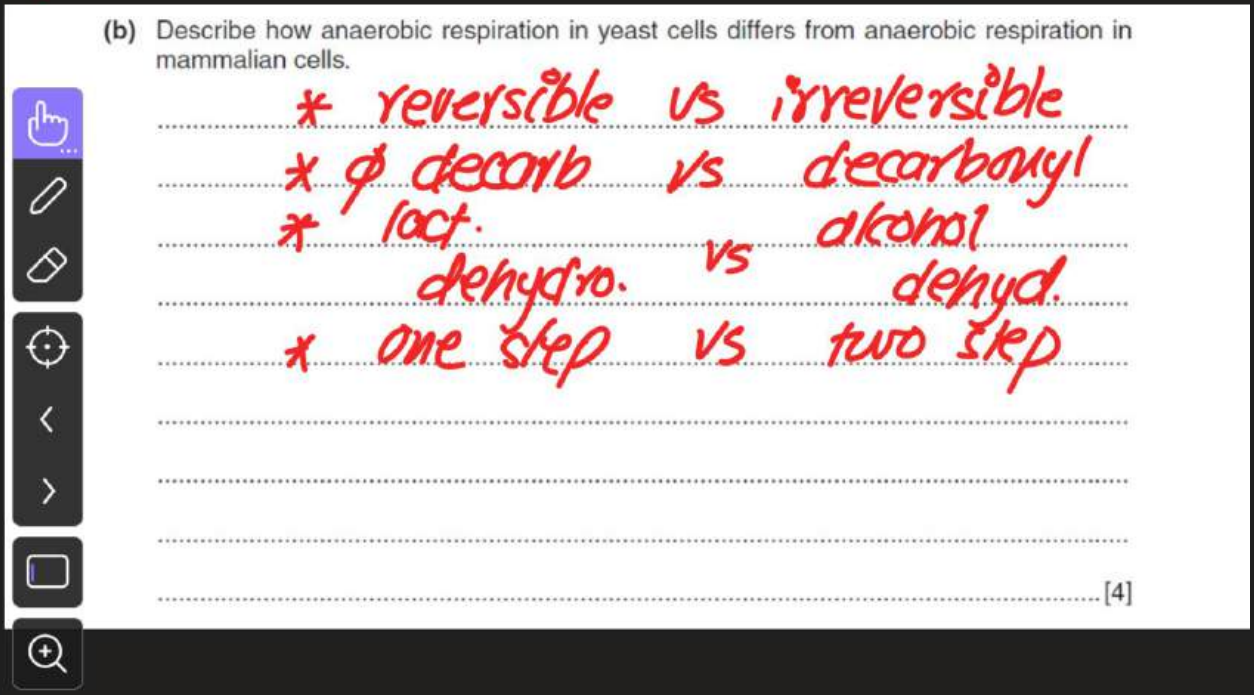
(ii) State **two** differences between anaerobic respiration in yeast cells and anaerobic respiration in human muscle cells.

reversible vs irreversible

∅ decarboxylation vs decarboxylation

[2]

Question 2



(b) Describe how anaerobic respiration in yeast cells differs from anaerobic respiration in mammalian cells.

* reversible vs irreversible

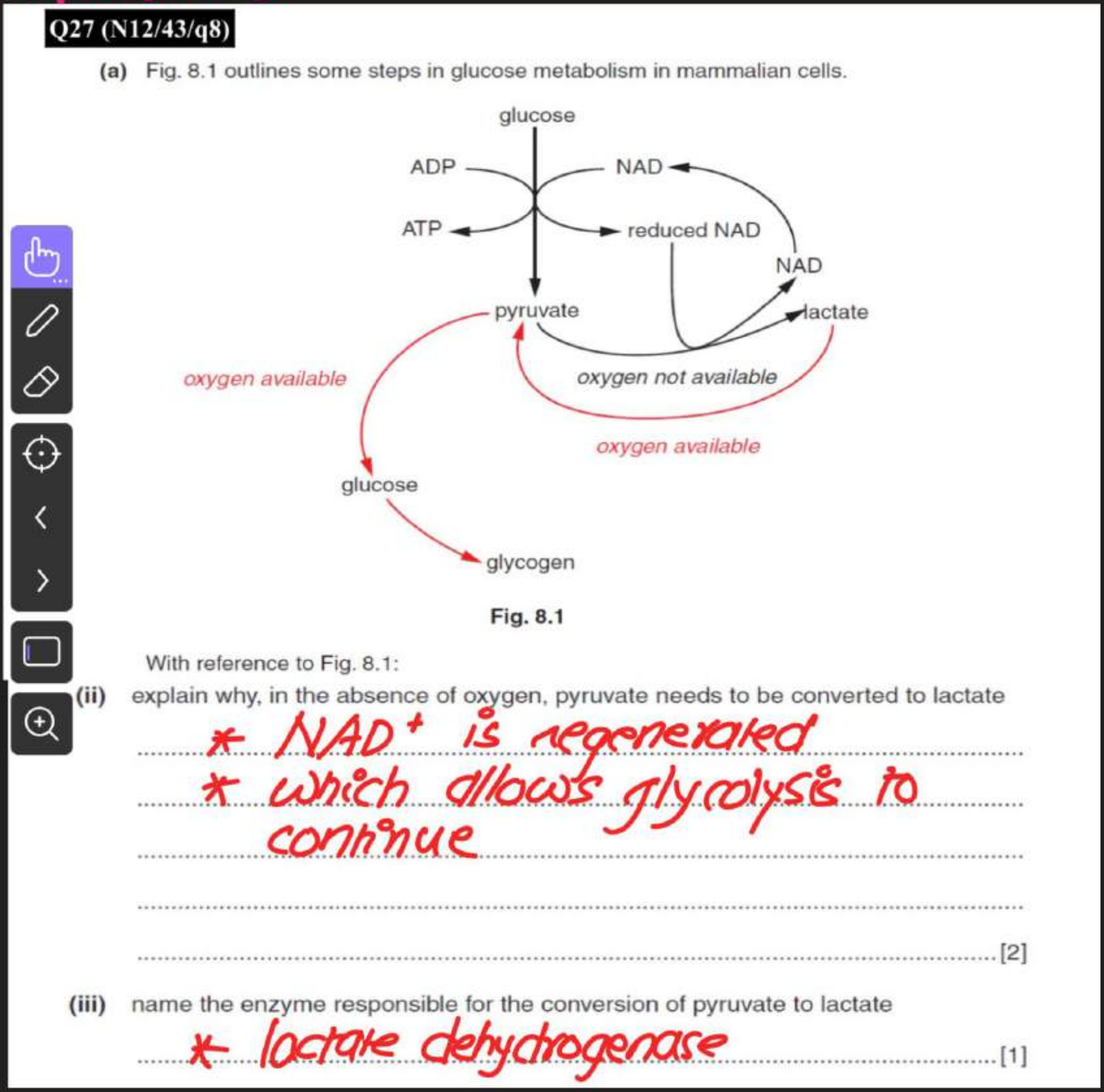
* ϕ decarb vs decarboxyl

* lact. dehydro. vs alcohol dehyd.

* one step vs two step

[4]

Question 3



Q27 (N12/43/q8)

(a) Fig. 8.1 outlines some steps in glucose metabolism in mammalian cells.

Fig. 8.1

With reference to Fig. 8.1:

(ii) explain why, in the absence of oxygen, pyruvate needs to be converted to lactate

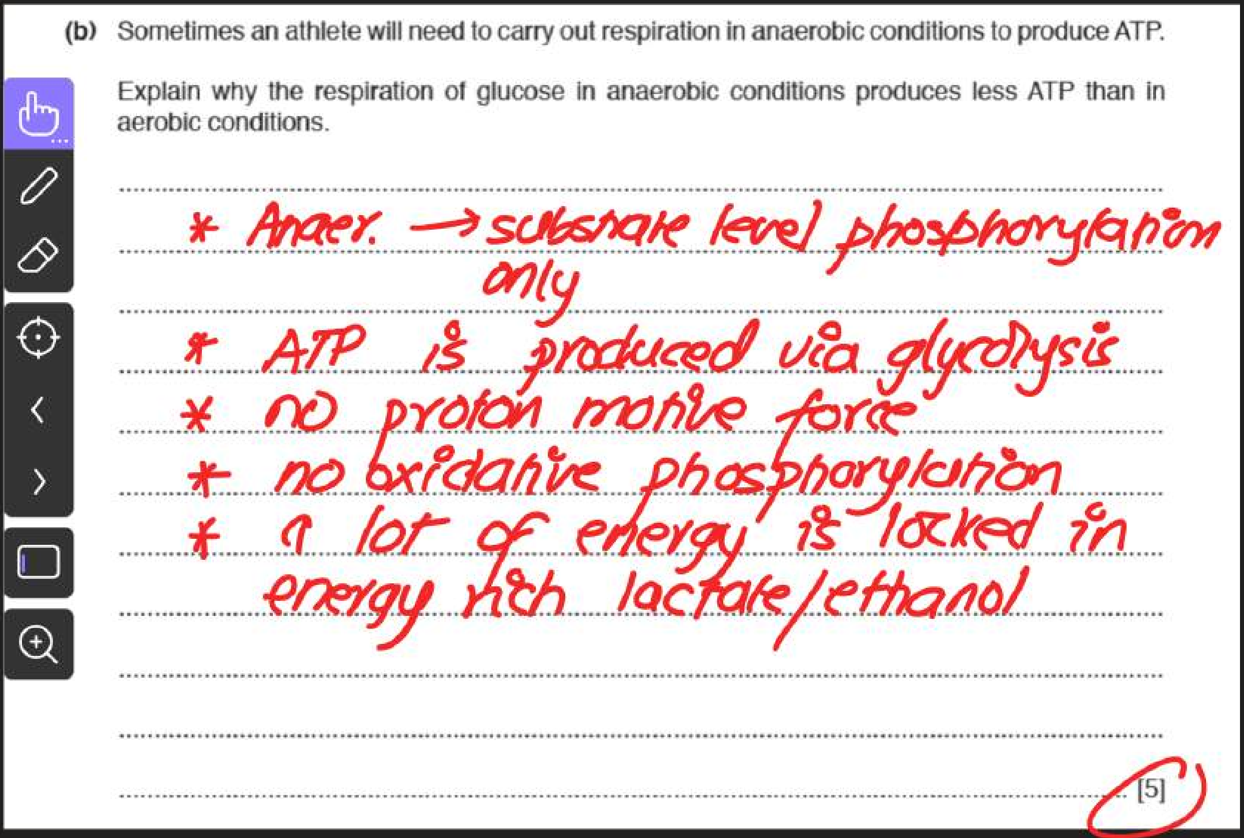
* NAD^+ is regenerated
* which allows glycolysis to continue

....[2]

(iii) name the enzyme responsible for the conversion of pyruvate to lactate

* lactate dehydrogenase ....[1]

Question 4



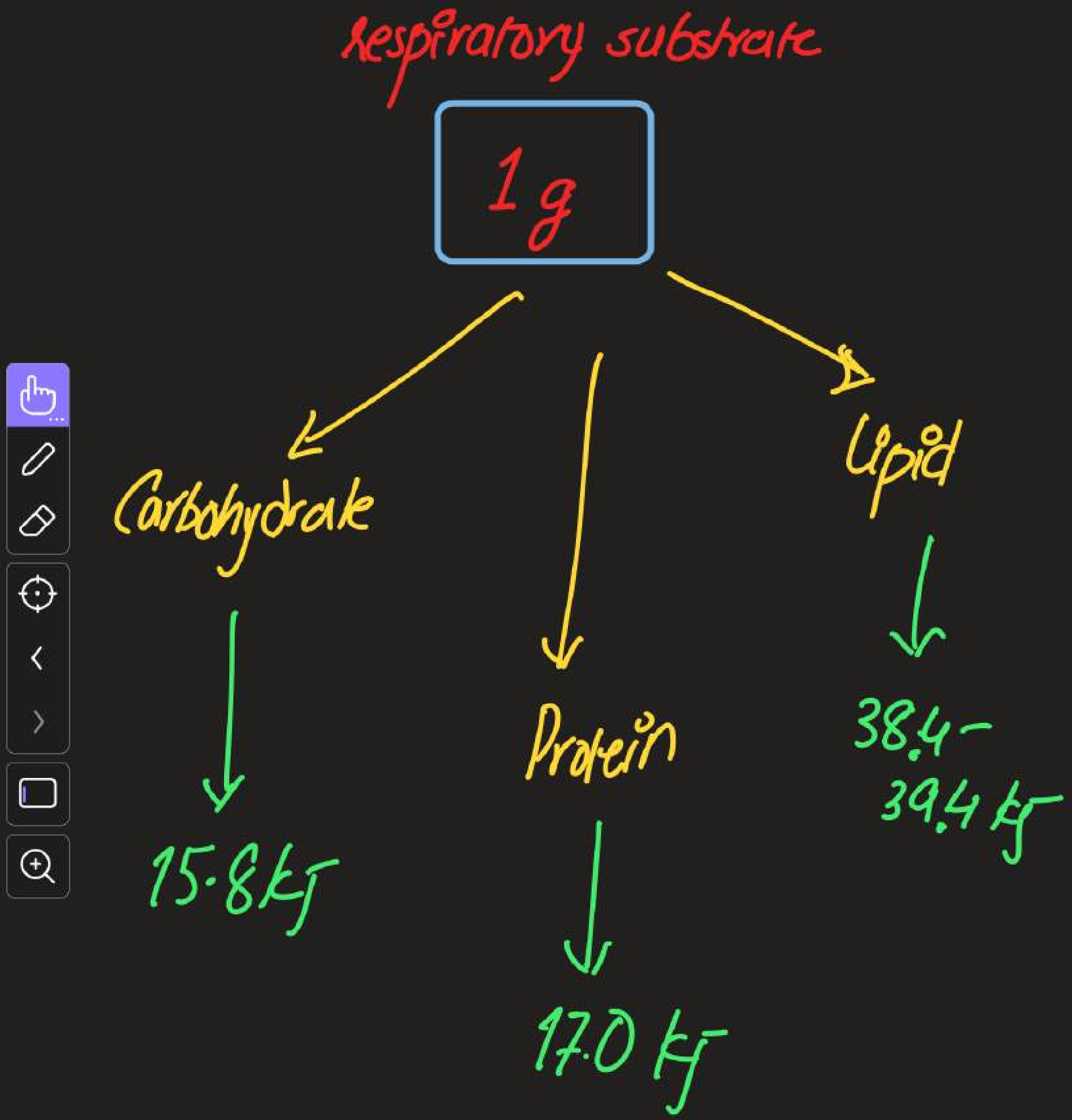
(b) Sometimes an athlete will need to carry out respiration in anaerobic conditions to produce ATP.

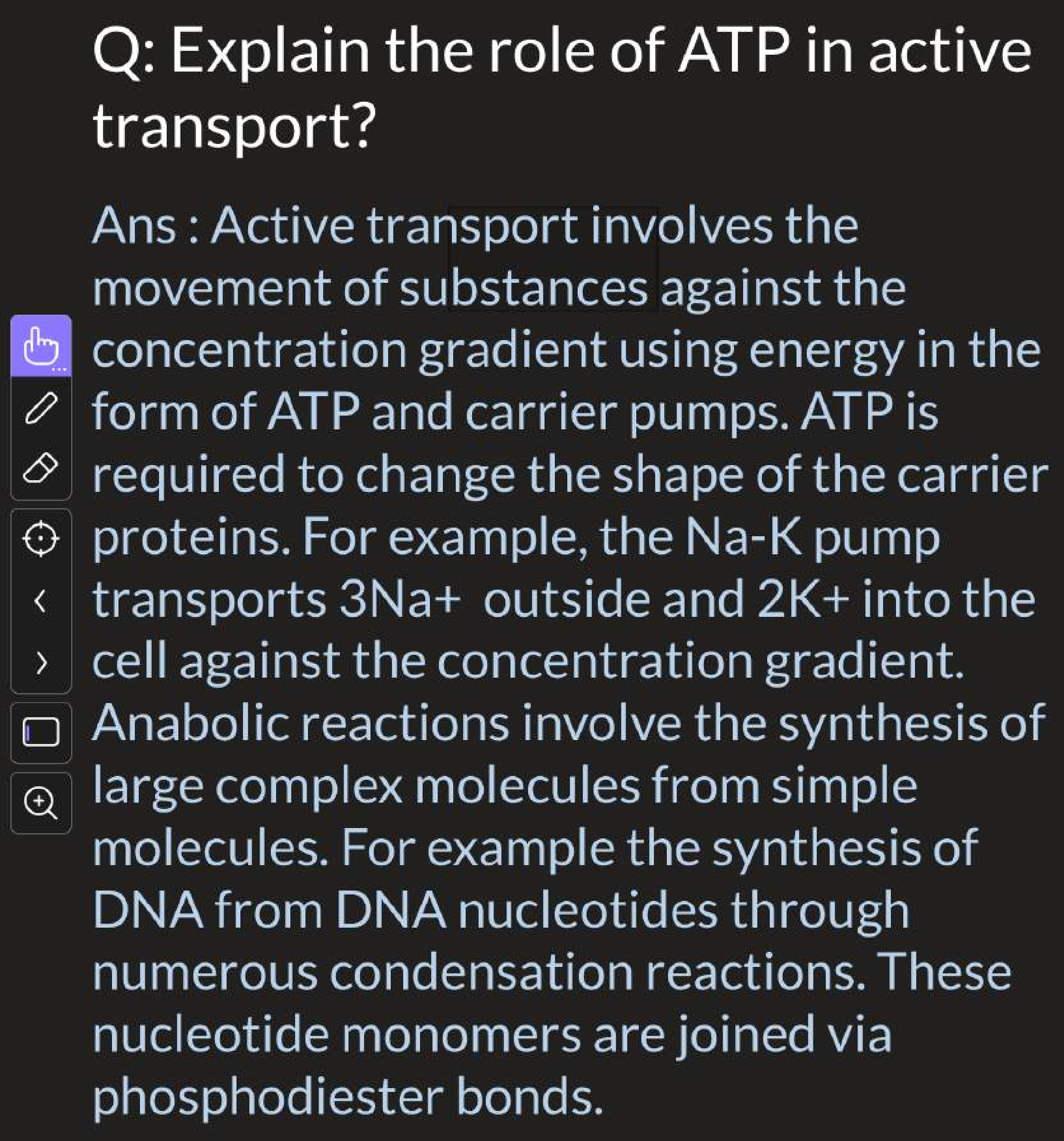
Explain why the respiration of glucose in anaerobic conditions produces less ATP than in aerobic conditions.

* Anaer. → substrate level phosphorylation only
* ATP is produced via glycolysis
* no proton motive force
* no oxidative phosphorylation
* a lot of energy is locked in energy rich lactate/ethanol

[5]

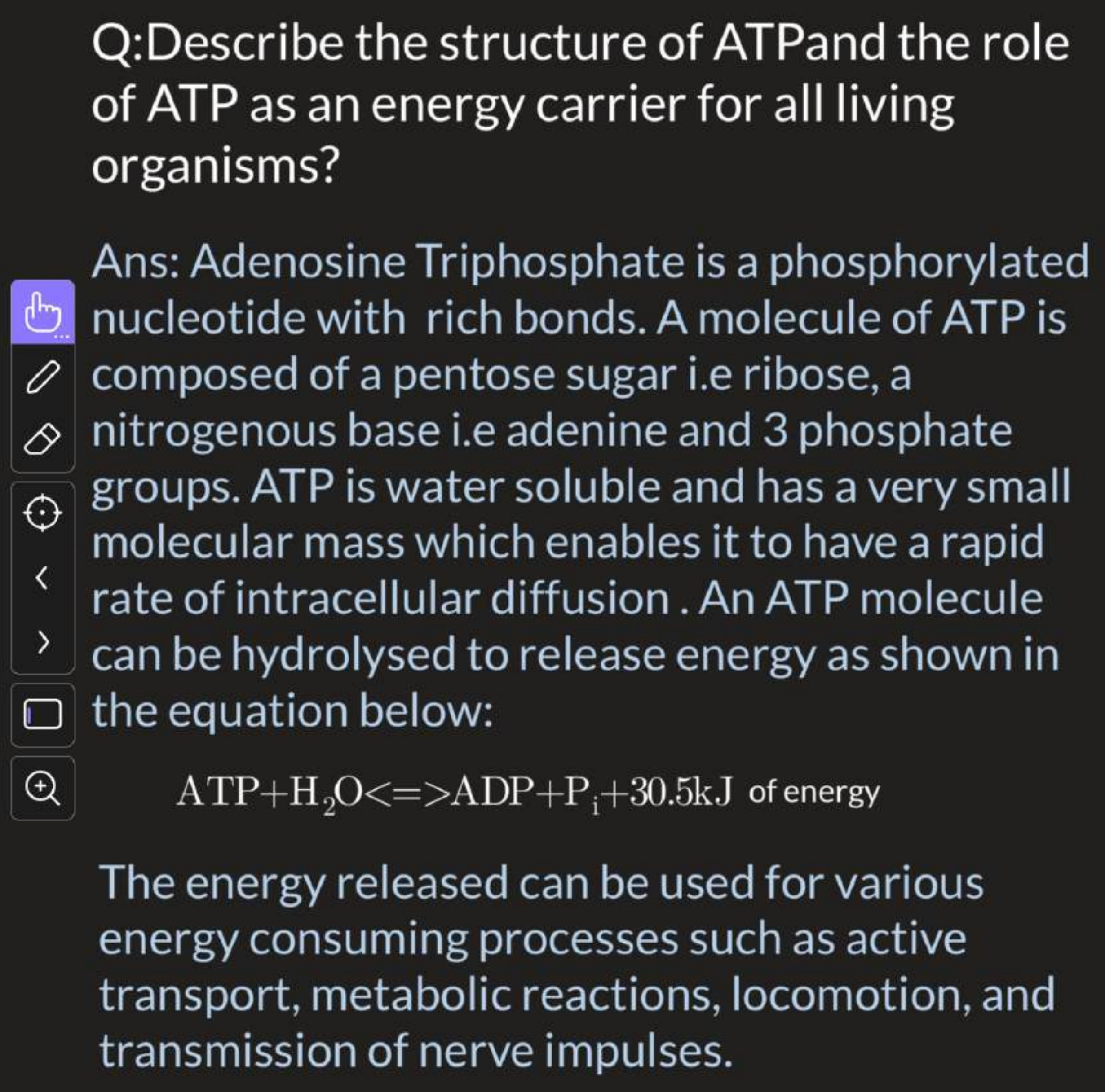
Energy Values of respiratory substrates


respiratory substrate
1 g
Carbohydrate
Protein
Lipid
15.8 kJ
17.0 kJ
38.4-
39.4 kJ



Q: Explain the role of ATP in active transport?

Ans : Active transport involves the movement of substances against the concentration gradient using energy in the form of ATP and carrier pumps. ATP is required to change the shape of the carrier proteins. For example, the Na-K pump transports 3Na+ outside and 2K+ into the cell against the concentration gradient. Anabolic reactions involve the synthesis of large complex molecules from simple molecules. For example the synthesis of DNA from DNA nucleotides through numerous condensation reactions. These nucleotide monomers are joined via phosphodiester bonds.

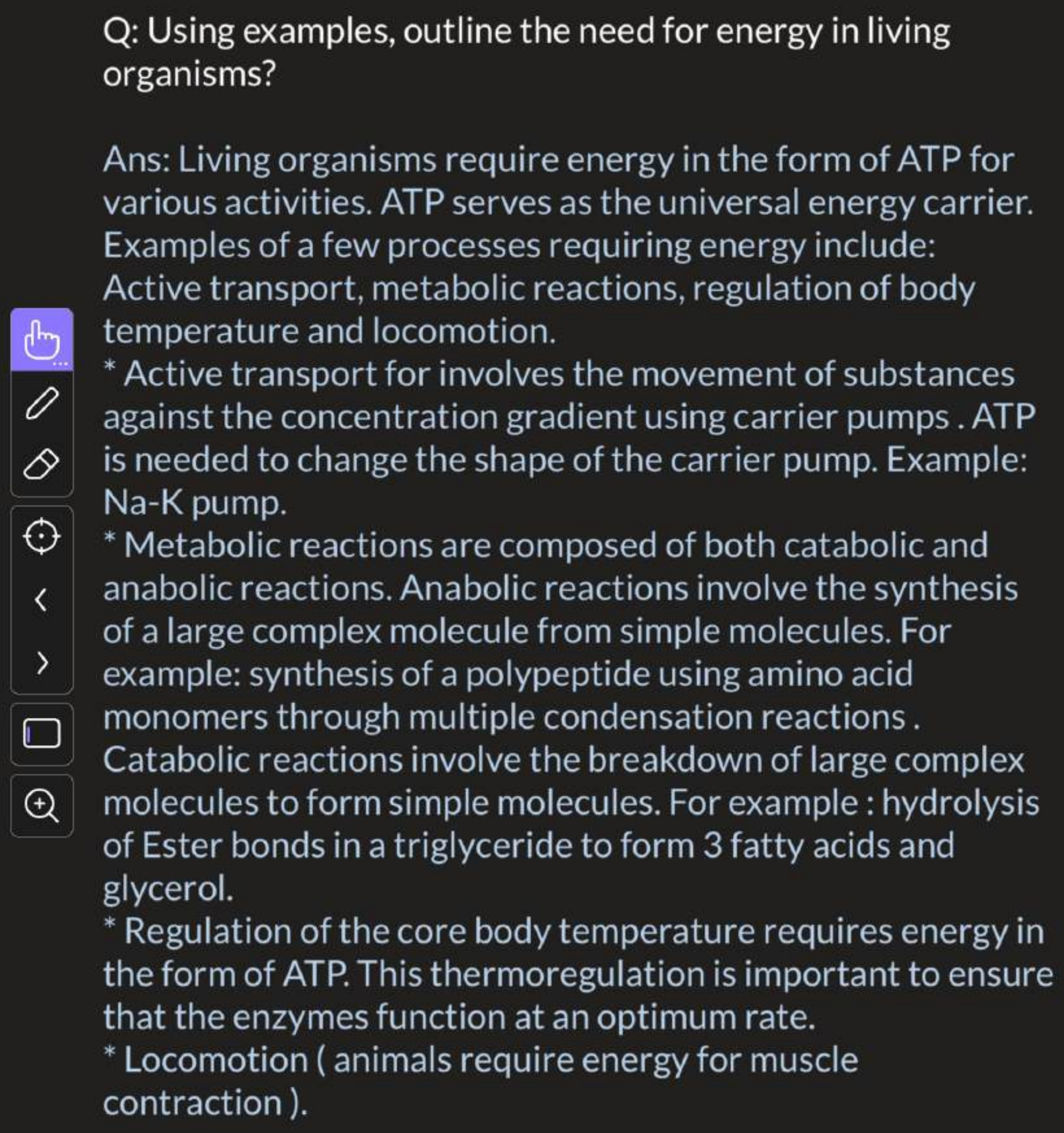


Q:Describe the structure of ATPand the role of ATP as an energy carrier for all living organisms?

Ans: Adenosine Triphosphate is a phosphorylated nucleotide with rich bonds. A molecule of ATP is composed of a pentose sugar i.e ribose, a nitrogenous base i.e adenine and 3 phosphate groups. ATP is water soluble and has a very small molecular mass which enables it to have a rapid rate of intracellular diffusion . An ATP molecule can be hydrolysed to release energy as shown in the equation below:

$$\mathrm{ATP}+\mathrm{H_2O}<=>\mathrm{ADP}+\mathrm{P_i}+30.5\mathrm{kJ}\ \text{of energy}$$

The energy released can be used for various energy consuming processes such as active transport, metabolic reactions, locomotion, and transmission of nerve impulses.



Q: Using examples, outline the need for energy in living organisms?

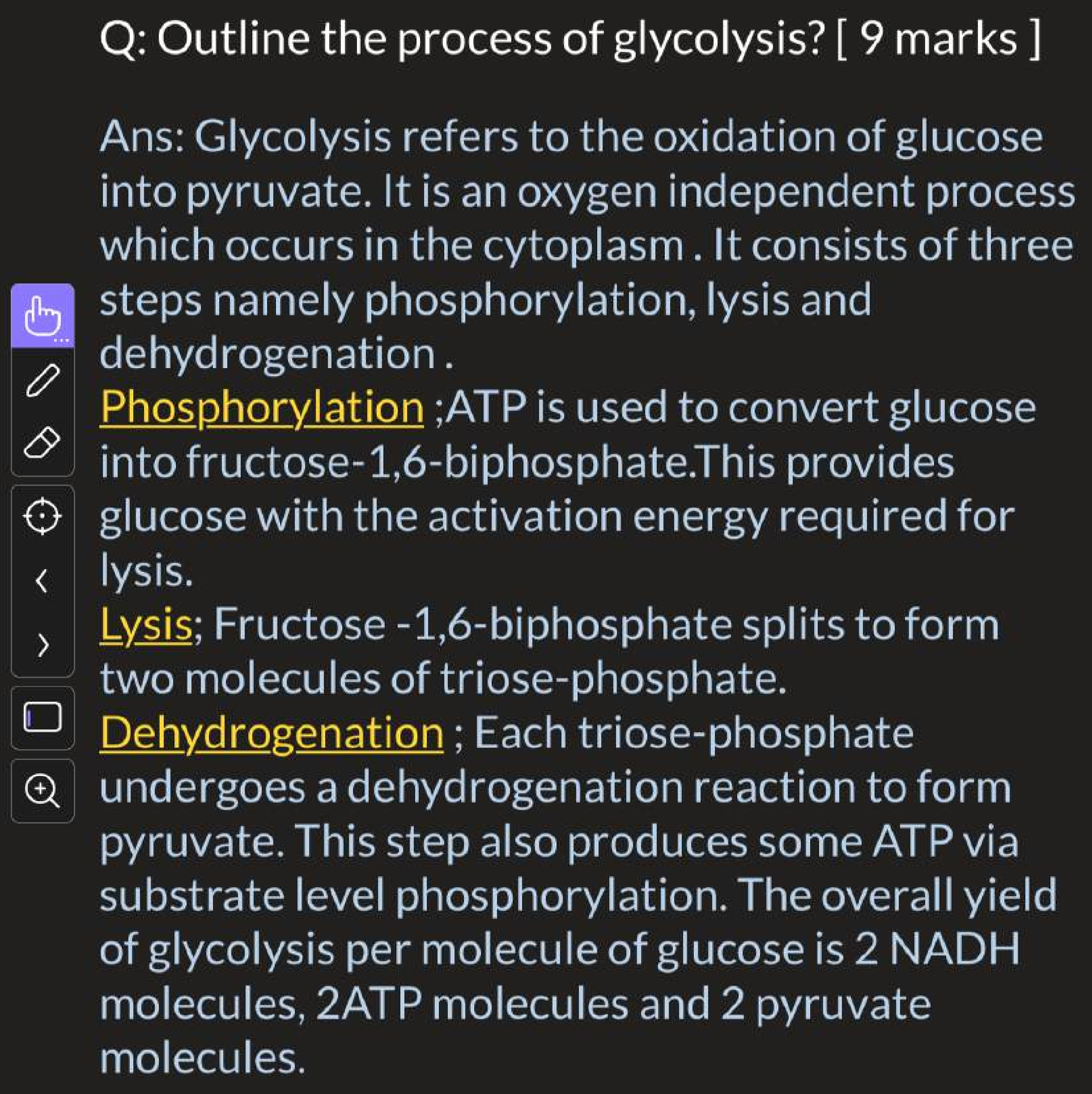
Ans: Living organisms require energy in the form of ATP for various activities. ATP serves as the universal energy carrier. Examples of a few processes requiring energy include: Active transport, metabolic reactions, regulation of body temperature and locomotion.

* Active transport for involves the movement of substances against the concentration gradient using carrier pumps . ATP is needed to change the shape of the carrier pump. Example: Na-K pump.

* Metabolic reactions are composed of both catabolic and anabolic reactions. Anabolic reactions involve the synthesis of a large complex molecule from simple molecules. For example: synthesis of a polypeptide using amino acid monomers through multiple condensation reactions . Catabolic reactions involve the breakdown of large complex molecules to form simple molecules. For example : hydrolysis of Ester bonds in a triglyceride to form 3 fatty acids and glycerol.

* Regulation of the core body temperature requires energy in the form of ATP. This thermoregulation is important to ensure that the enzymes function at an optimum rate.

* Locomotion (animals require energy for muscle contraction).



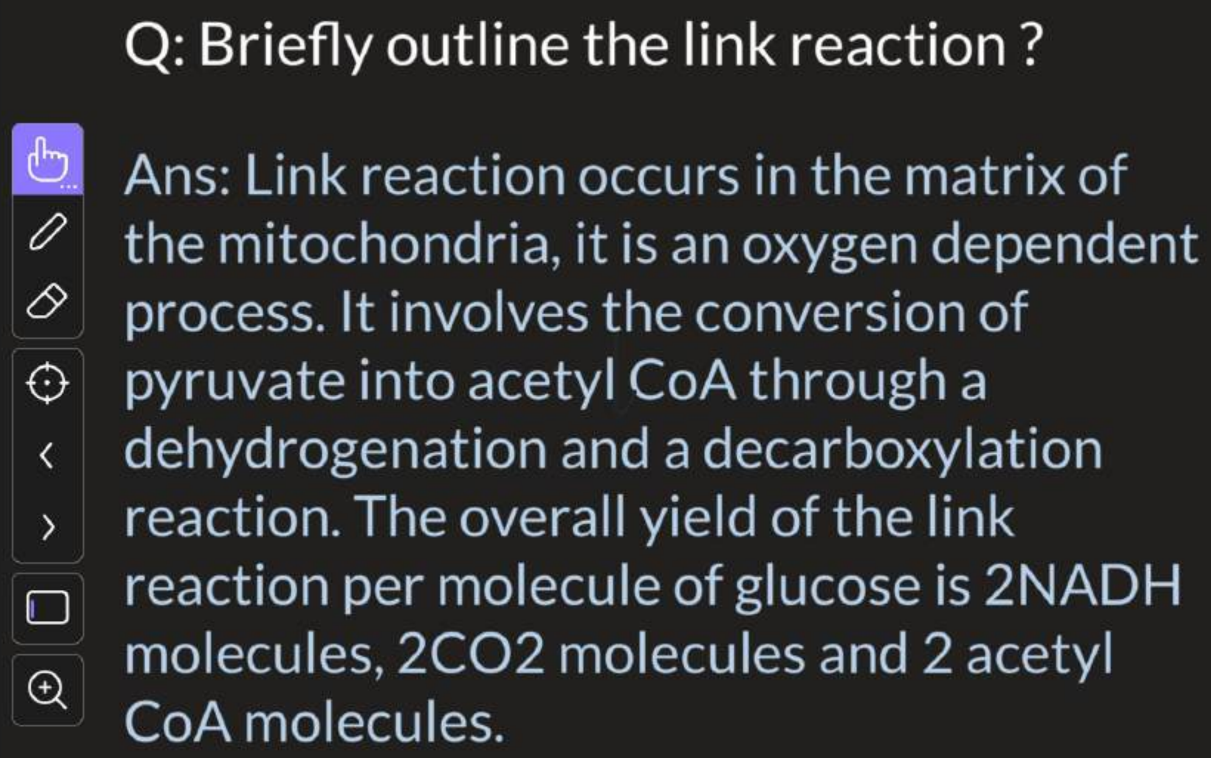
Q: Outline the process of glycolysis? [9 marks]

Ans: Glycolysis refers to the oxidation of glucose into pyruvate. It is an oxygen independent process which occurs in the cytoplasm . It consists of three steps namely phosphorylation, lysis and dehydrogenation .

Phosphorylation ;ATP is used to convert glucose into fructose-1,6-biphosphate.This provides glucose with the activation energy required for lysis.

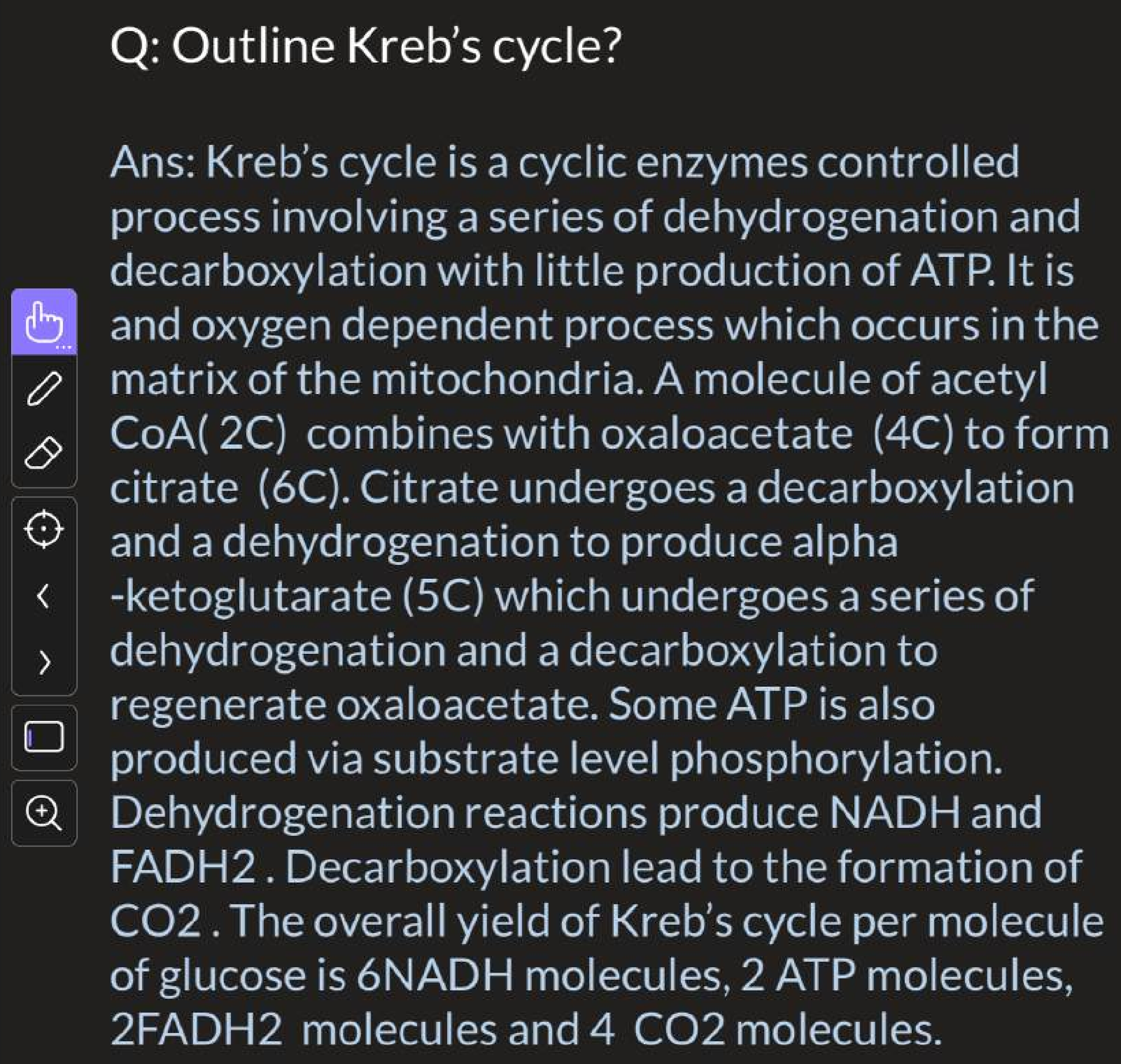
Lysis; Fructose -1,6-biphosphate splits to form two molecules of triose-phosphate.

Dehydrogenation ; Each triose-phosphate undergoes a dehydrogenation reaction to form pyruvate. This step also produces some ATP via substrate level phosphorylation. The overall yield of glycolysis per molecule of glucose is 2 NADH molecules, 2ATP molecules and 2 pyruvate molecules.



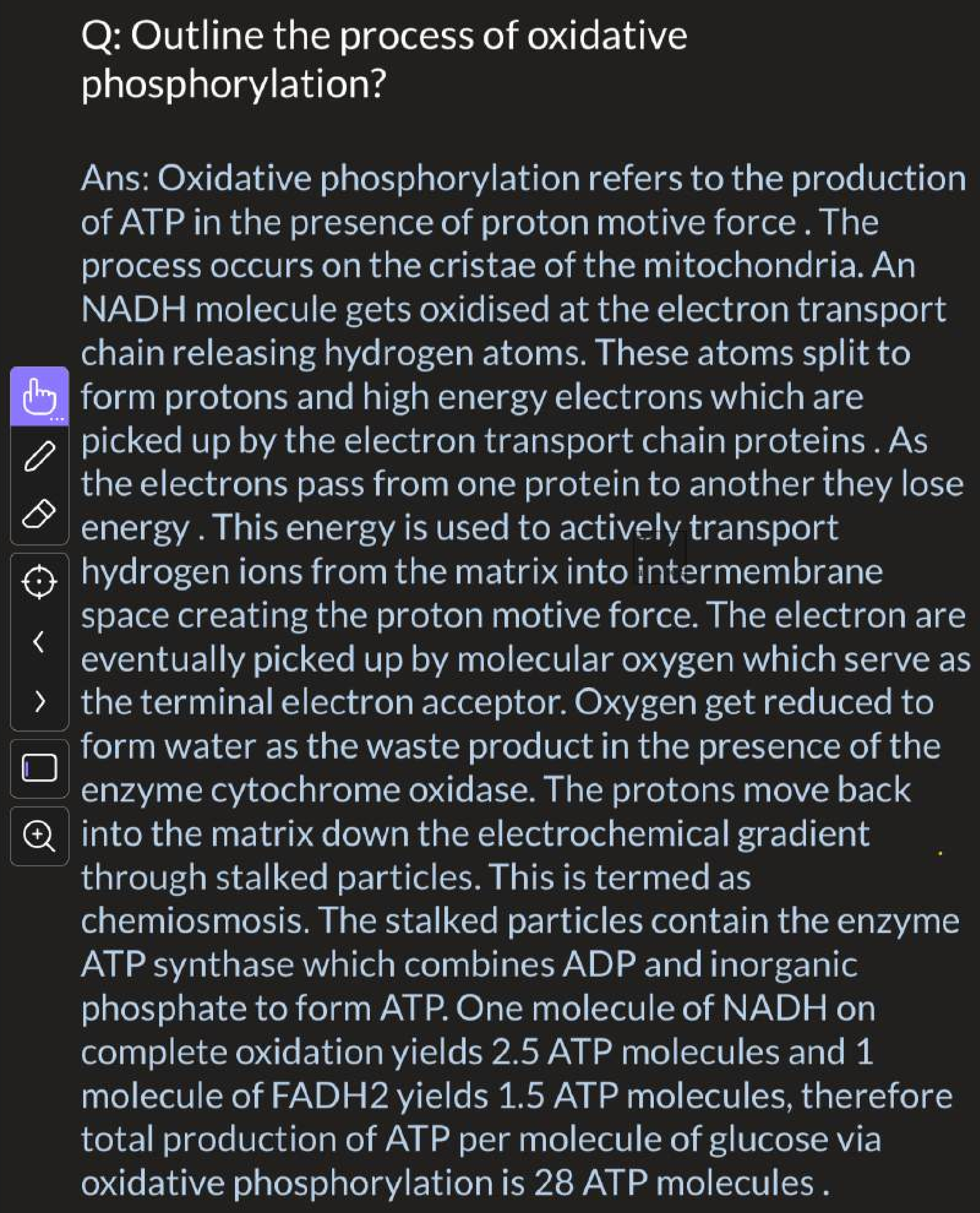
Q: Briefly outline the link reaction ?

Ans: Link reaction occurs in the matrix of the mitochondria, it is an oxygen dependent process. It involves the conversion of pyruvate into acetyl CoA through a dehydrogenation and a decarboxylation reaction. The overall yield of the link reaction per molecule of glucose is 2NADH molecules, 2CO2 molecules and 2 acetyl CoA molecules.



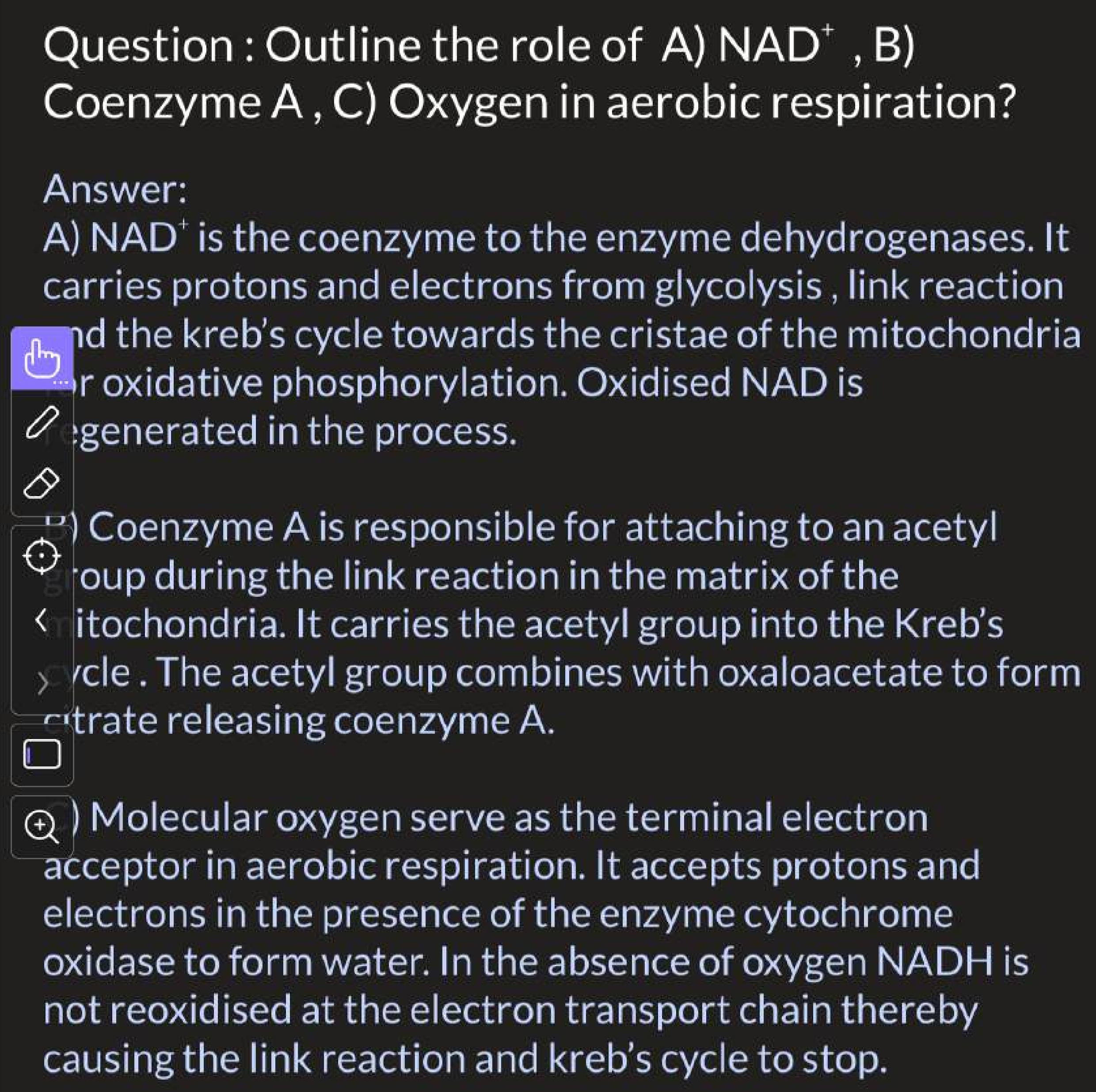
Q: Outline Kreb's cycle?

Ans: Kreb's cycle is a cyclic enzymes controlled process involving a series of dehydrogenation and decarboxylation with little production of ATP. It is and oxygen dependent process which occurs in the matrix of the mitochondria. A molecule of acetyl CoA(2C) combines with oxaloacetate (4C) to form citrate (6C). Citrate undergoes a decarboxylation and a dehydrogenation to produce alpha -ketoglutarate (5C) which undergoes a series of dehydrogenation and a decarboxylation to regenerate oxaloacetate. Some ATP is also produced via substrate level phosphorylation. Dehydrogenation reactions produce NADH and FADH2 . Decarboxylation lead to the formation of CO2 . The overall yield of Kreb's cycle per molecule of glucose is 6NADH molecules, 2 ATP molecules, 2FADH2 molecules and 4 CO2 molecules.



Q: Outline the process of oxidative phosphorylation?

Ans: Oxidative phosphorylation refers to the production of ATP in the presence of proton motive force . The process occurs on the cristae of the mitochondria. An NADH molecule gets oxidised at the electron transport chain releasing hydrogen atoms. These atoms split to form protons and high energy electrons which are picked up by the electron transport chain proteins . As the electrons pass from one protein to another they lose energy . This energy is used to actively transport hydrogen ions from the matrix into intermembrane space creating the proton motive force. The electron are eventually picked up by molecular oxygen which serve as the terminal electron acceptor. Oxygen get reduced to form water as the waste product in the presence of the enzyme cytochrome oxidase. The protons move back into the matrix down the electrochemical gradient through stalked particles. This is termed as chemiosmosis. The stalked particles contain the enzyme ATP synthase which combines ADP and inorganic phosphate to form ATP. One molecule of NADH on complete oxidation yields 2.5 ATP molecules and 1 molecule of FADH2 yields 1.5 ATP molecules, therefore total production of ATP per molecule of glucose via oxidative phosphorylation is 28 ATP molecules .



Question : Outline the role of A) NAD^+ , B) Coenzyme A , C) Oxygen in aerobic respiration?

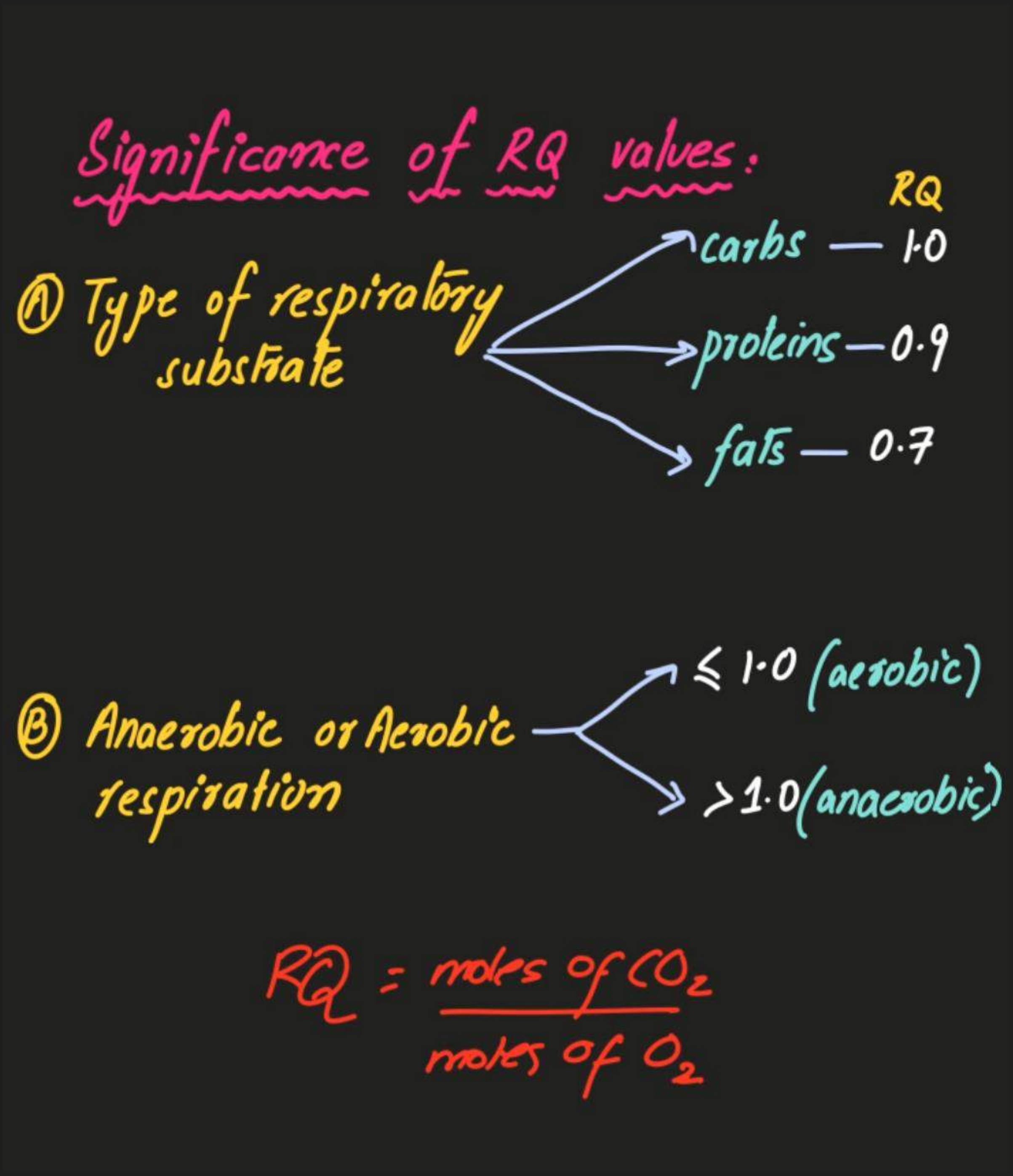
Answer:
A) NAD^+ is the coenzyme to the enzyme dehydrogenases. It carries protons and electrons from glycolysis , link reaction and the kreb's cycle towards the cristae of the mitochondria for oxidative phosphorylation. Oxidised NAD is regenerated in the process.

B) Coenzyme A is responsible for attaching to an acetyl group during the link reaction in the matrix of the mitochondria. It carries the acetyl group into the Kreb's cycle . The acetyl group combines with oxaloacetate to form citrate releasing coenzyme A.

C) Molecular oxygen serve as the terminal electron acceptor in aerobic respiration. It accepts protons and electrons in the presence of the enzyme cytochrome oxidase to form water. In the absence of oxygen NADH is not reoxidised at the electron transport chain thereby causing the link reaction and kreb's cycle to stop.

HEUSER

Energy & Respiration



Significance of RQ values:

Ⓐ Type of respiratory substrate

	RQ
carbs	1.0
proteins	0.9
fats	0.7

Ⓑ Anaerobic or Aerobic respiration

≤ 1.0 (aerobic)

> 1.0 (anaerobic)

$$RQ = \frac{\text{moles of } CO_2}{\text{moles of } O_2}$$

With

Mohammad Hussham Arshad, MD

ADVANCED LEVEL BIOLOGY 9700

UNIT 12: ENERGY AND RESPIRATION

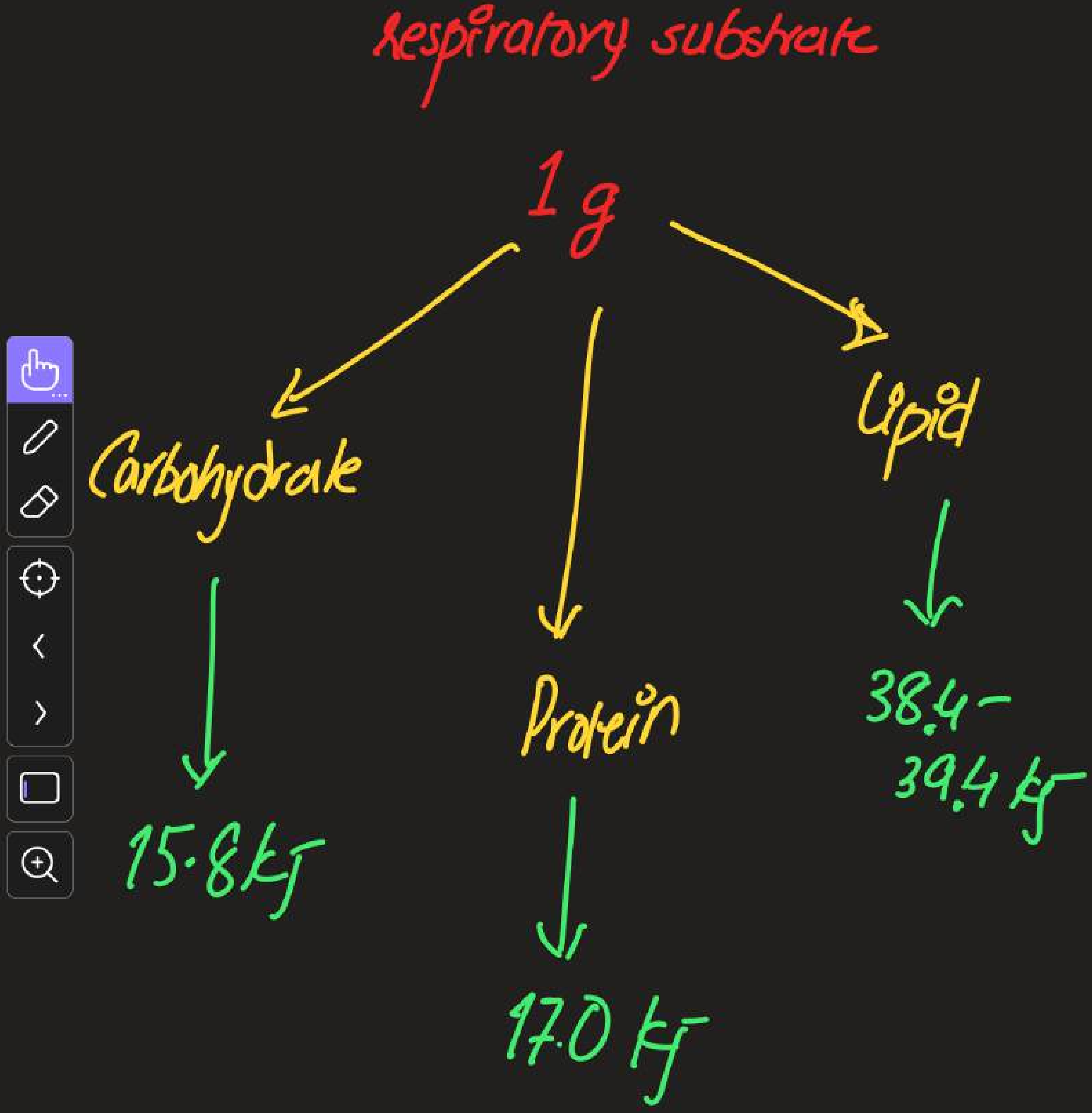
Learning Objectives:

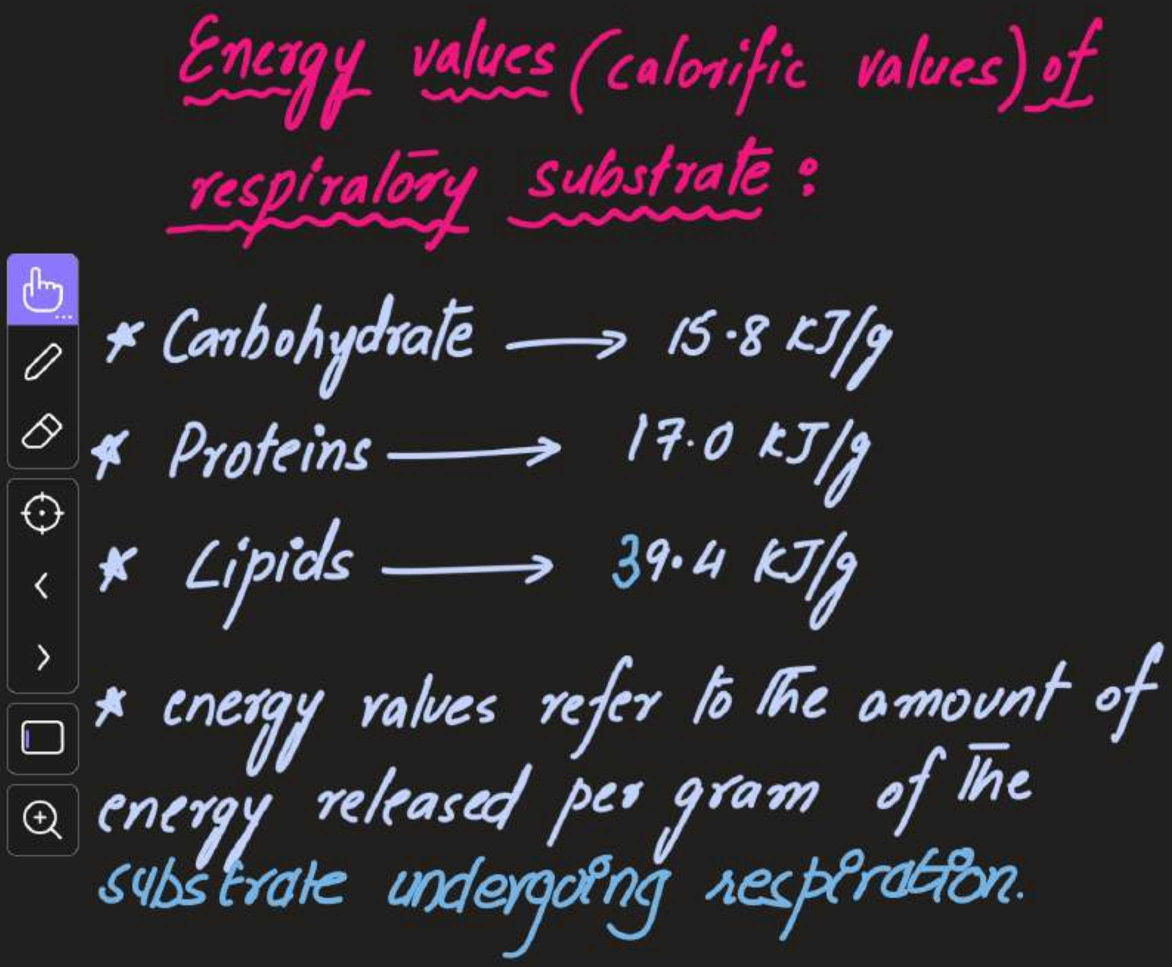
- Energy Values
- RQ Value
- Oxygen Debt

Video Lecture 9 Slides

Mohammad Hussham Arshad, MD
Biology Department

Energy Values of respiratory substrates


respiratory substrate
1 g
Carbohydrate
Protein
Lipid
15·8 kJ
17·0 kJ
38.4–
39.4 kJ

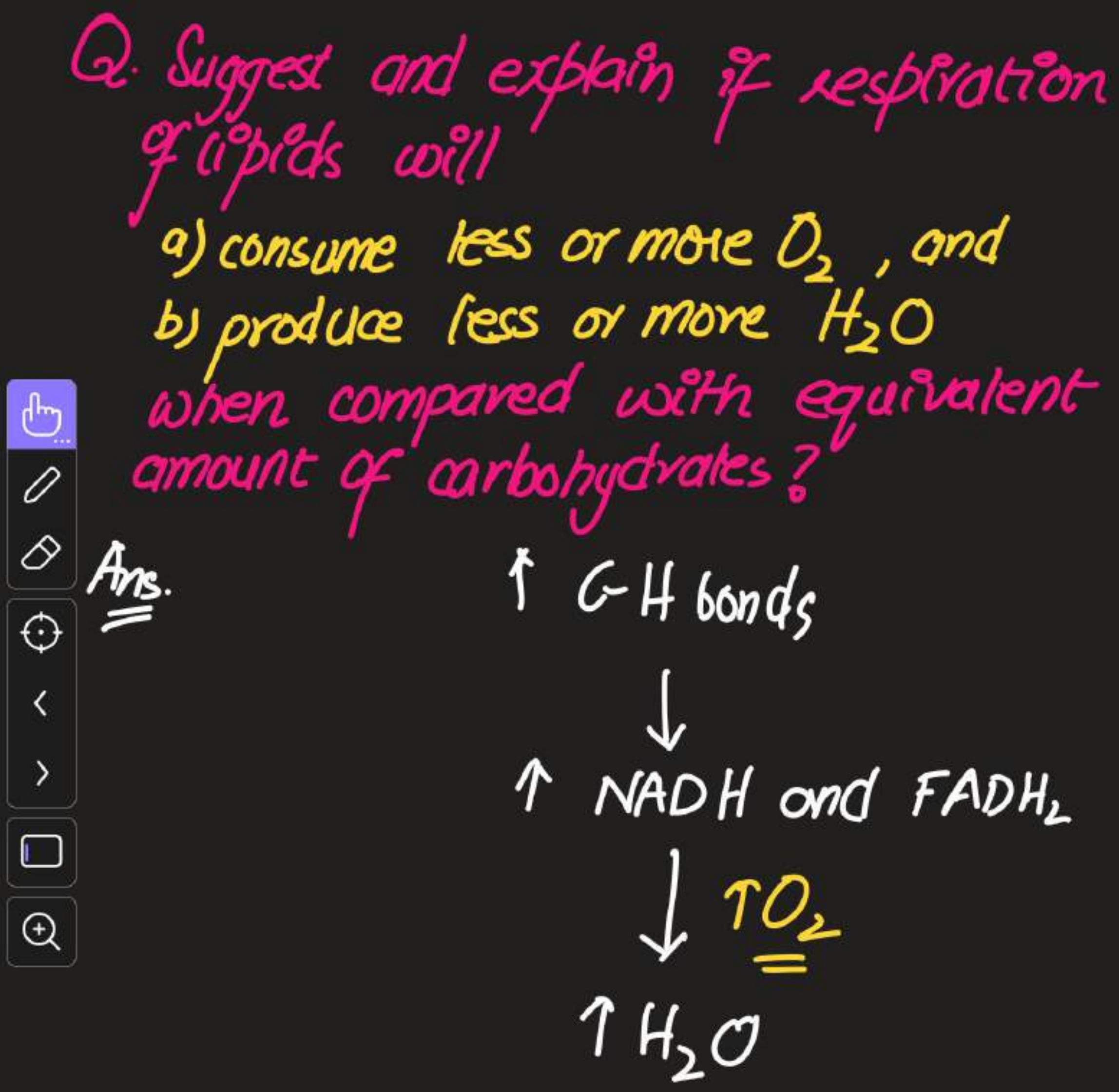


Energy values (calorific values) of respiratory substrate :

- Carbohydrate ⟶ 15·8 kJ/g
- Proteins ⟶ 17·0 kJ/g
- Lipids ⟶ 39·4 kJ/g
- energy values refer to the amount of energy released per gram of the substrate undergoing respiration.

Q. Explain why lipids/fats have a much higher energy value than proteins or carbs?

* Fats have a much high energy value because of the greater number of C–H bonds → hence greater number of H toms per gram of the substrate which yields → More NADH and $FADH_2$ → more ATP via oxidative phosphorylation.



Q. Suggest and explain if respiration of lipids will

a) consume less or more O_2 , and

b) produce less or more H_2O

when compared with equivalent amount of carbohydrates?

Ans.

↑ C-H bonds

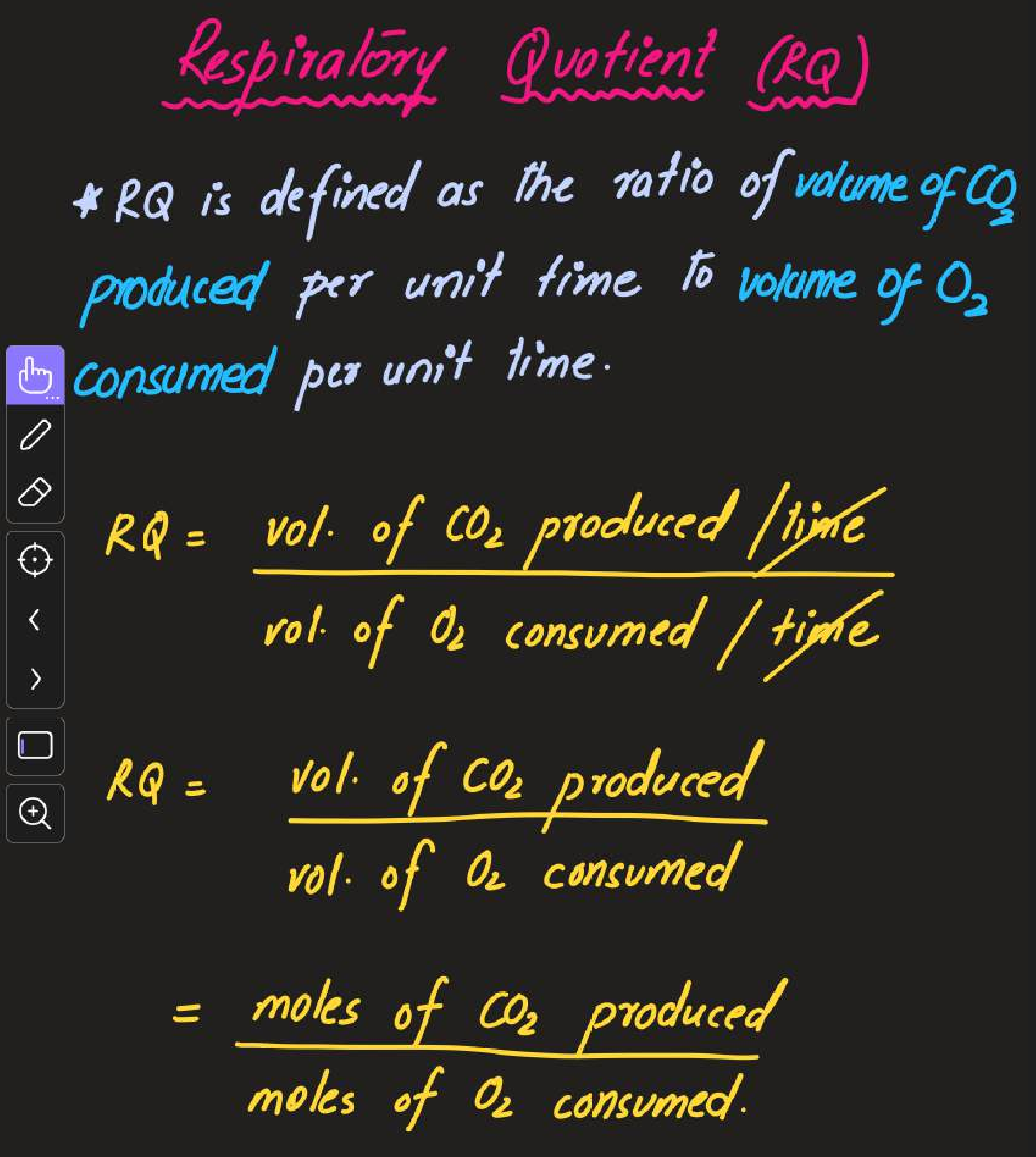
↓

↑ NADH and $FADH_2$

↓ ↑O_2

↑ H_2O

Respiratory Quotient (RQ)



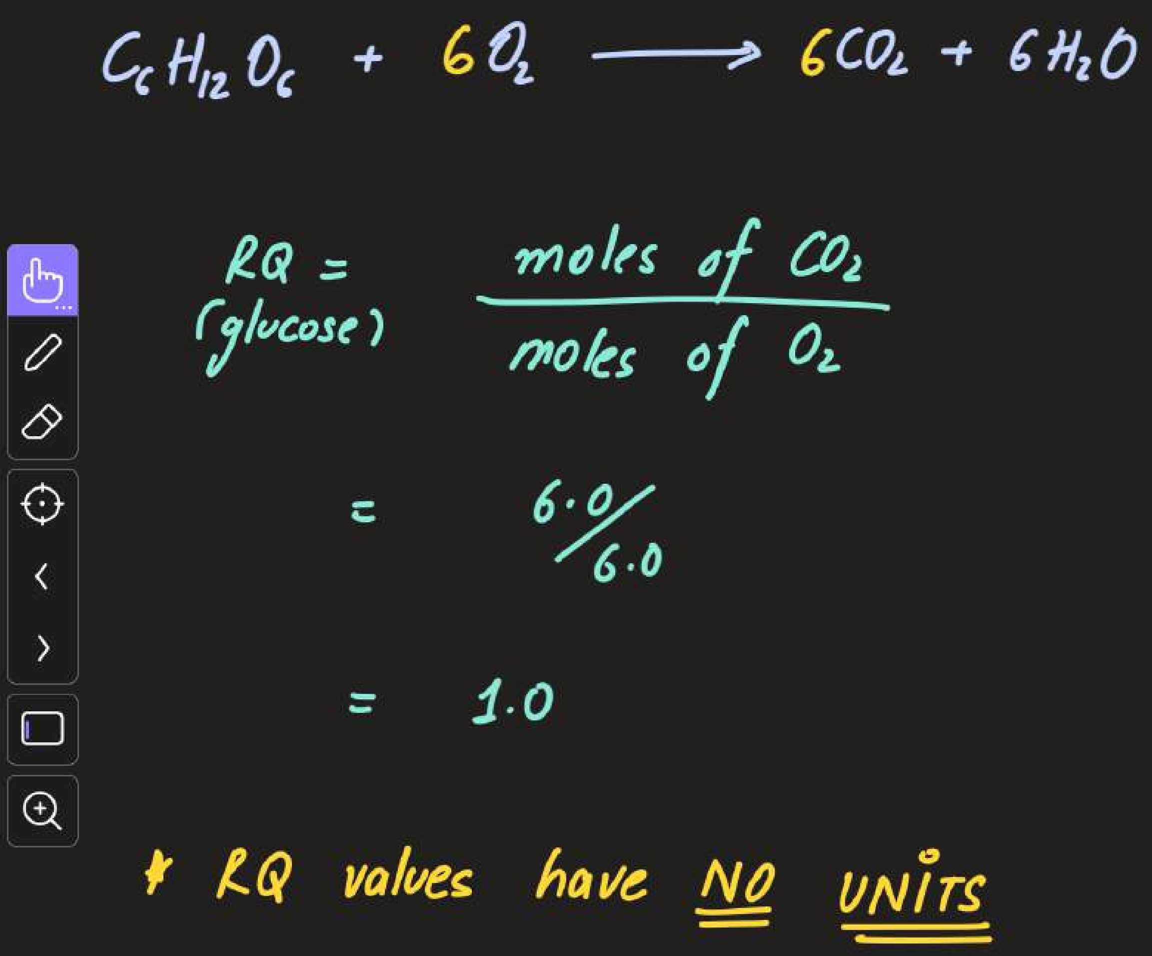
Respiratory Quotient (RQ)

* RQ is defined as the ratio of volume of CO_2 produced per unit time to volume of O_2 consumed per unit time.

$$RQ = \frac{\text{vol. of } CO_2 \text{ produced} / \cancel{\text{time}}}{\text{vol. of } O_2 \text{ consumed} / \cancel{\text{time}}}$$

$$RQ = \frac{\text{vol. of } CO_2 \text{ produced}}{\text{vol. of } O_2 \text{ consumed}}$$

$$= \frac{\text{moles of } CO_2 \text{ produced}}{\text{moles of } O_2 \text{ consumed.}}$$



$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

$$\underset{\text{(glucose)}}{RQ} = \frac{\text{moles of } CO_2}{\text{moles of } O_2}$$

$$= 6.0/6.0$$

$$= 1.0$$

* RQ values have $\underline{\underline{\text{NO}}}$ $\underline{\underline{\text{UNITS}}}$

Q. Given below is an equation to represent the respiration of fatty acid, oleic acid:

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

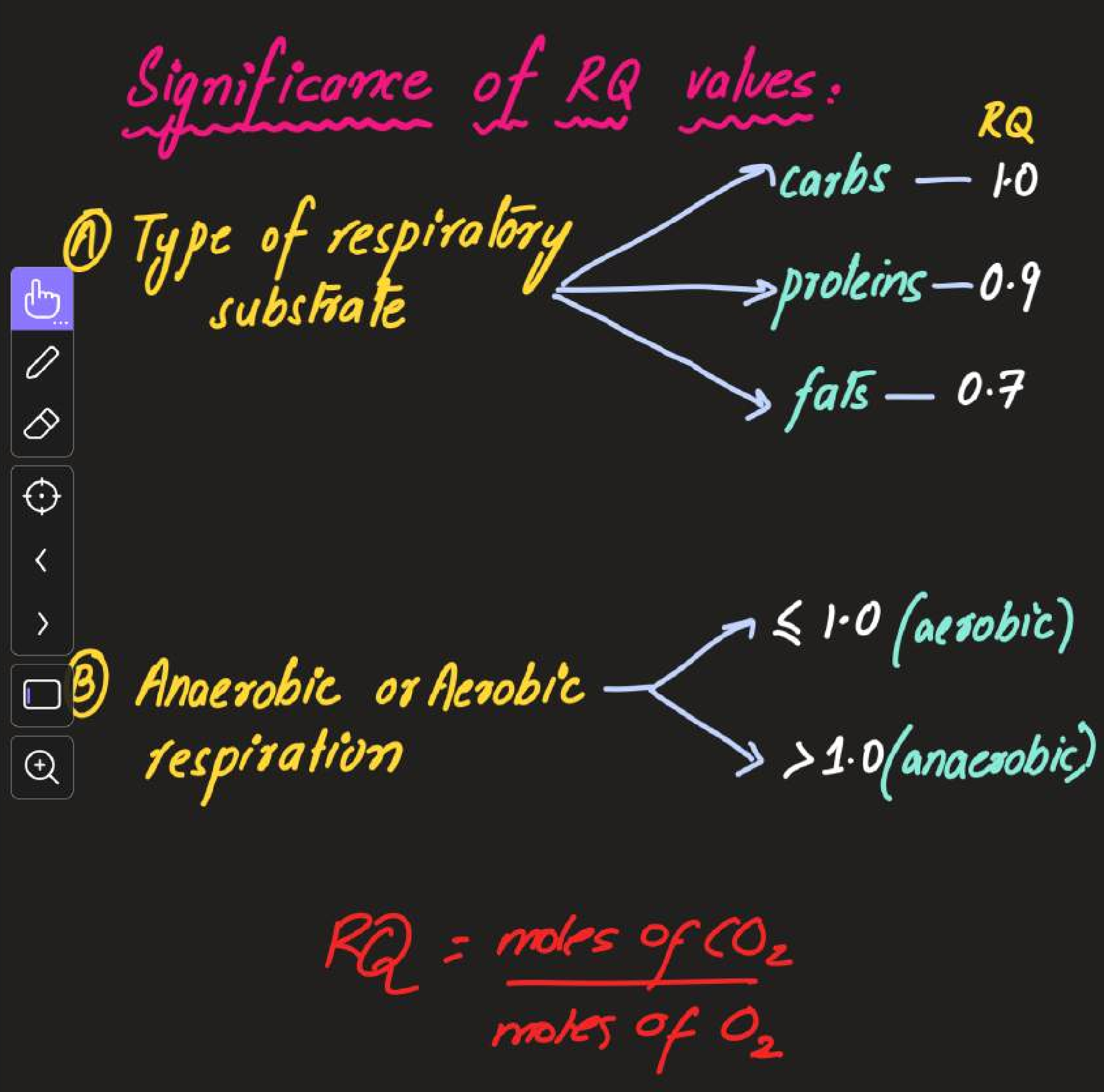
Determine the RQ value.

Ans

$$RQ = \frac{\text{moles of } CO_2 \text{ prod.}}{\text{moles of } O_2 \text{ consumed}}$$

$$= 36/51 = 0.7$$

$$2C_xH_yO_z + 2\left(x + y/4 - \frac{z}{2}\right)O_2 \rightarrow 2xCO_2 + \frac{2y}{2}H_2O$$



Significance of RQ values:

RQ

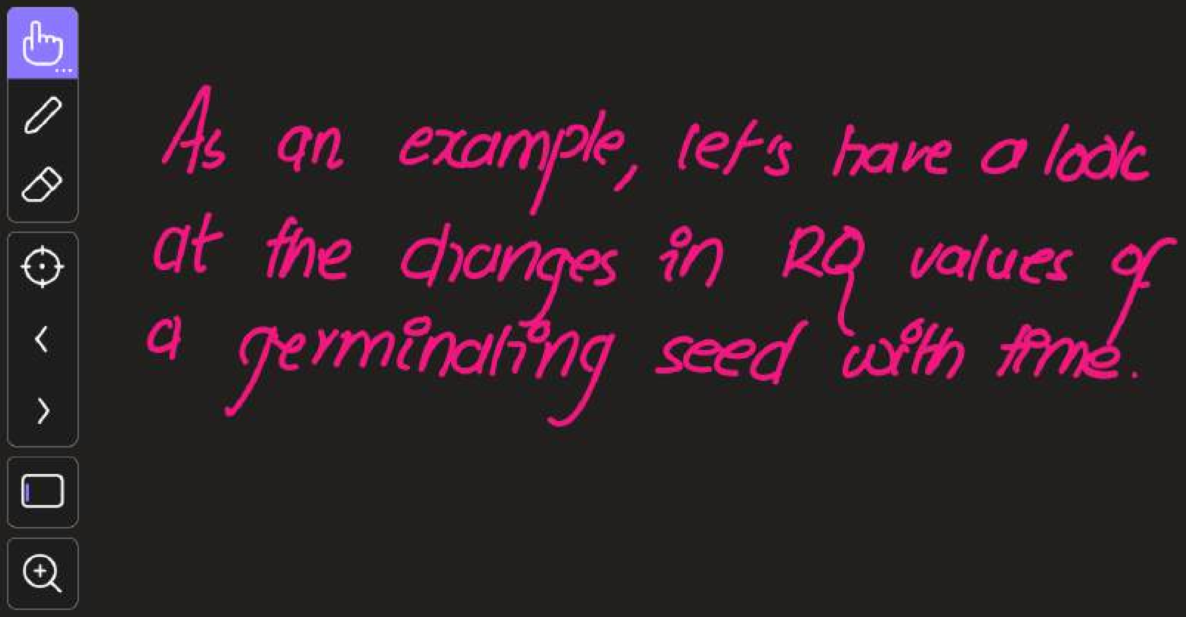
Ⓐ Type of respiratory substrate

carbs — 1·0
proteins — 0·9
fats — 0·7

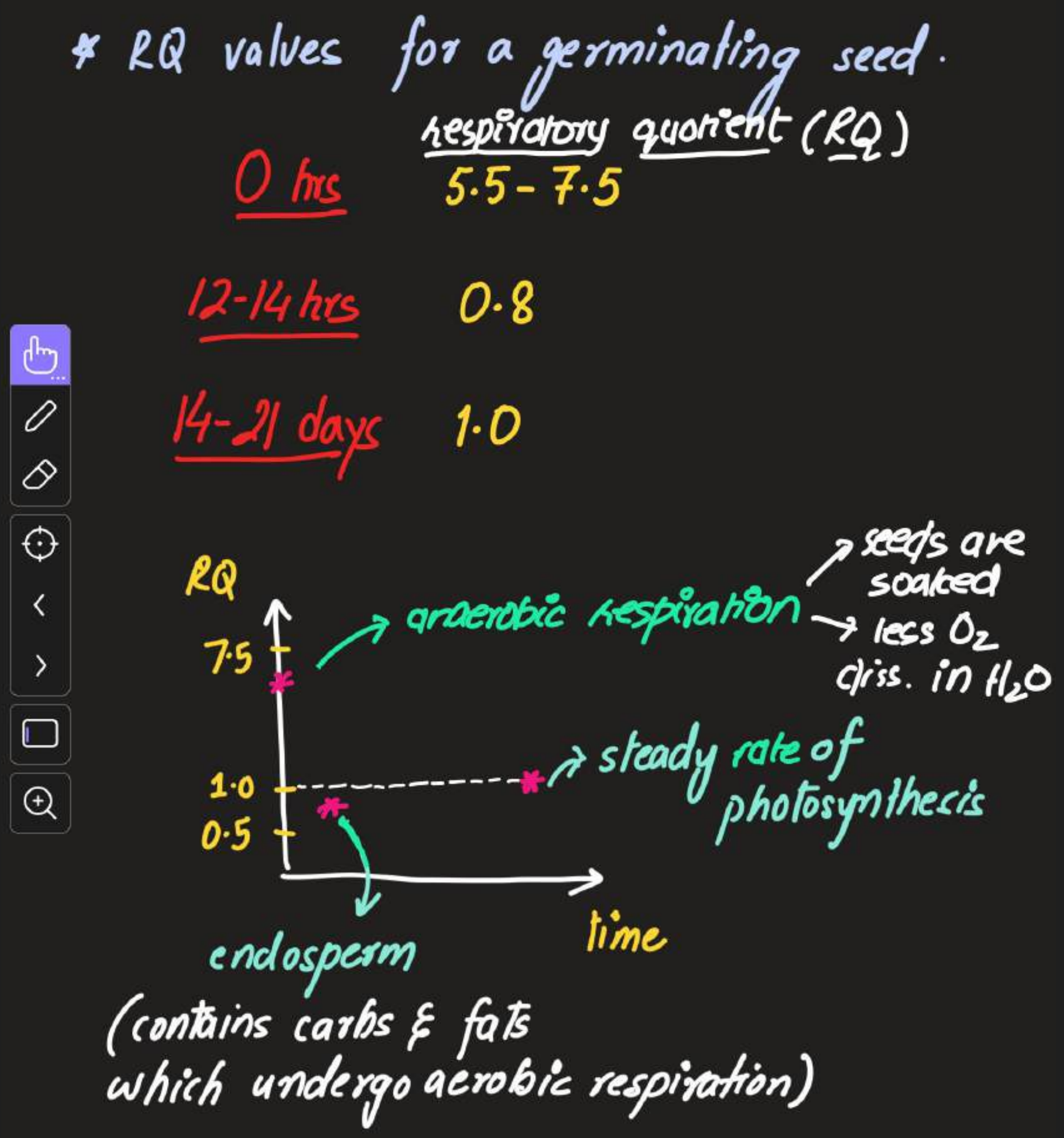
Ⓑ Anaerobic or Aerobic respiration

$\leq 1\cdot0$ (aerobic)
$> 1\cdot0$ (anaerobic)

$$RQ = \frac{\text{moles of } CO_2}{\text{moles of } O_2}$$



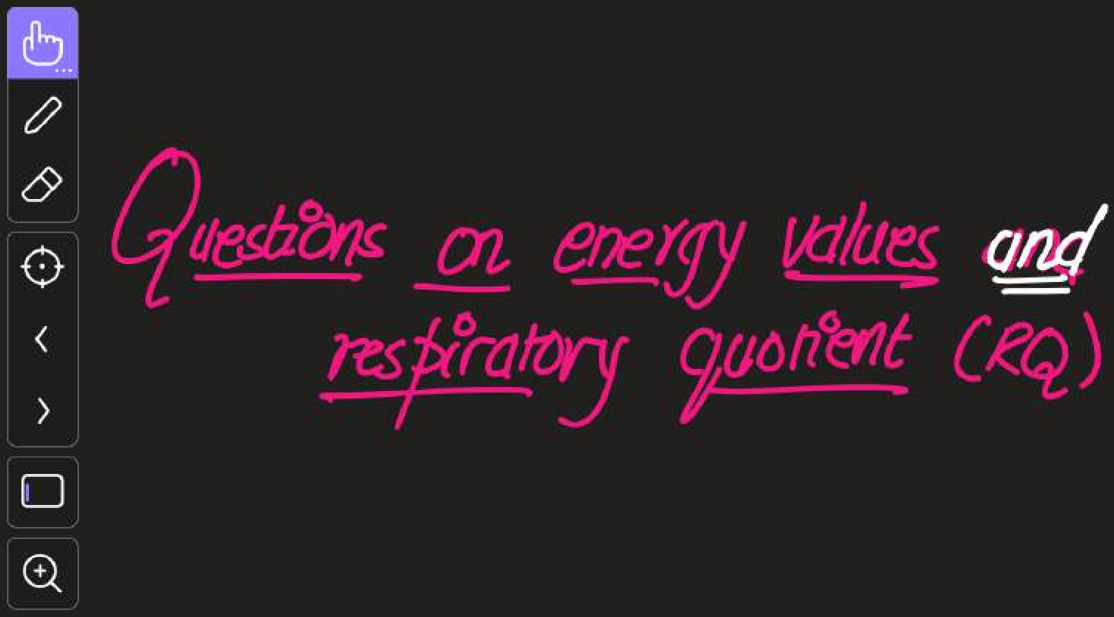
As an example, let's have a look at the changes in RQ values of a germinating seed with time.



* RQ values for a germinating seed.

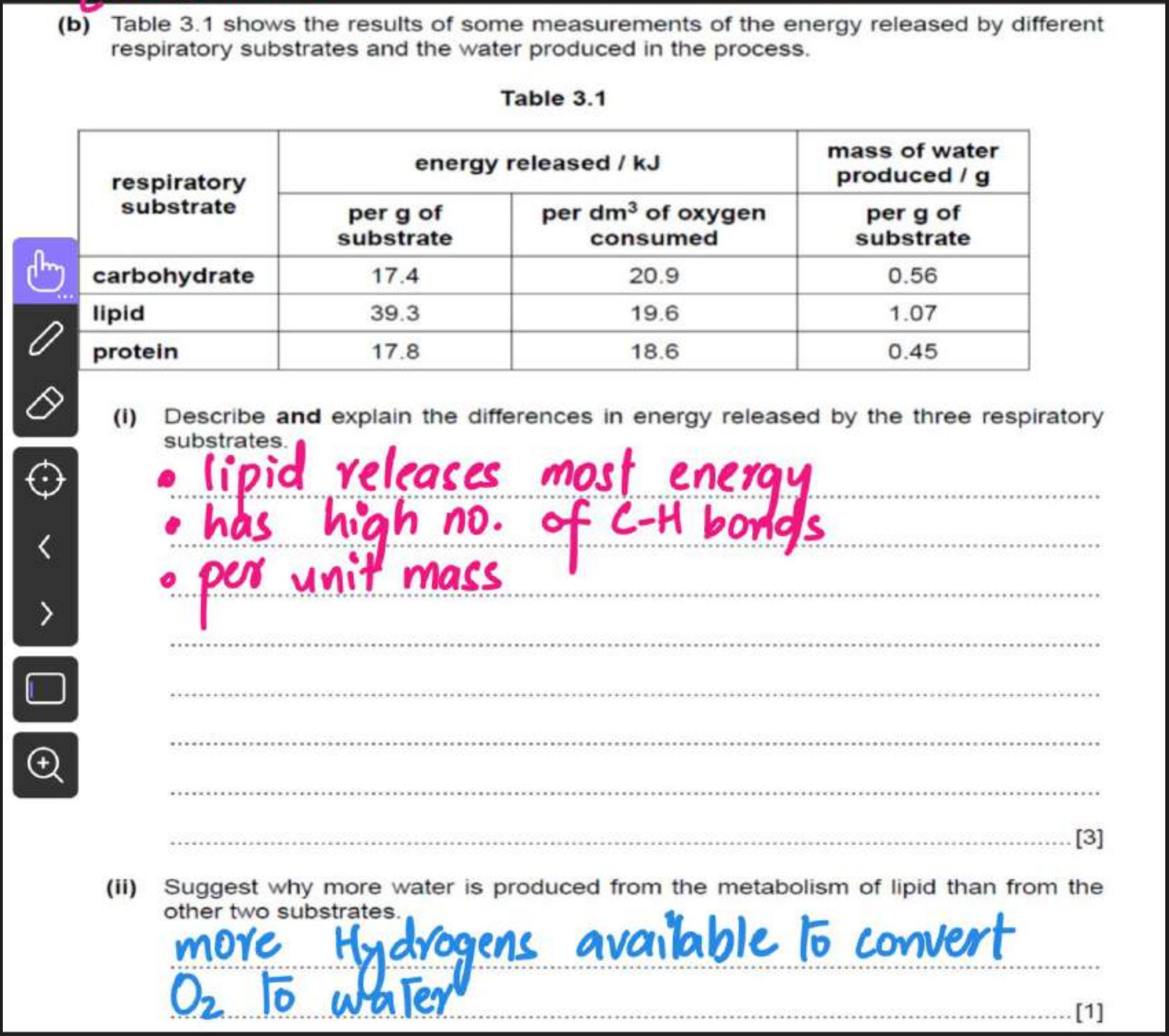
	Respiratory quotient (RQ)
0 hrs	5.5 - 7.5
12-14 hrs	0.8
14-21 days	1.0

(contains carbs & fats which undergo aerobic respiration)



Questions on energy values and respiratory quotient (RQ)

Question 1



(b) Table 3.1 shows the results of some measurements of the energy released by different respiratory substrates and the water produced in the process.

Table 3.1

respiratory substrate	**energy released / kJ**		**mass of water produced / g**
	per g of substrate	**per dm³ of oxygen consumed**	**per g of substrate**
carbohydrate	17.4	20.9	0.56
lipid	39.3	19.6	1.07
protein	17.8	18.6	0.45

(i) Describe **and** explain the differences in energy released by the three respiratory substrates.

- lipid releases most energy
- has high no. of C-H bonds
- per unit mass

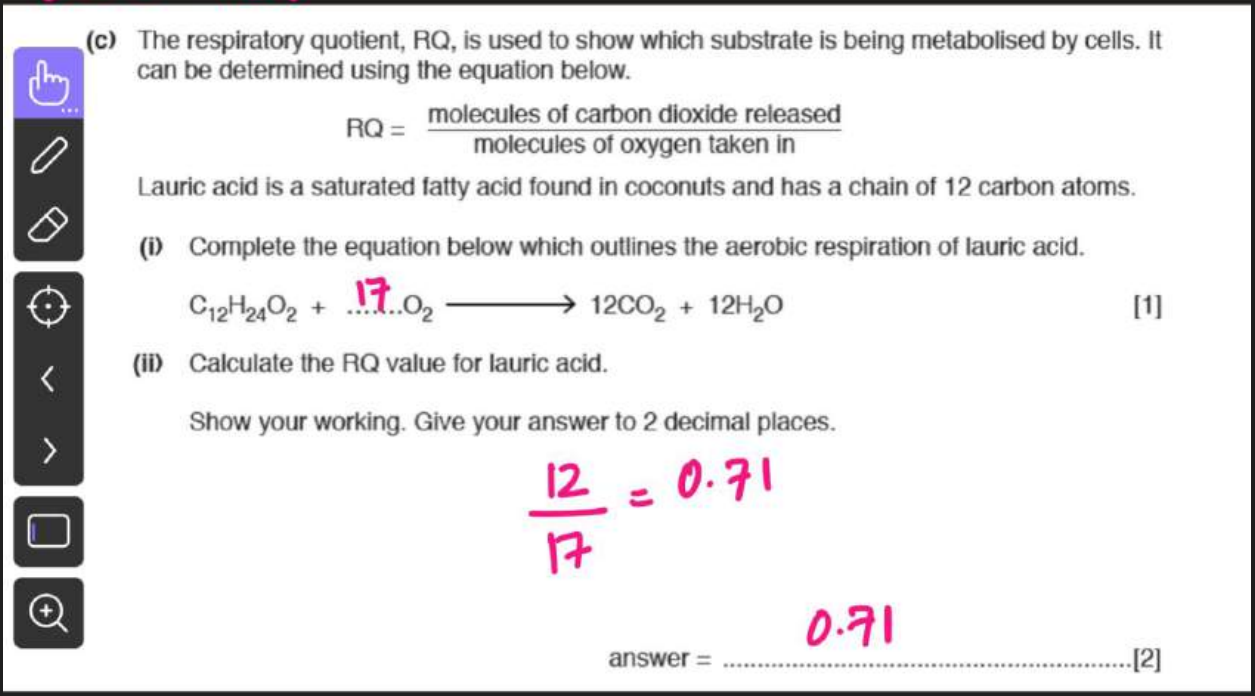
[3]

(ii) Suggest why more water is produced from the metabolism of lipid than from the other two substrates.

more Hydrogens available to convert O_2 to water

[1]

Question 2



(c) The respiratory quotient, RQ, is used to show which substrate is being metabolised by cells. It can be determined using the equation below.

$$\text{RQ} = \frac{\text{molecules of carbon dioxide released}}{\text{molecules of oxygen taken in}}$$

Lauric acid is a saturated fatty acid found in coconuts and has a chain of 12 carbon atoms.

(i) Complete the equation below which outlines the aerobic respiration of lauric acid.

$C_{12}H_{24}O_2$ + ...17...O_2 $\longrightarrow$ $12CO_2$ + $12H_2O$ [1]

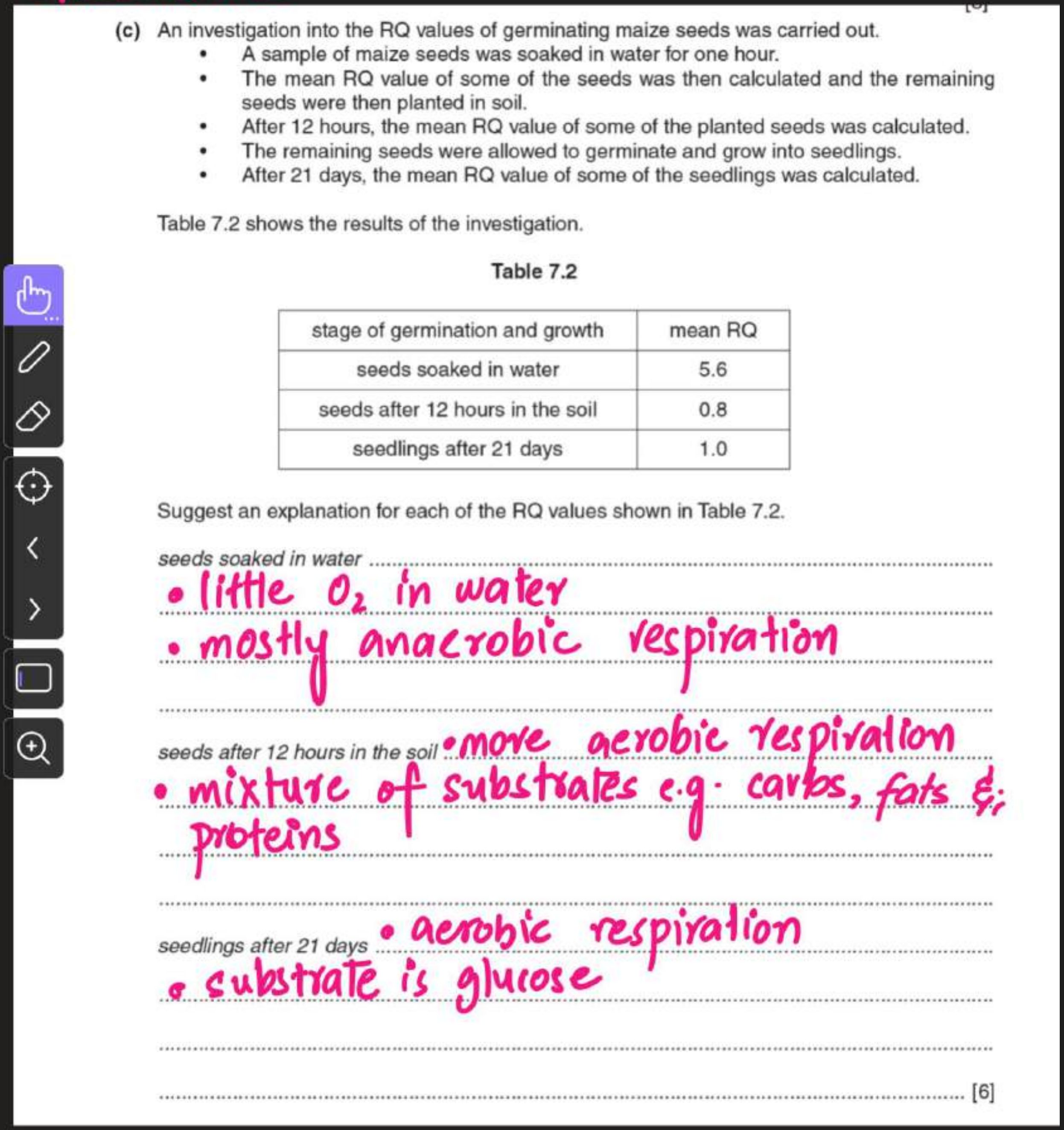
(ii) Calculate the RQ value for lauric acid.

Show your working. Give your answer to 2 decimal places.

$$\frac{12}{17} = 0.71$$

answer = ...0.71.... [2]

Question 3



(c) An investigation into the RQ values of germinating maize seeds was carried out.

- A sample of maize seeds was soaked in water for one hour.
- The mean RQ value of some of the seeds was then calculated and the remaining seeds were then planted in soil.
- After 12 hours, the mean RQ value of some of the planted seeds was calculated.
- The remaining seeds were allowed to germinate and grow into seedlings.
- After 21 days, the mean RQ value of some of the seedlings was calculated.

Table 7.2 shows the results of the investigation.

Table 7.2

stage of germination and growth	mean RQ
seeds soaked in water	5.6
seeds after 12 hours in the soil	0.8
seedlings after 21 days	1.0

Suggest an explanation for each of the RQ values shown in Table 7.2.

seeds soaked in water

- little O_2 in water
- mostly anaerobic respiration

seeds after 12 hours in the soil

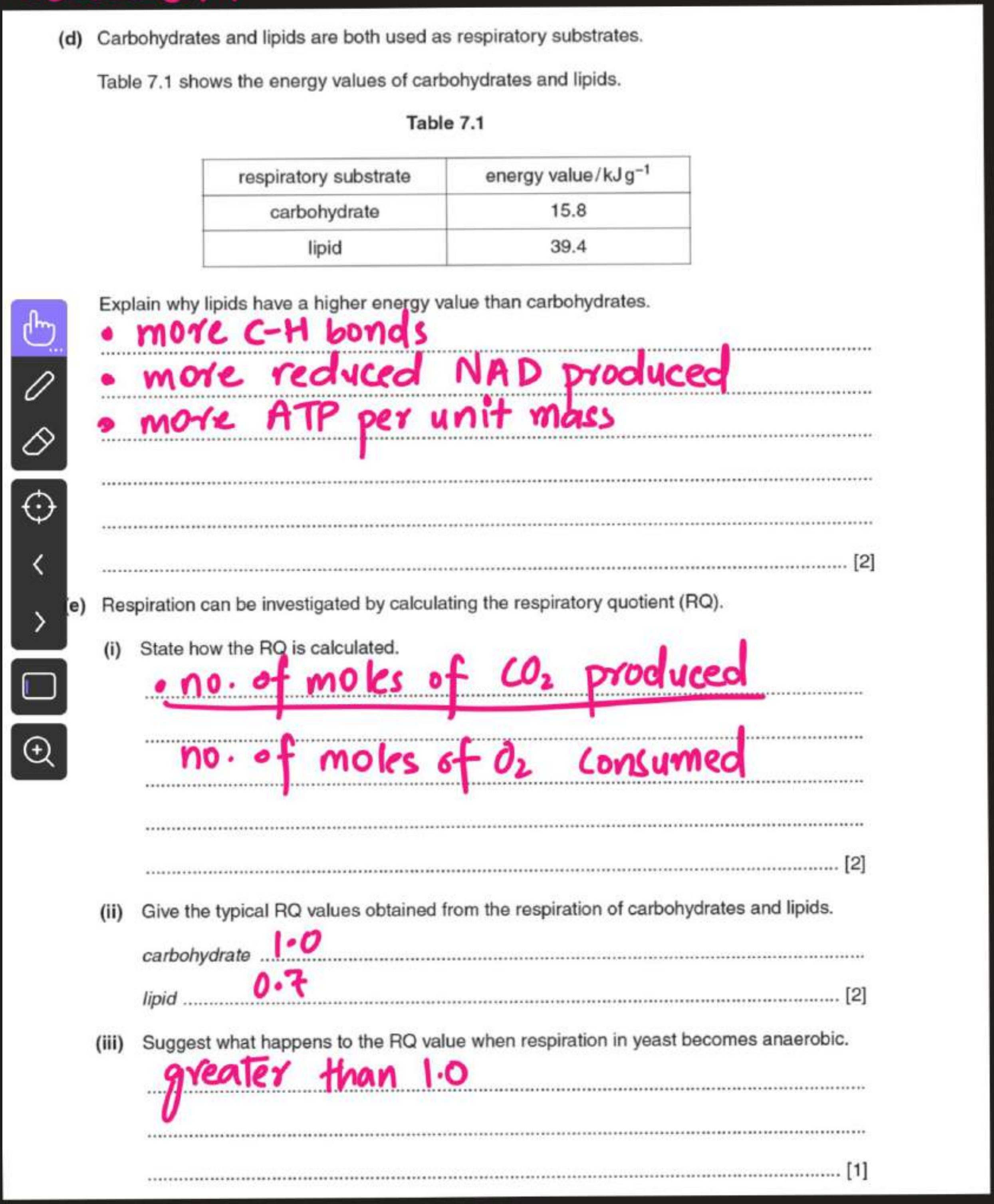
- more aerobic respiration
- mixture of substrates e.g. carbs, fats & proteins

seedlings after 21 days

- aerobic respiration
- substrate is glucose

[6]

Question 4



(d) Carbohydrates and lipids are both used as respiratory substrates.

Table 7.1 shows the energy values of carbohydrates and lipids.

Table 7.1

respiratory substrate	energy value / $kJ\,g^{-1}$
carbohydrate	15.8
lipid	39.4

Explain why lipids have a higher energy value than carbohydrates.

- more C-H bonds
- more reduced NAD produced
- more ATP per unit mass

[2]

(e) Respiration can be investigated by calculating the respiratory quotient (RQ).

(i) State how the RQ is calculated.

$$\bullet \frac{\text{no. of moles of } CO_2 \text{ produced}}{\text{no. of moles of } O_2 \text{ consumed}}$$

[2]

(ii) Give the typical RQ values obtained from the respiration of carbohydrates and lipids.

carbohydrate 1·0

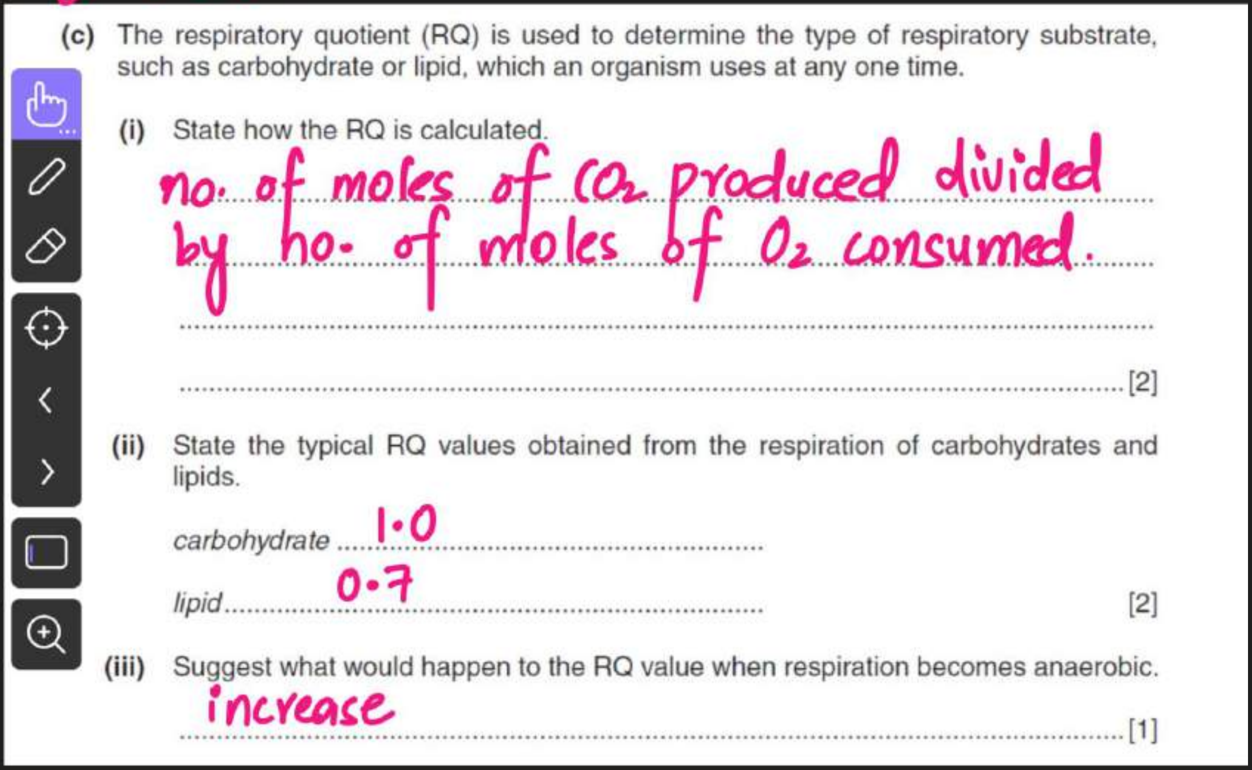
lipid 0·7 [2]

(iii) Suggest what happens to the RQ value when respiration in yeast becomes anaerobic.

greater than 1·0

[1]

Question 5



(c) The respiratory quotient (RQ) is used to determine the type of respiratory substrate, such as carbohydrate or lipid, which an organism uses at any one time.

(i) State how the RQ is calculated.

no. of moles of CO_2 produced divided by no. of moles of O_2 consumed. [2]

(ii) State the typical RQ values obtained from the respiration of carbohydrates and lipids.

carbohydrate 1·0

lipid 0·7 [2]

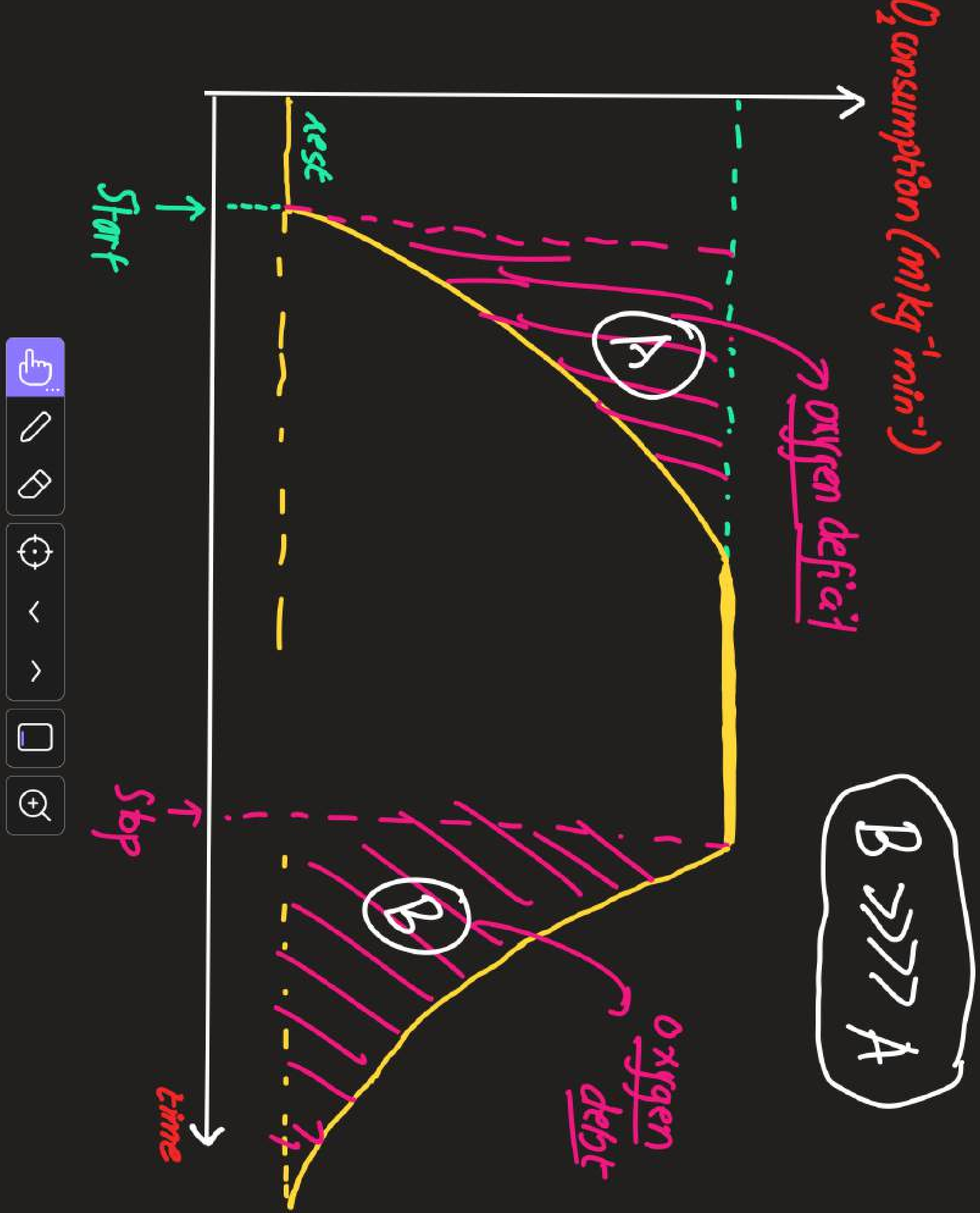
(iii) Suggest what would happen to the RQ value when respiration becomes anaerobic.

increase [1]

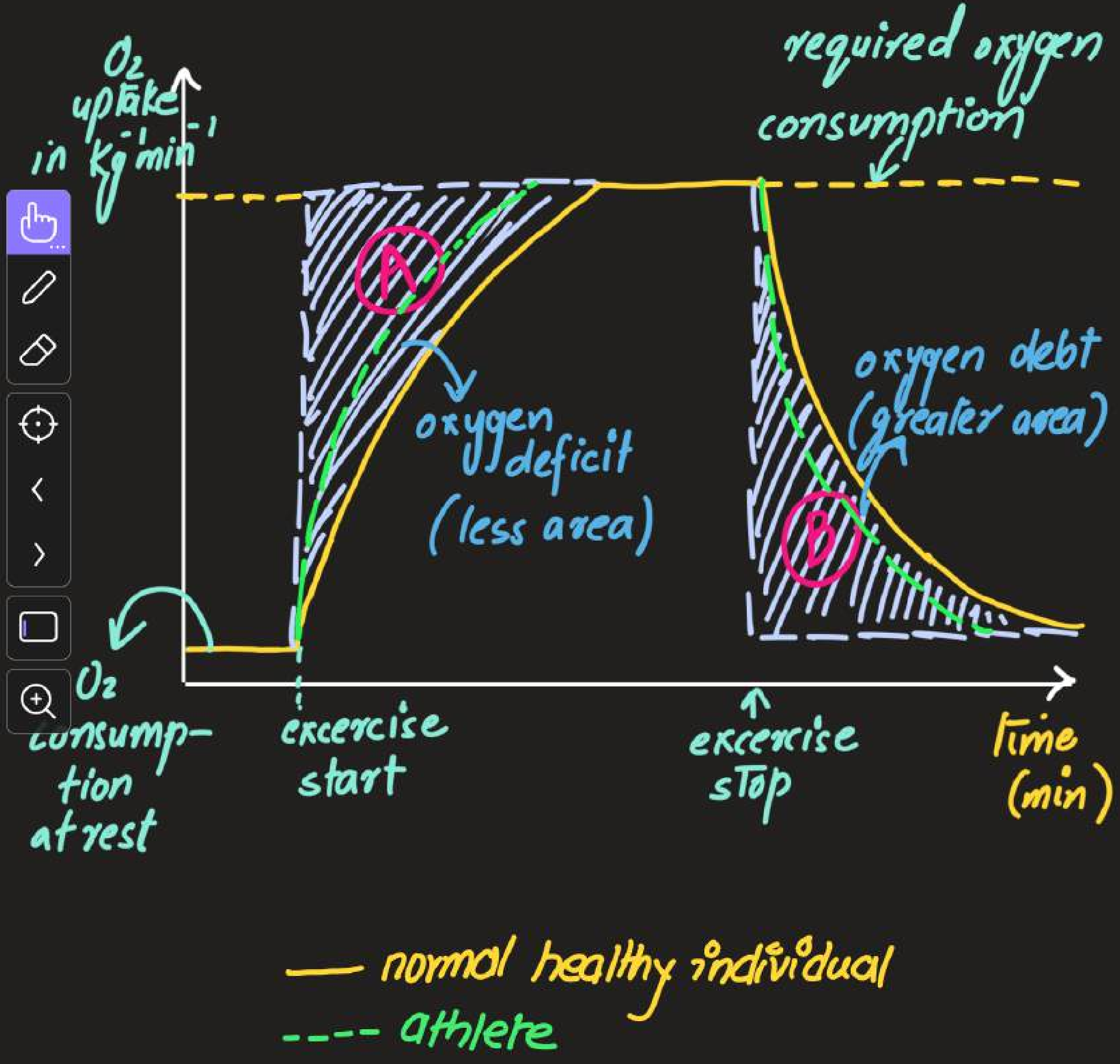
Oxygen deficit

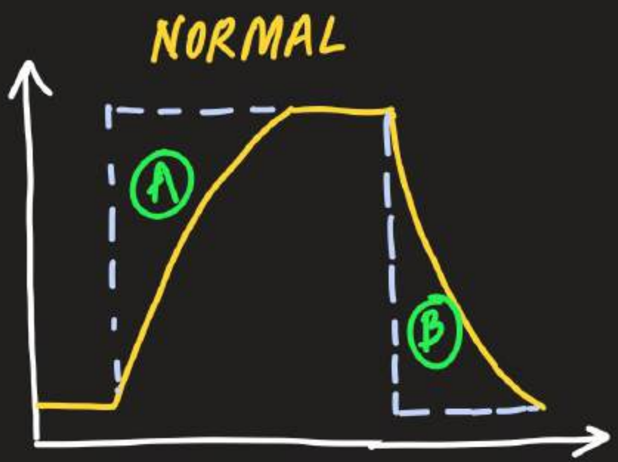
and

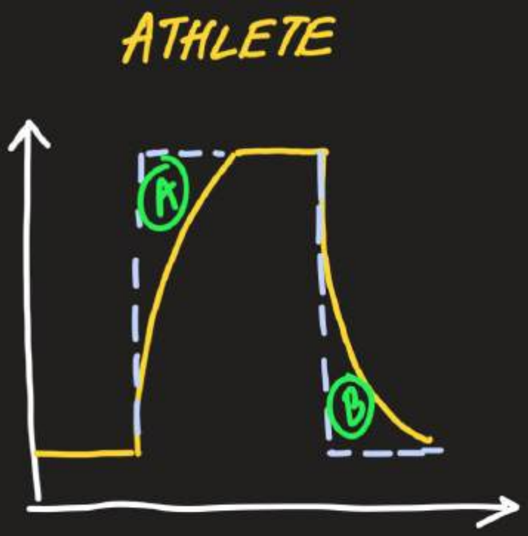
Oxygen debt


O_2 consumption (ml kg⁻¹ min⁻¹)
rest
Start
Stop
time
A
oxygen deficit
B
oxygen debt
B >>> A

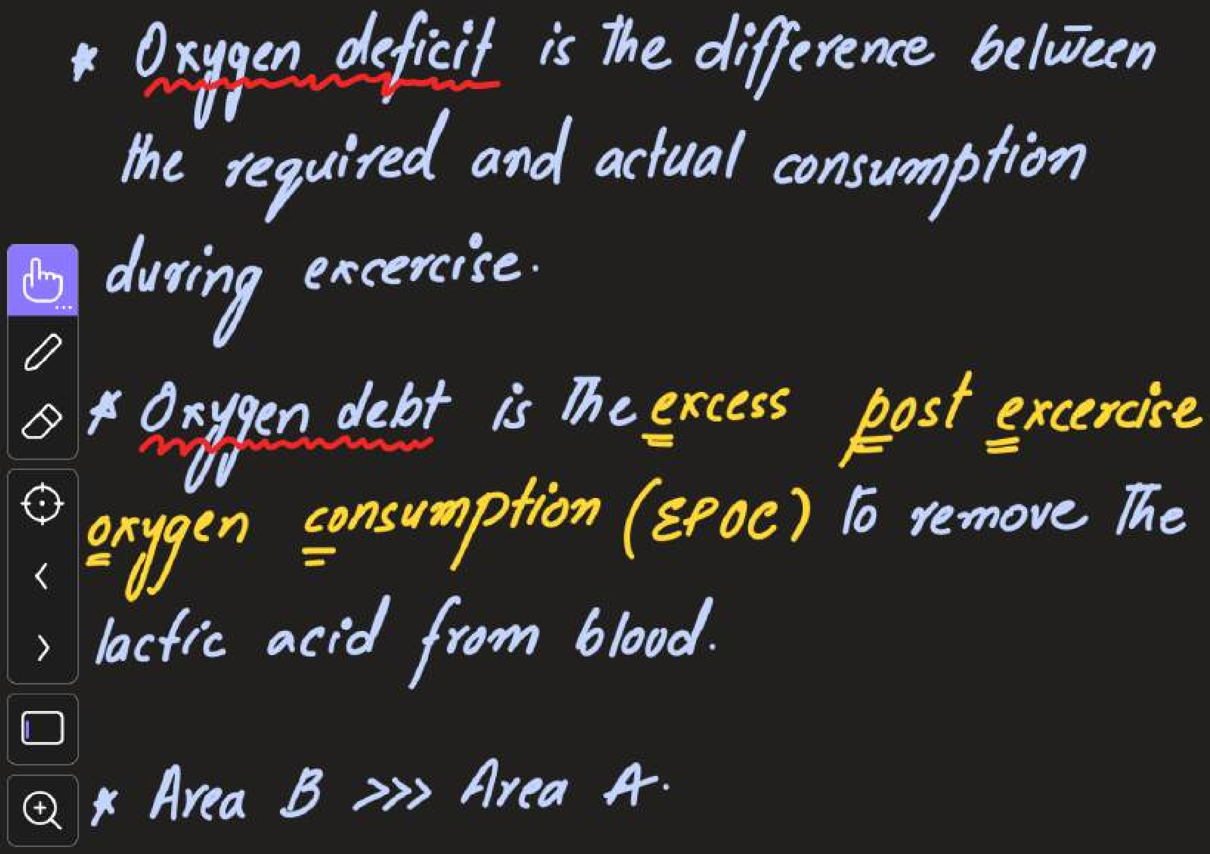
Oxygen debt


O_2 uptake in $kg^{-1}min^{-1}$
required oxygen consumption
Ⓐ
oxygen deficit (less area)
oxygen debt (greater area)
Ⓑ
O_2 consumption at rest
excercise start
excercise stop
time (min)
— normal healthy individual
---- athlete





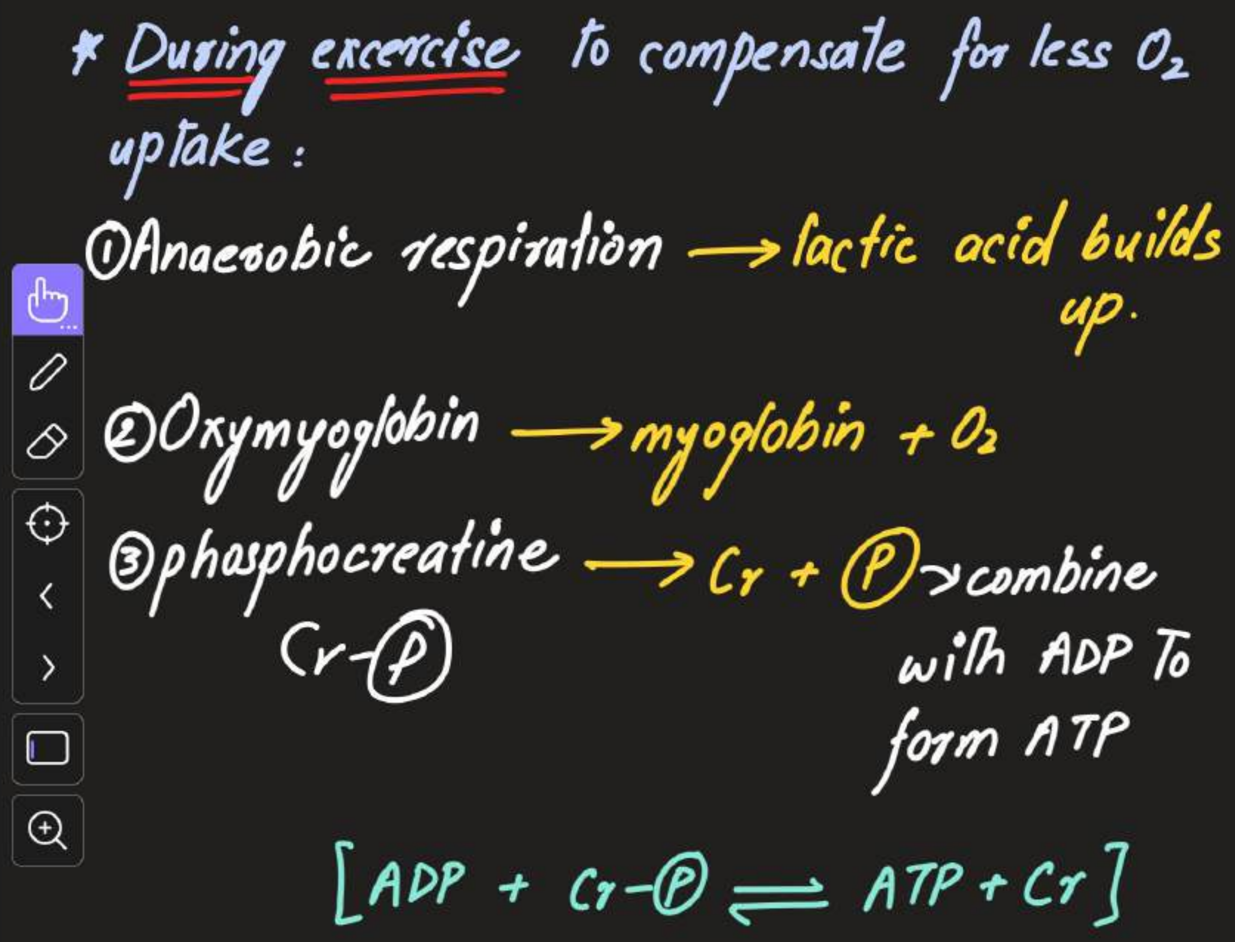
* In both cases, Area B will be greater than their Area A.



* Oxygen deficit is the difference between the required and actual consumption during excercise.

* Oxygen debt is the excess post excercise oxygen consumption (EPOC) to remove the lactic acid from blood.

* Area B >>> Area A.



* During excercise to compensate for less O_2 uptake :

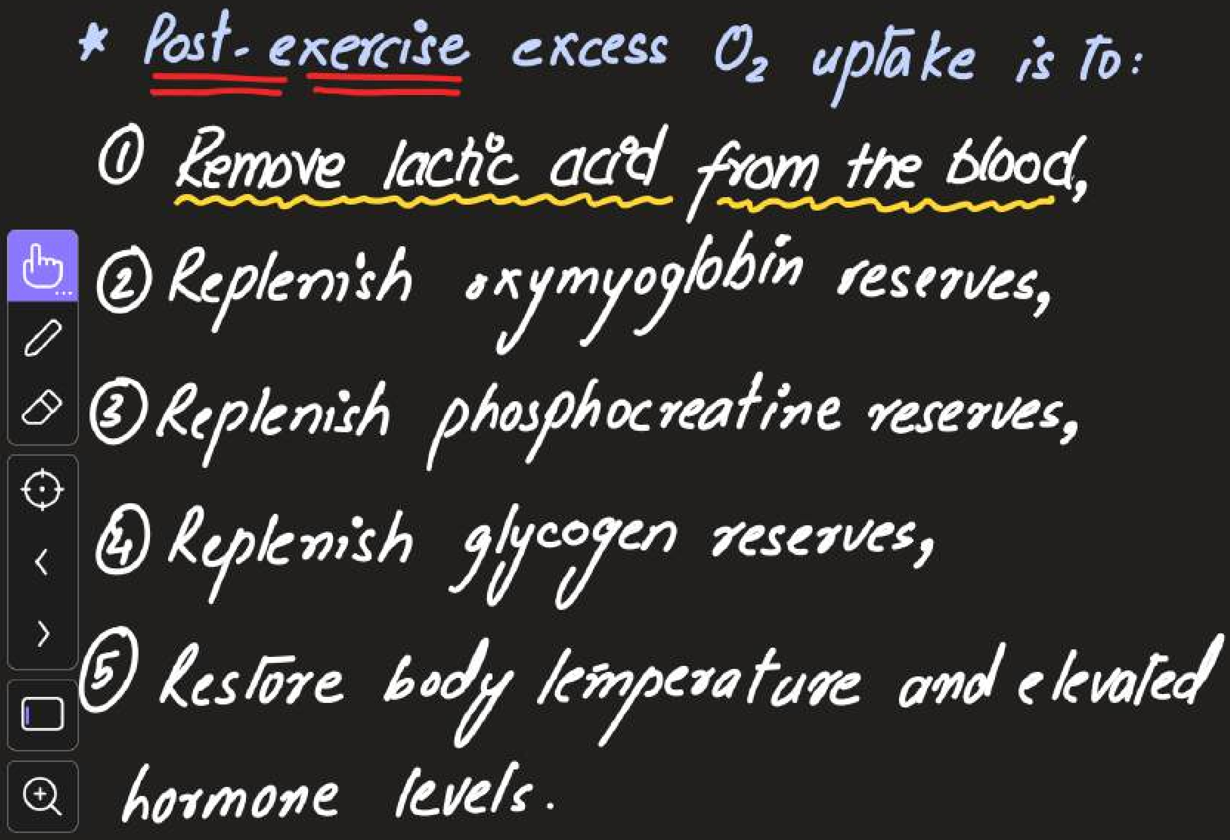
① Anaerobic respiration → lactic acid builds up.

② Oxymyoglobin → myoglobin + O_2

③ phosphocreatine → $Cr + \textcircled{P}$ → combine with ADP To form ATP

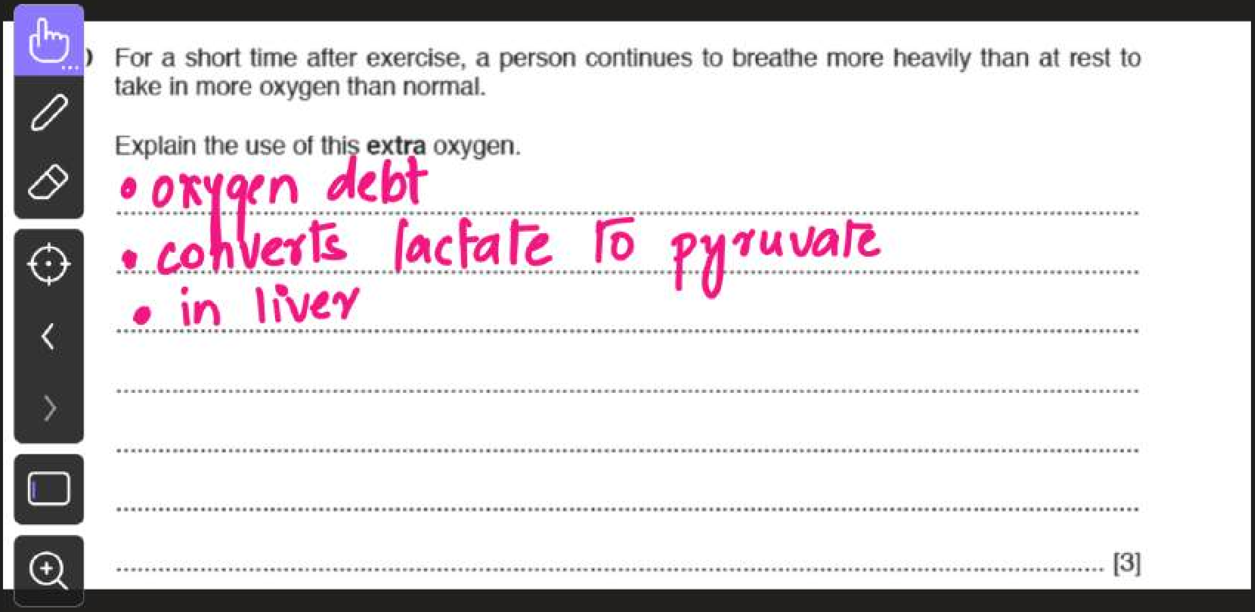
$Cr\text{-}\textcircled{P}$

$$[ADP + Cr\text{-}\textcircled{P} \rightleftharpoons ATP + Cr]$$



* Post-exercise excess O_2 uptake is to:

① Remove lactic acid from the blood,
② Replenish oxymyoglobin reserves,
③ Replenish phosphocreatine reserves,
④ Replenish glycogen reserves,
⑤ Restore body temperature and elevated hormone levels.



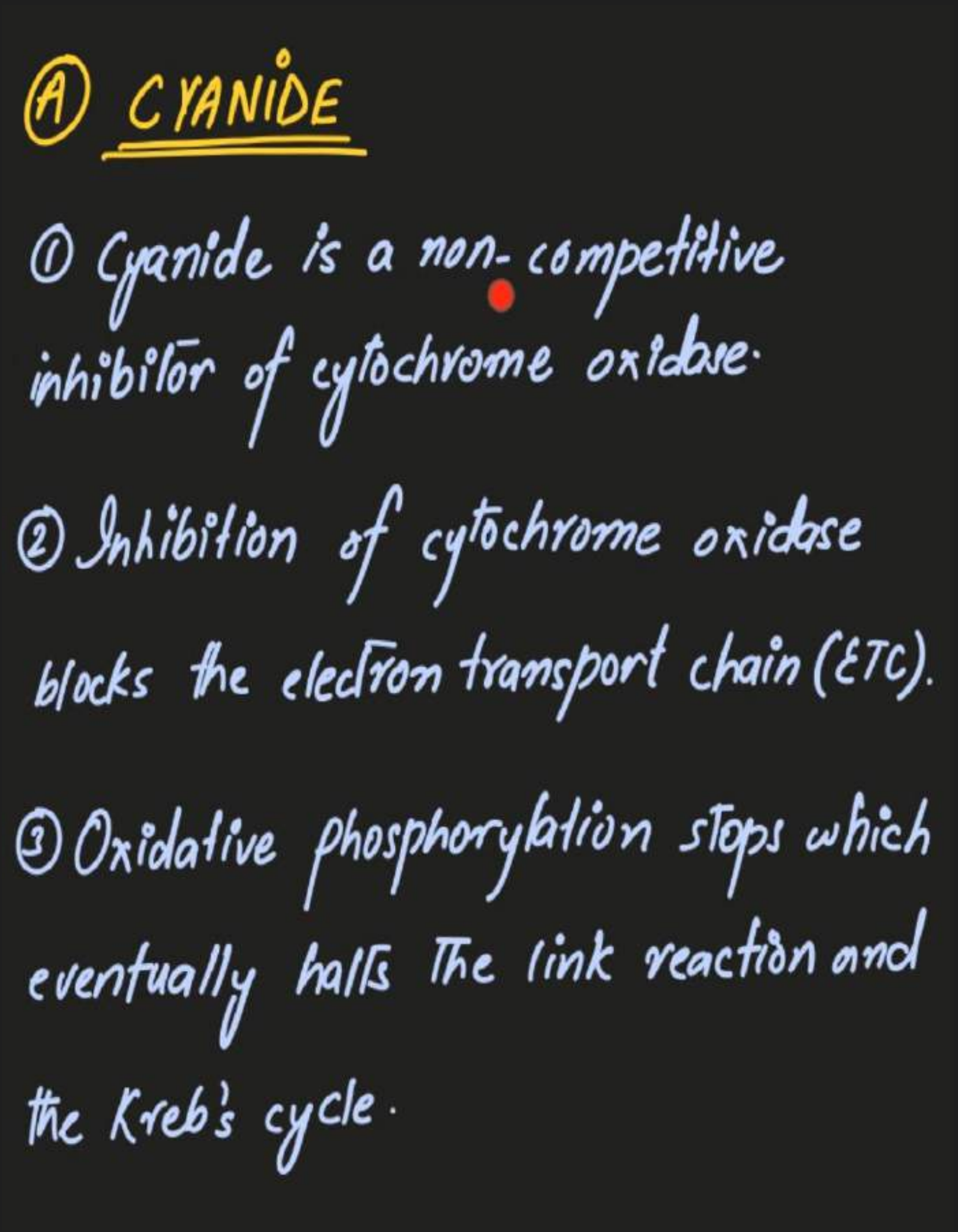
) For a short time after exercise, a person continues to breathe more heavily than at rest to take in more oxygen than normal.

Explain the use of this **extra** oxygen.

- oxygen debt
- converts lactate to pyruvate
- in liver

[3]

Energy & Respiration



Ⓐ CYANIDE

① Cyanide is a non-competitive inhibitor of cytochrome oxidase.

② Inhibition of cytochrome oxidase blocks the electron transport chain (ETC).

③ Oxidative phosphorylation stops which eventually halts the link reaction and the Kreb's cycle.

ADVANCED LEVEL BIOLOGY 9700

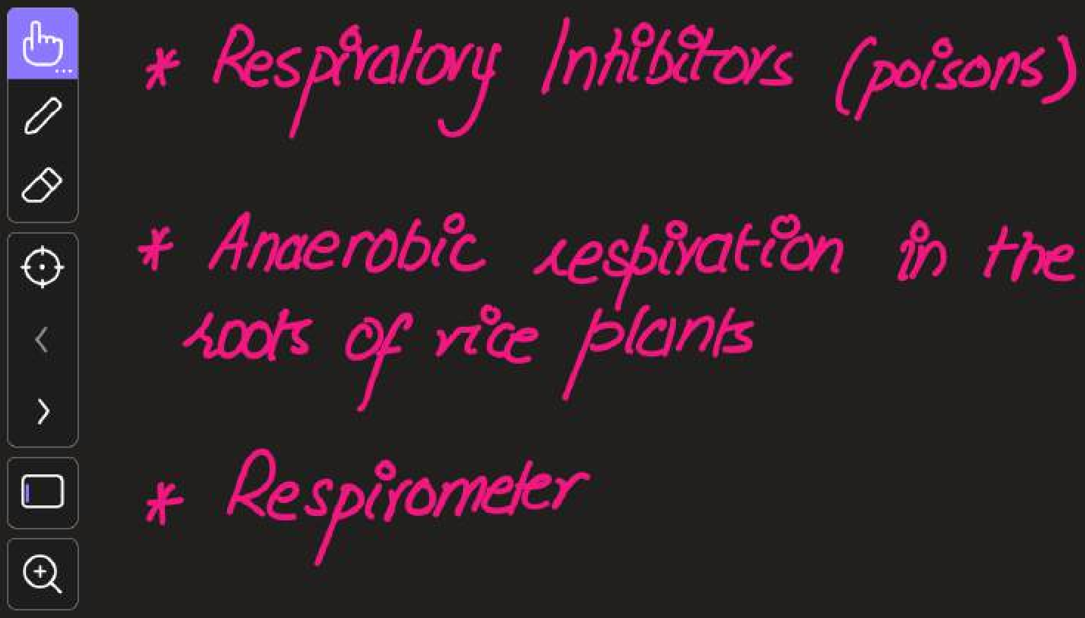
UNIT 12: ENERGY AND RESPIRATION

Learning Objectives:

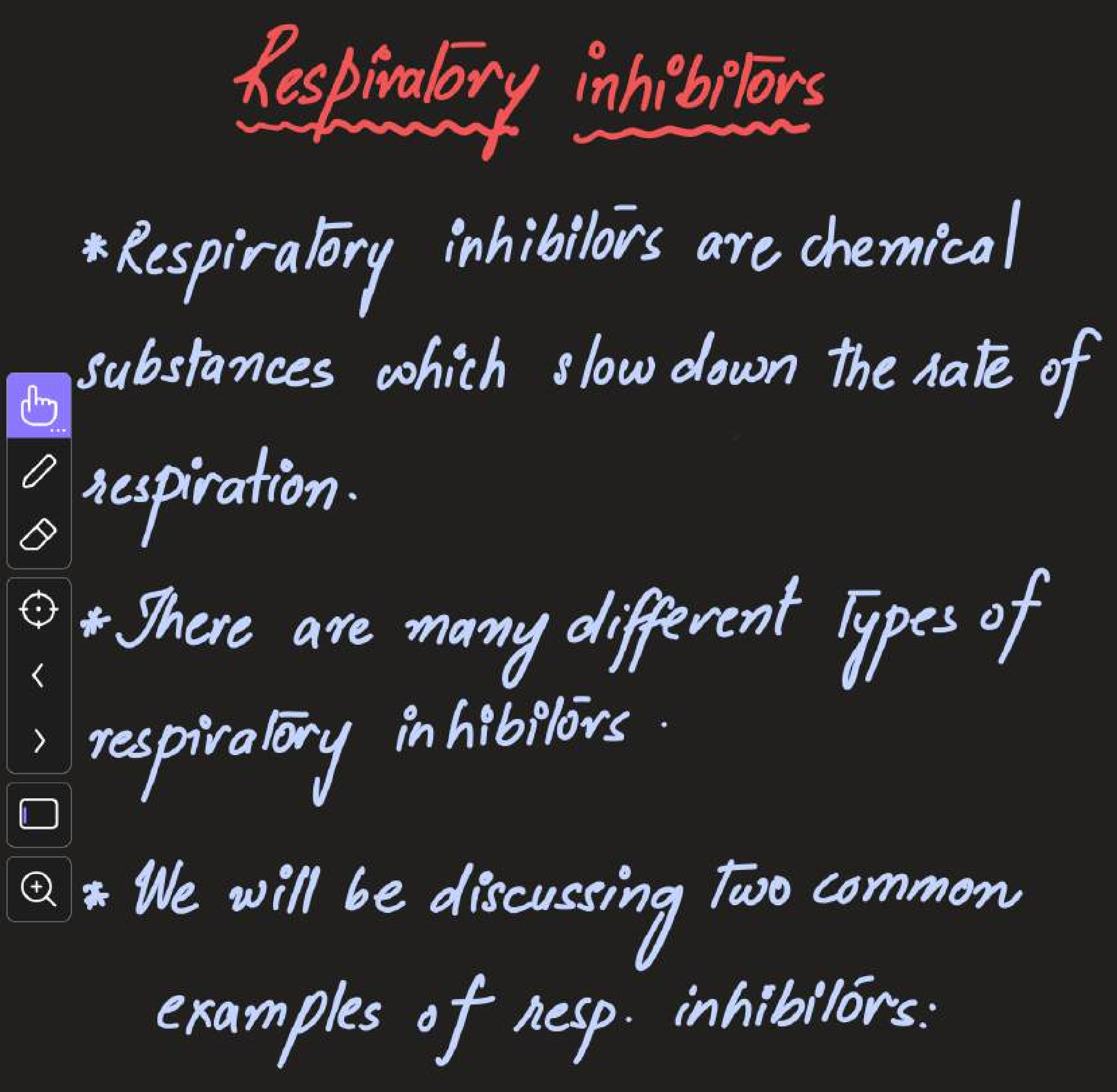
- Respiratory Inhibitors
- Respirometer
- Adaptation of Rice plant to respire Anaerobically

Video Lecture 10 Slides

Mohammad Hussham Arshad, MD
Biology Department



- * Respiratory Inhibitors (poisons)
- * Anaerobic respiration in the roots of rice plants
- * Respirometer

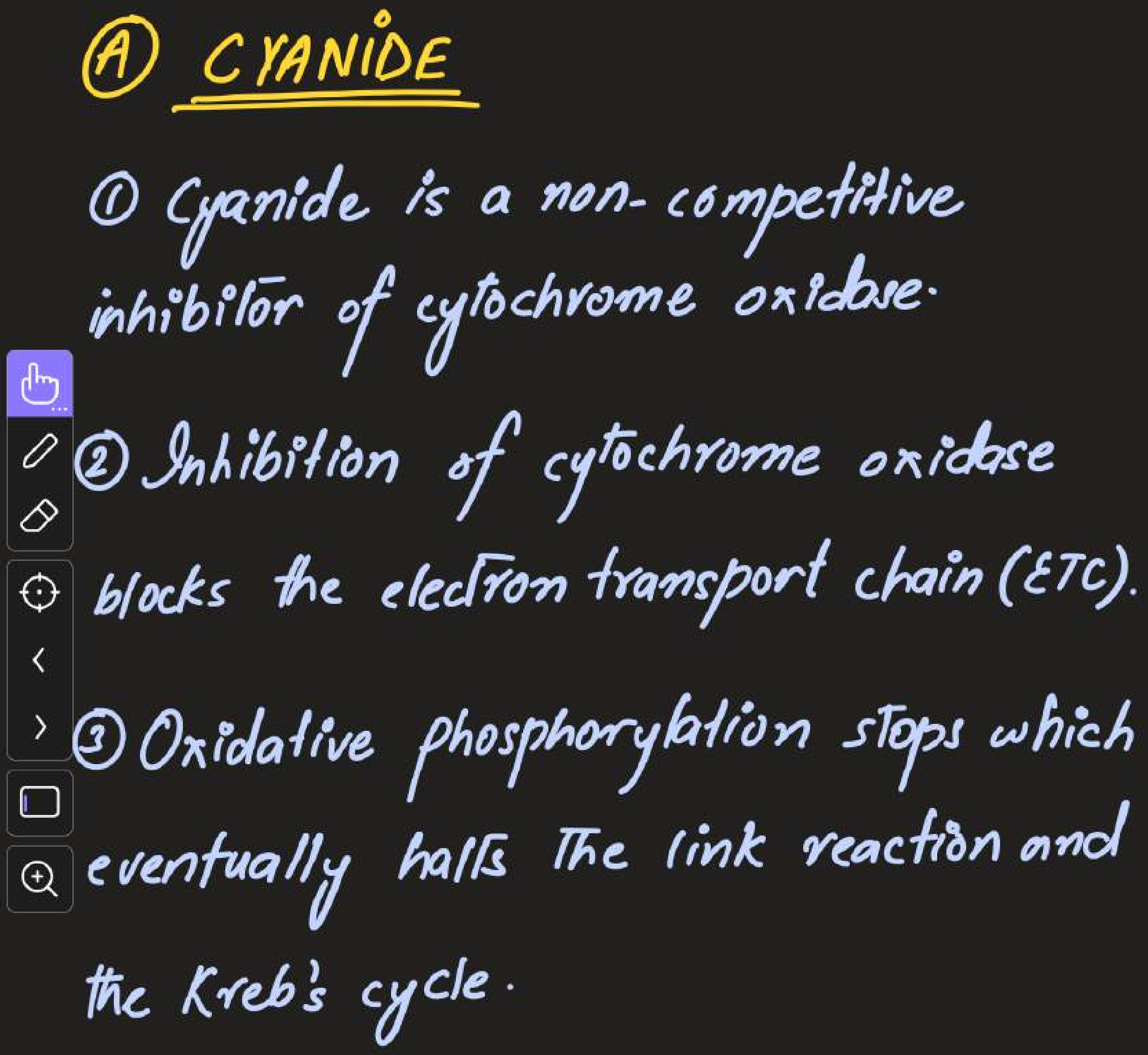


Respiratory inhibitors

* Respiratory inhibitors are chemical substances which slow down the rate of respiration.

* There are many different types of respiratory inhibitors.

* We will be discussing two common examples of resp. inhibitors:

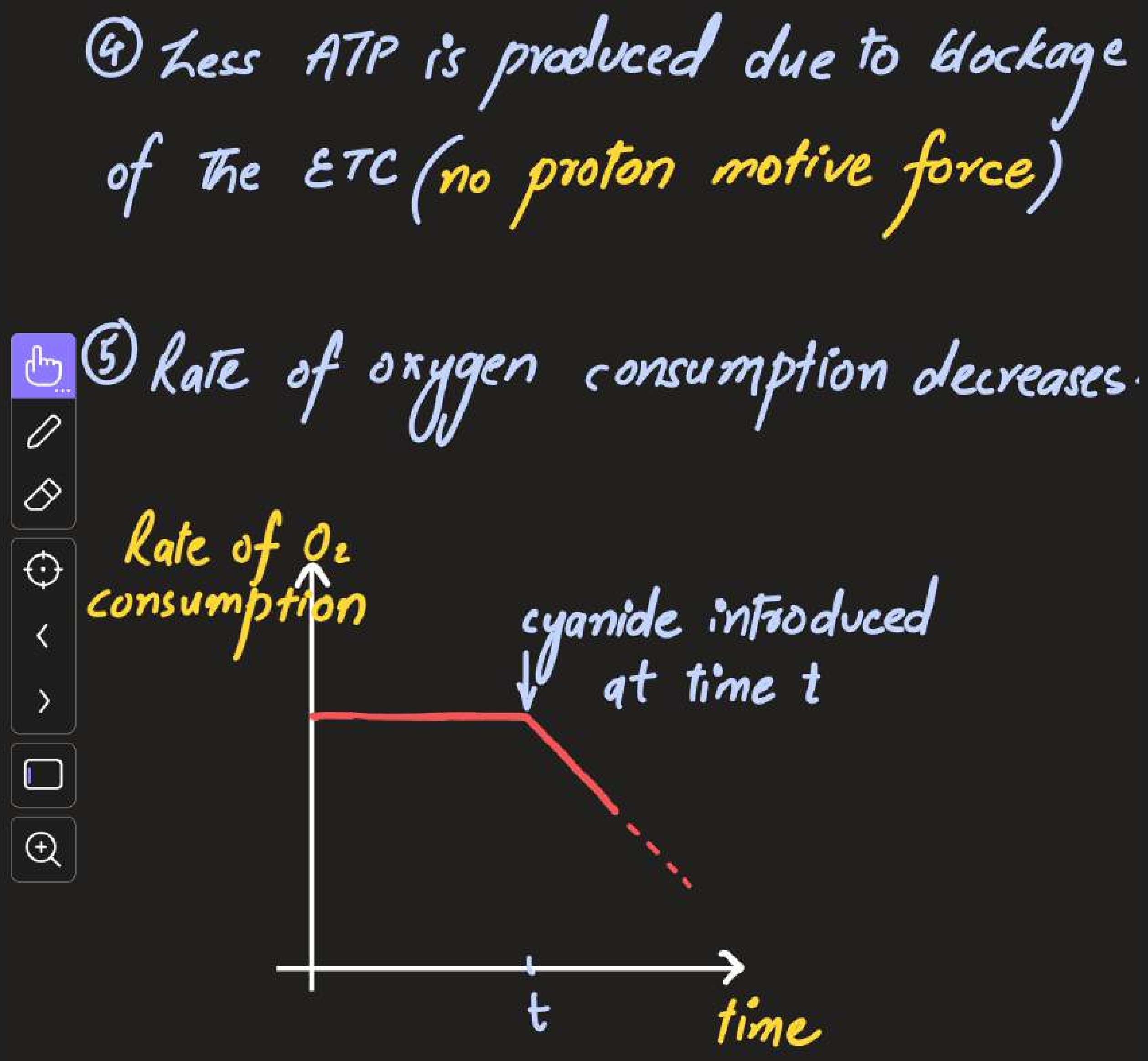


Ⓐ CYANIDE

① Cyanide is a non-competitive inhibitor of cytochrome oxidase.

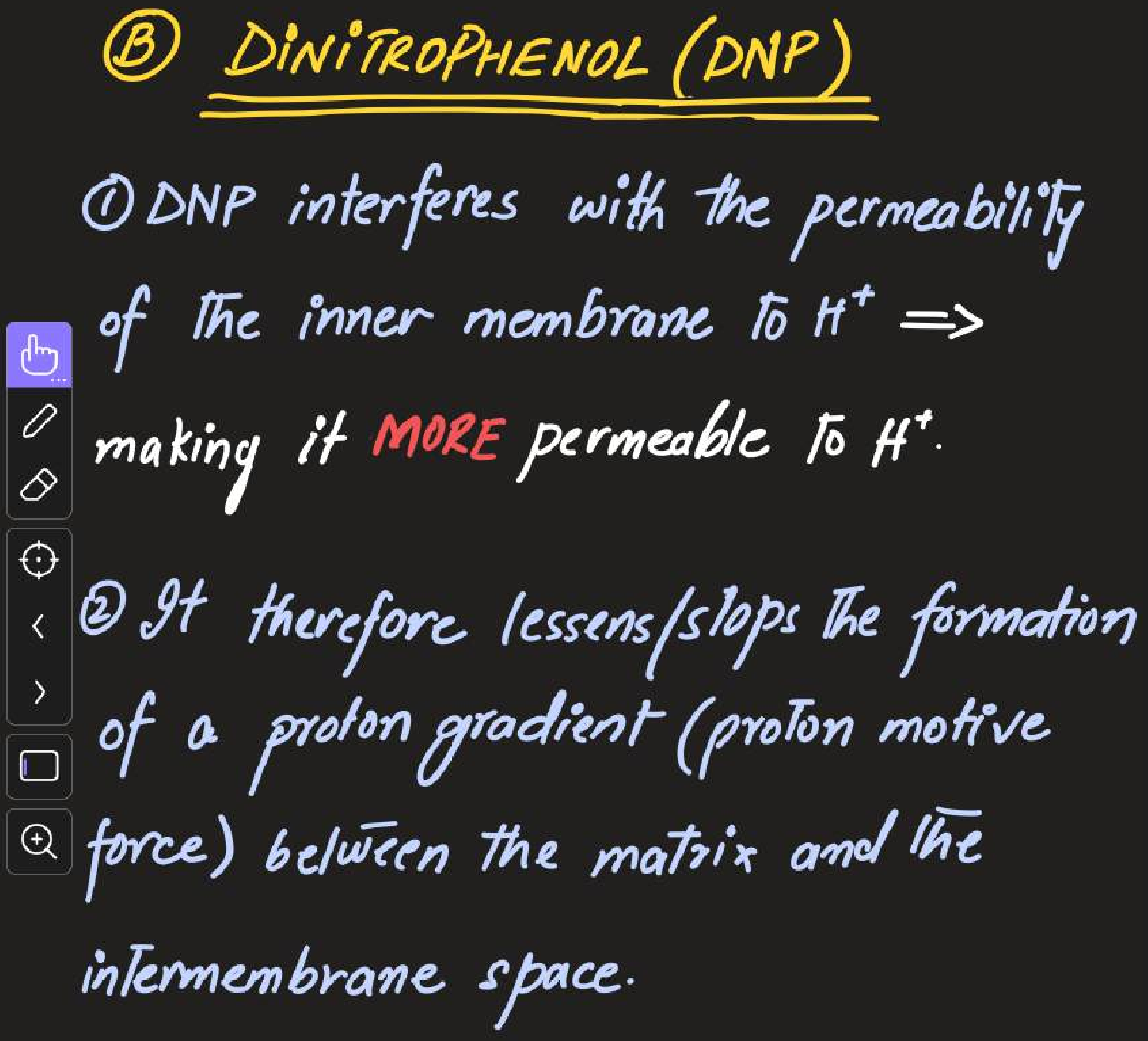
② Inhibition of cytochrome oxidase blocks the electron transport chain (ETC).

③ Oxidative phosphorylation stops which eventually halts The link reaction and the Kreb's cycle.



④ Less ATP is produced due to blockage of the ETC (no proton motive force)

⑤ Rate of oxygen consumption decreases.



Ⓑ DINITROPHENOL (DNP)

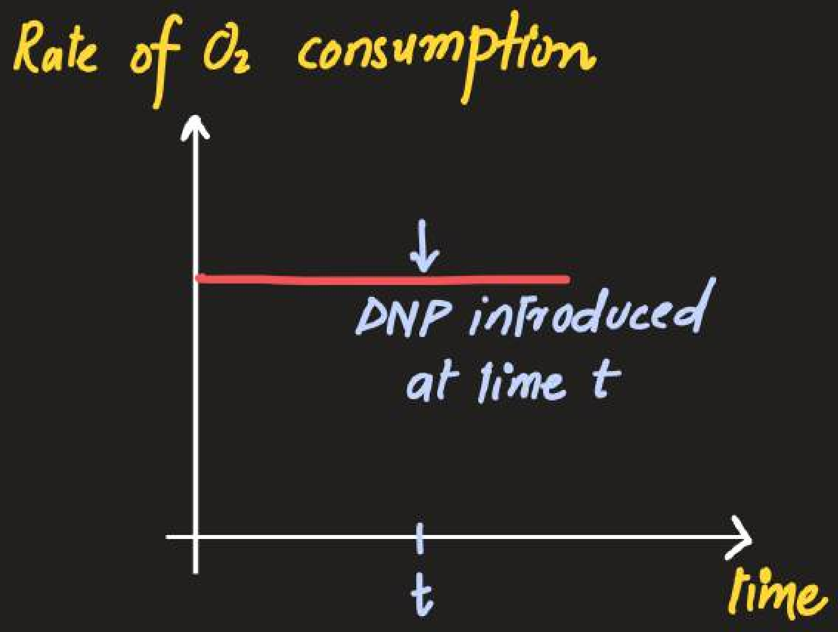
① DNP interferes with the permeability of the inner membrane to H^+ ⟹ making it **MORE** permeable to H^+.

② It therefore lessens/stops the formation of a proton gradient (proton motive force) between the matrix and the intermembrane space.

③ This leads to fewer ATP molecules being formed via oxidative phosphorylation since less H^+ pass through the stalked particles (as they leak through the membrane into the matrix)

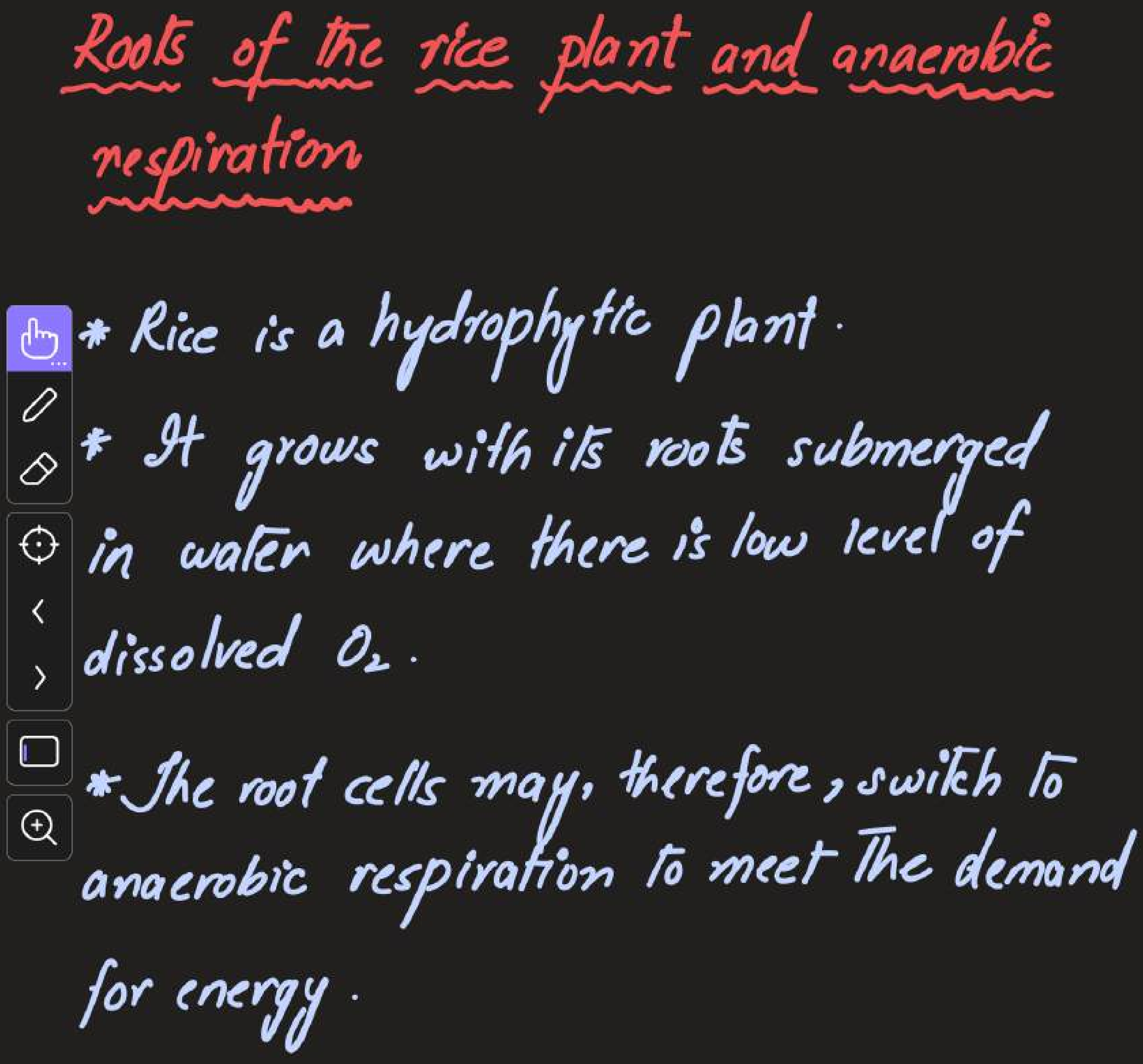
④ The ETC is still working and therefore the rate of O_2 consumption is unaffected.

⑤ A large amount of heat is released by the cell because most of the energy in the form of proton motive force is lost as thermal energy.



Rice plants and anaerobic respiration

paddy field culture of rice – planting out of rice seedlings



Roots of the rice plant and anaerobic respiration

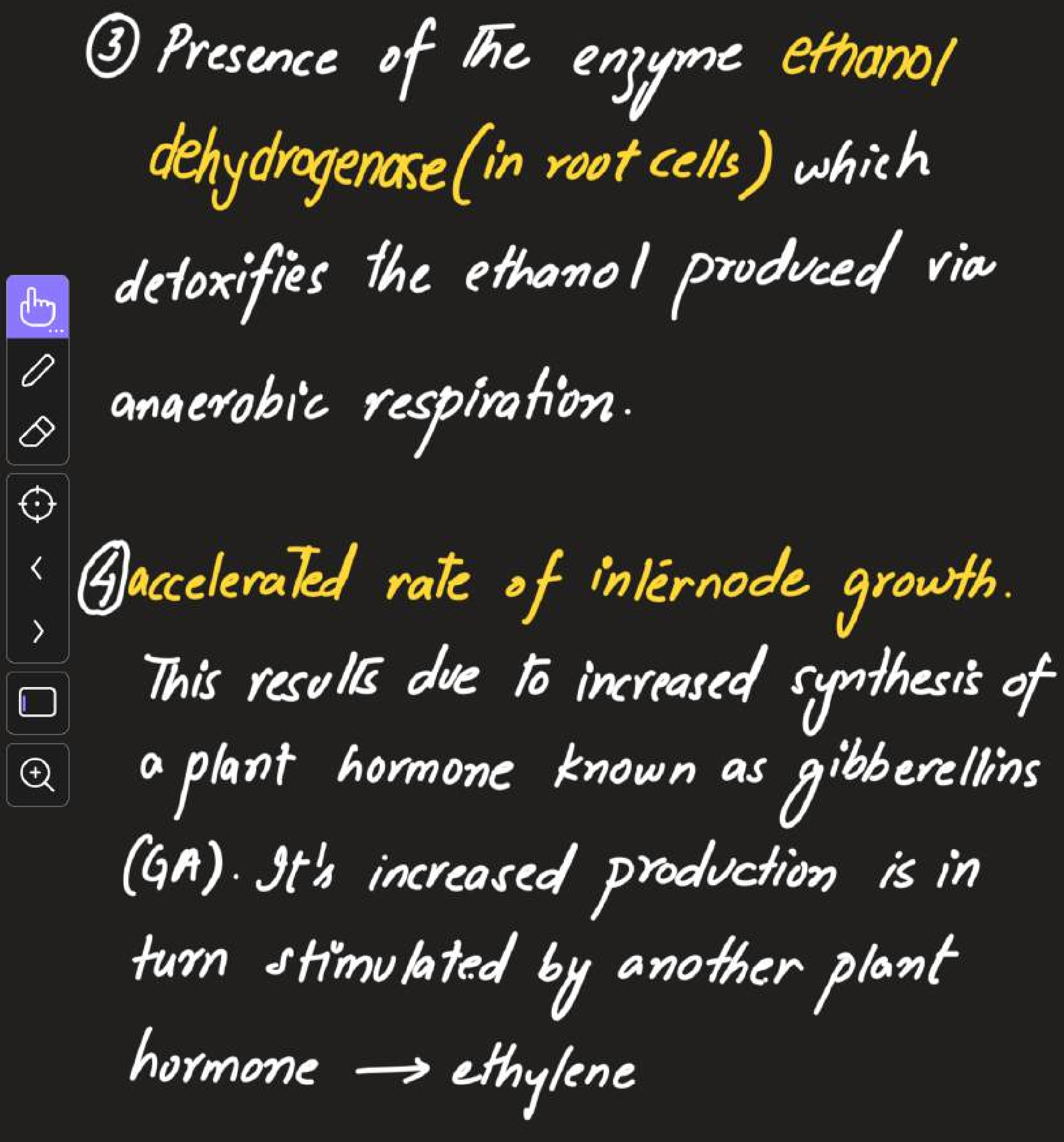
- Rice is a hydrophytic plant.
- It grows with its roots submerged in water where there is low level of dissolved O_2.
- The root cells may, therefore, switch to anaerobic respiration to meet the demand for energy.

* The roots of the rice plant are adapted to survive under such conditions due to the following plant adaptations:

① Shallow root system ⟶ closer to the air above the surface of water.

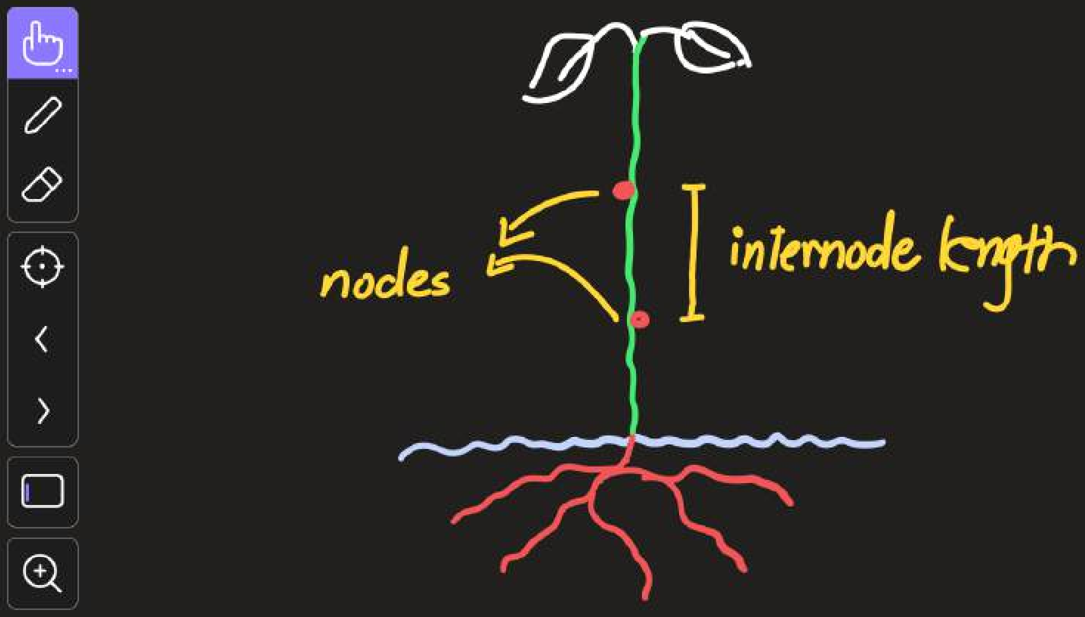
② Presence of a continuous system of air spaces within the stem and the roots.

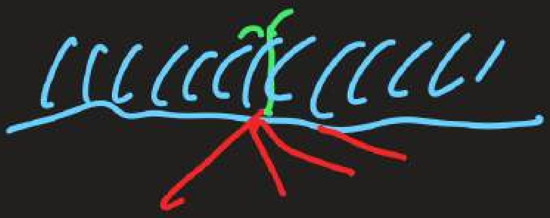
This system is known as the aerenchyma. It ensures that O_2 may diffuse from the air towards the roots.

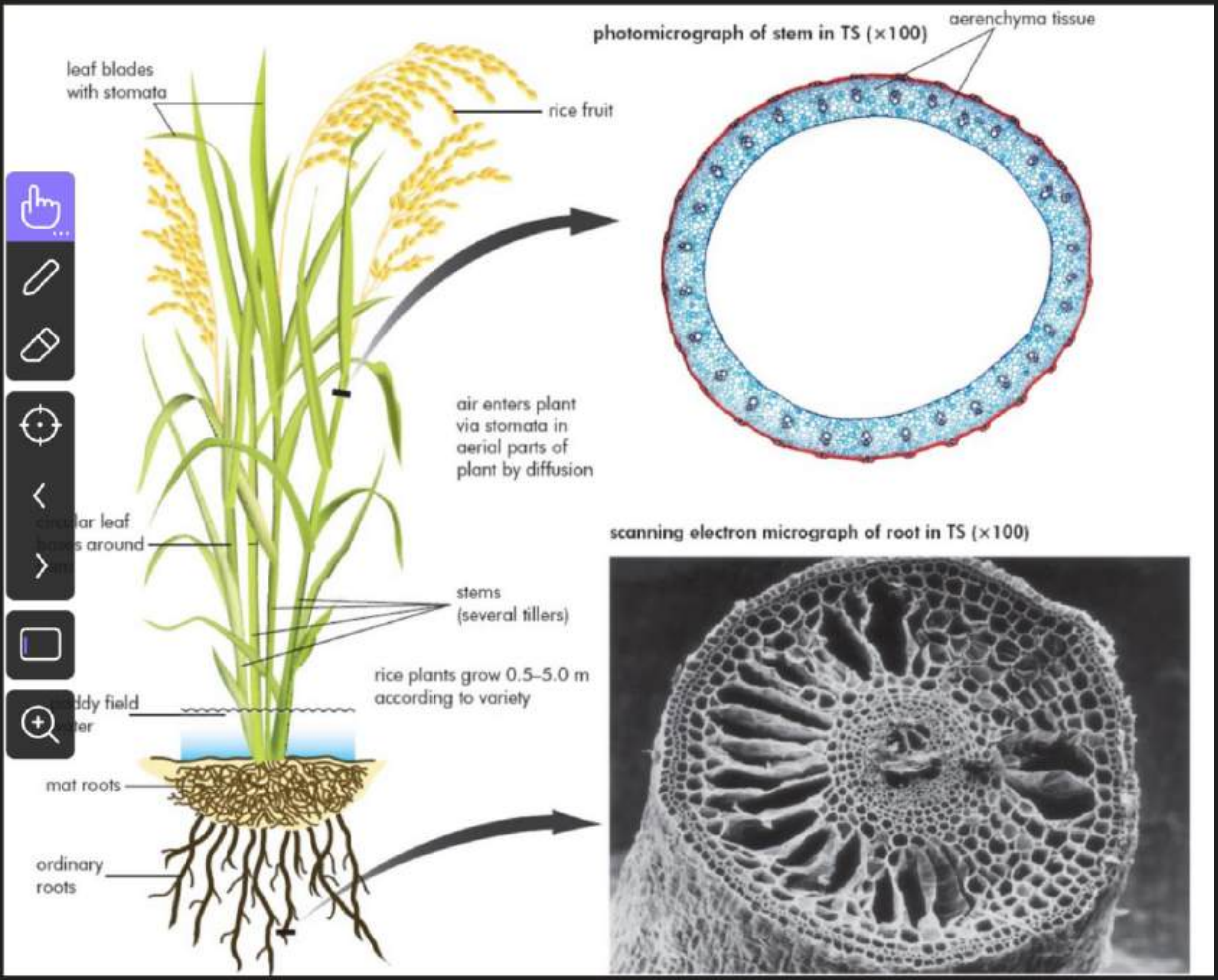


③ Presence of the enzyme ethanol dehydrogenase (in root cells) which detoxifies the ethanol produced via anaerobic respiration.

④ accelerated rate of internode growth.
This results due to increased synthesis of a plant hormone known as gibberellins (GA). It's increased production is in turn stimulated by another plant hormone → ethylene


nodes
internode length

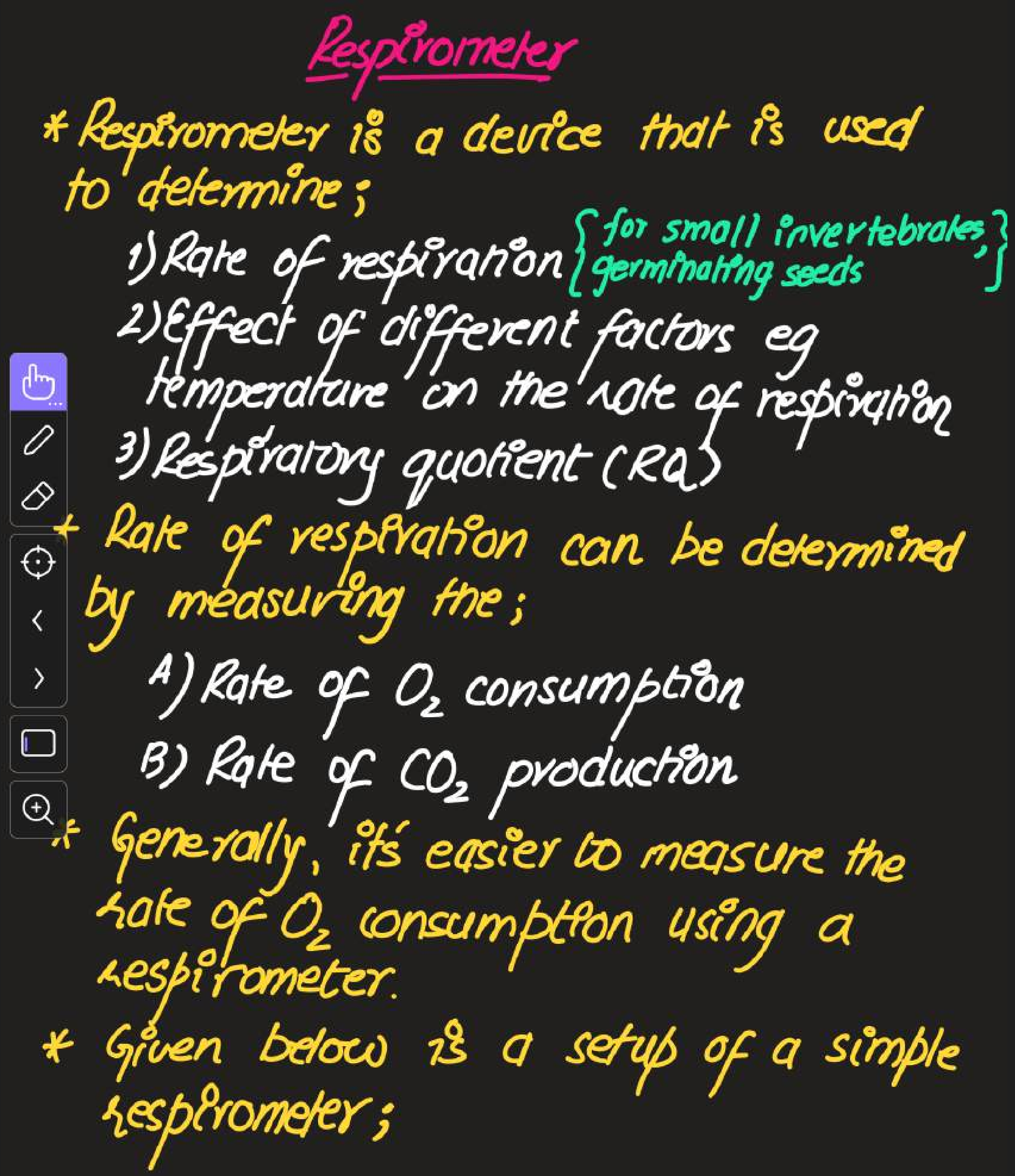




photomicrograph of stem in TS (×100)

scanning electron micrograph of root in TS (×100)

Respirometer ≠ Spirometer



Respirometer

* Respirometer is a device that is used to determine;

1) Rate of respiration {for small invertebrates, germinating seeds}
2) Effect of different factors eg temperature on the rate of respiration
3) Respiratory quotient (RQ)

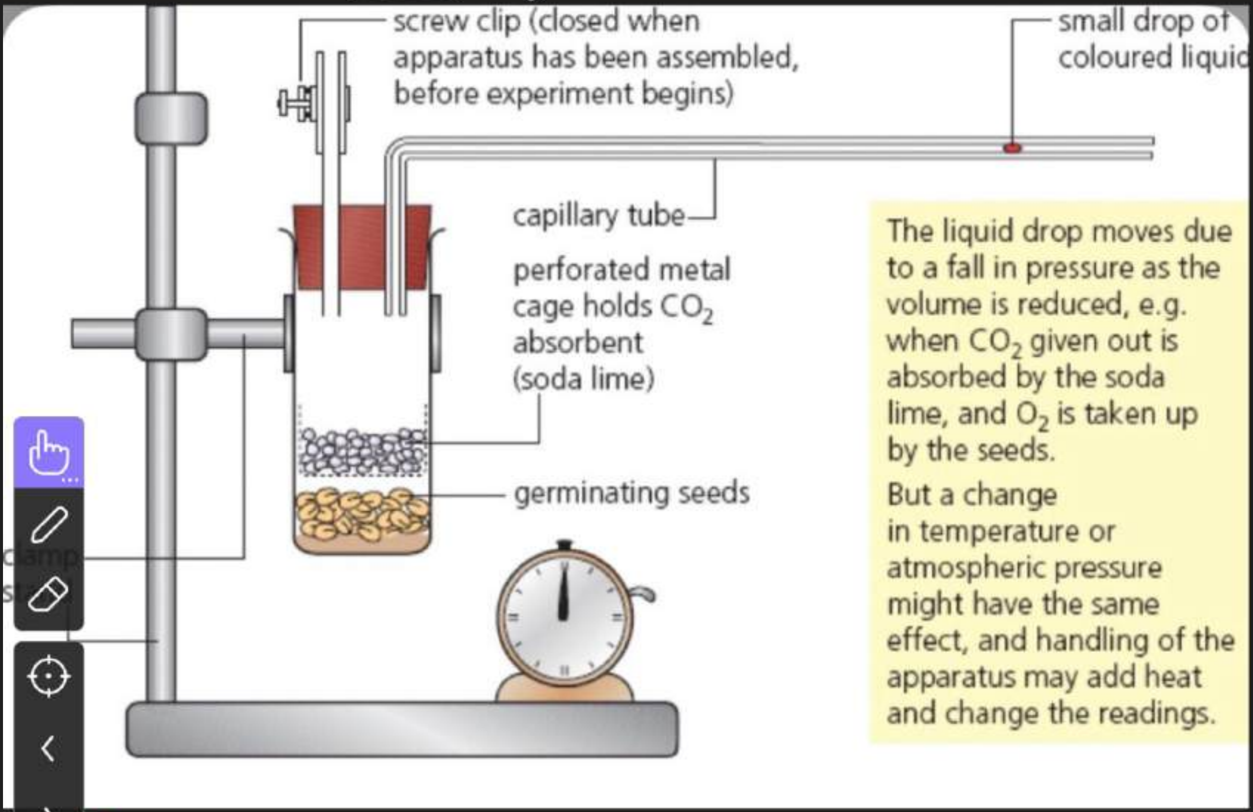
* Rate of respiration can be determined by measuring the;

A) Rate of O_2 consumption
B) Rate of CO_2 production

* Generally, it's easier to measure the rate of O_2 consumption using a respirometer.

* Given below is a setup of a simple respirometer;

Rate of Respiration



The liquid drop moves due to a fall in pressure as the volume is reduced, e.g. when CO_2 given out is absorbed by the soda lime, and O_2 is taken up by the seeds.

But a change in temperature or atmospheric pressure might have the same effect, and handling of the apparatus may add heat and change the readings.

) Setup the apparatus as shown above

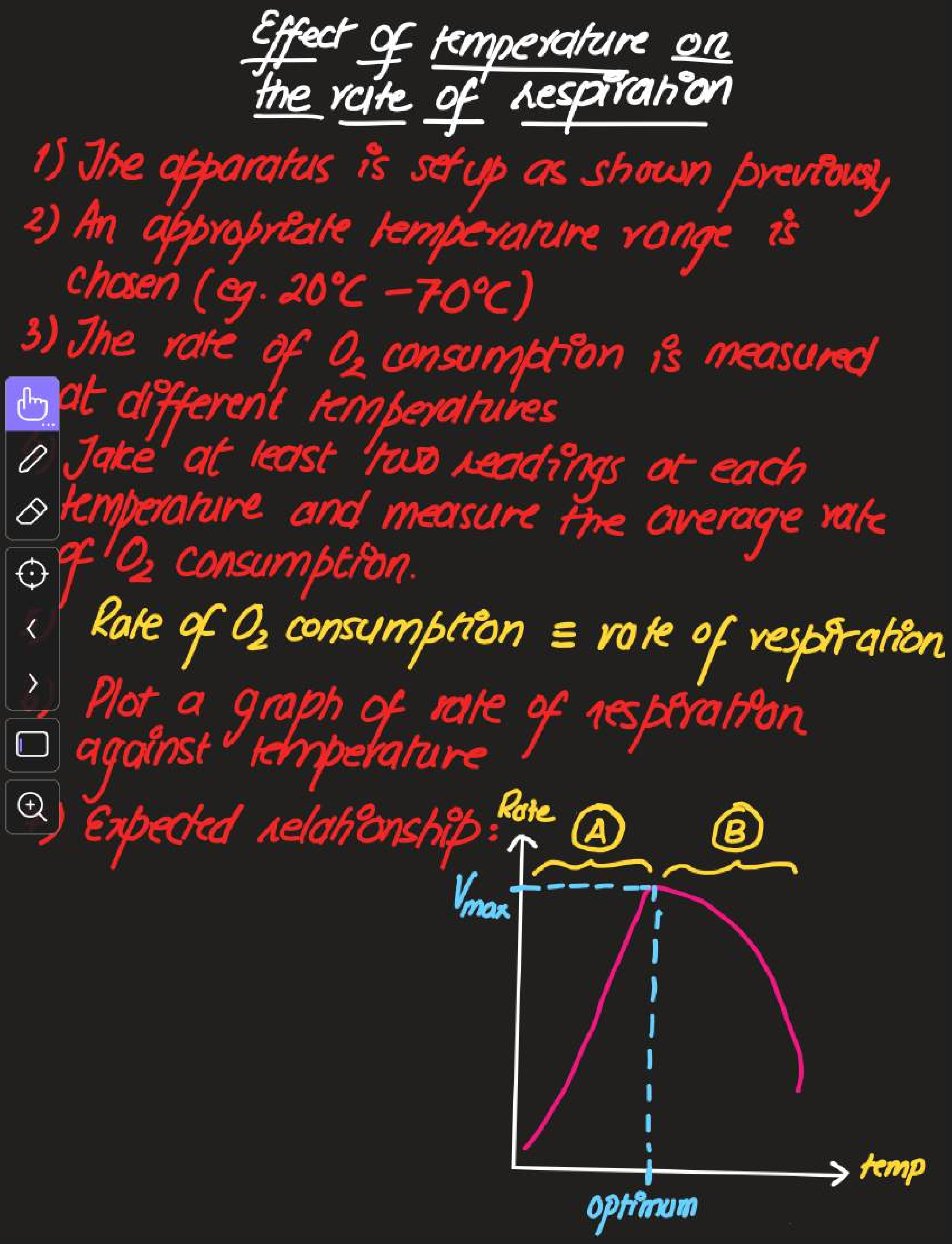
) Allow the germinating seeds to acclimatise with the conditions (10-15 mins)

3) Start the stopwatch

4) Measure the distance (d) moved by the drop in 15 minutes.

5) Calculate the volume of O_2 consumed by using the expression ⇒ cross-sectional area x d

6) Rate of respiration = Vol. of oxygen / time



Effect of temperature on the rate of respiration

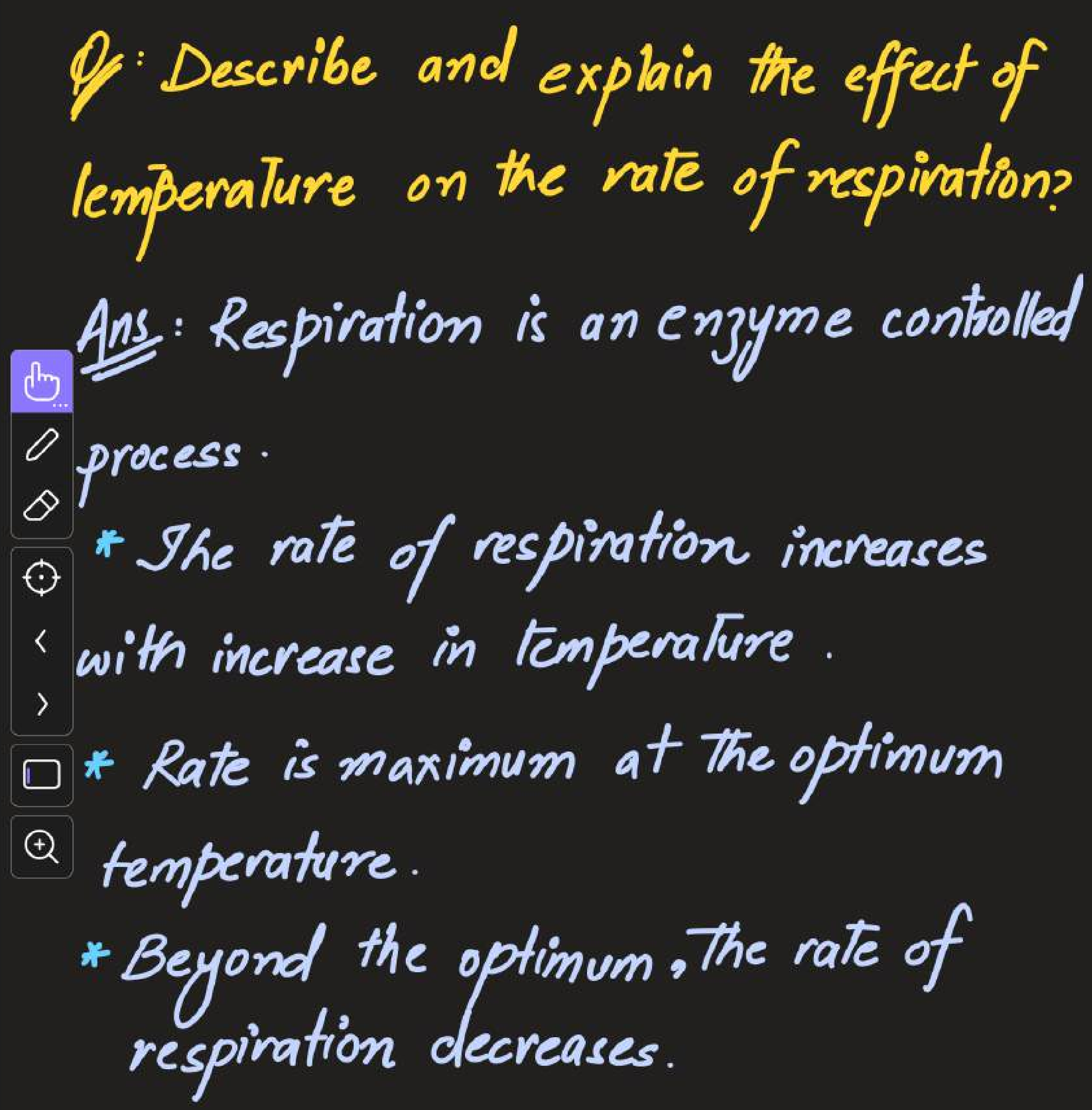
1) The apparatus is set up as shown previously
2) An appropriate temperature range is chosen (eg. 20°C – 70°C)
3) The rate of O_2 consumption is measured at different temperatures

Take at least two readings at each temperature and measure the average rate of O_2 consumption.

Rate of O_2 consumption ≡ rate of respiration

Plot a graph of rate of respiration against temperature

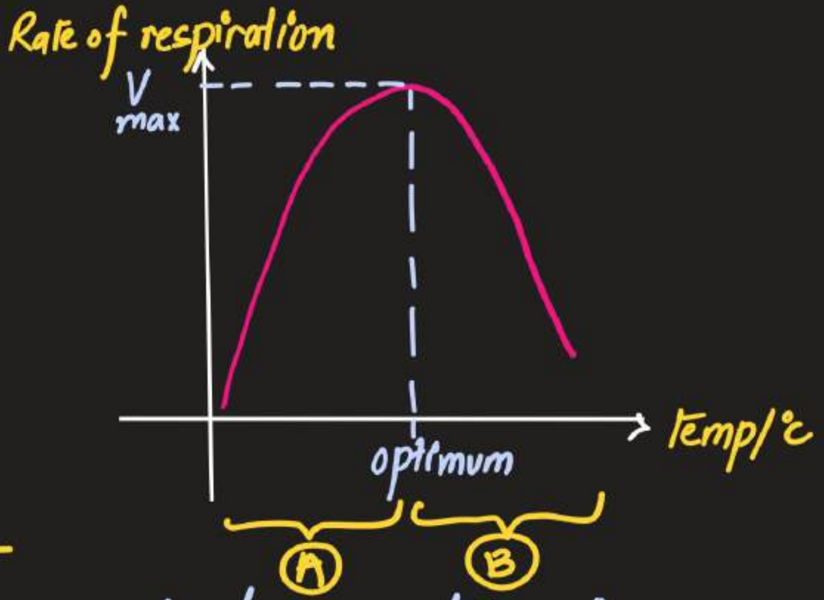
Expected relationship:



Q: Describe and explain the effect of temperature on the rate of respiration?

Ans: Respiration is an enzyme controlled process.

* The rate of respiration increases with increase in temperature.
* Rate is maximum at the optimum temperature.
* Beyond the optimum, the rate of respiration decreases.



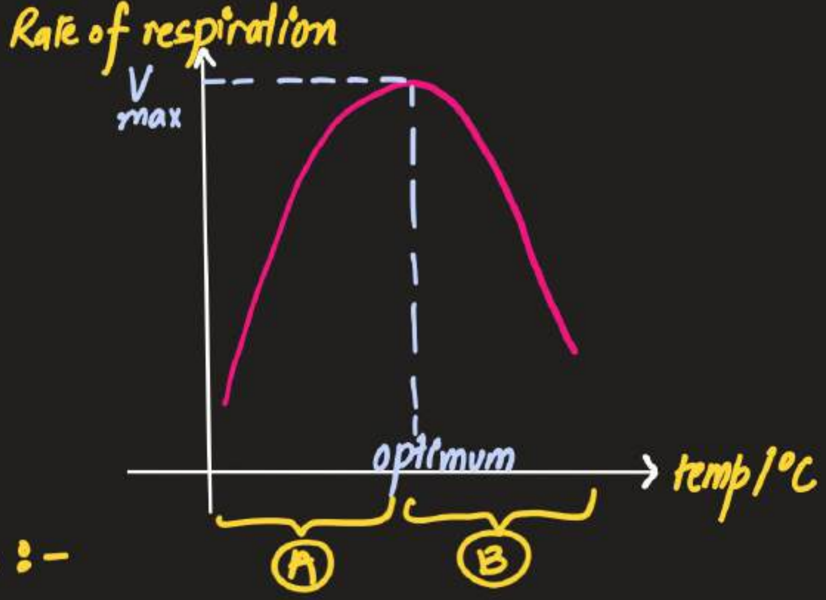
A :-

* Increase in temperature increases the kinetic energy of the enzyme and substrate molecules.

* Increases frequency of successful collisions → more E-S complexes.

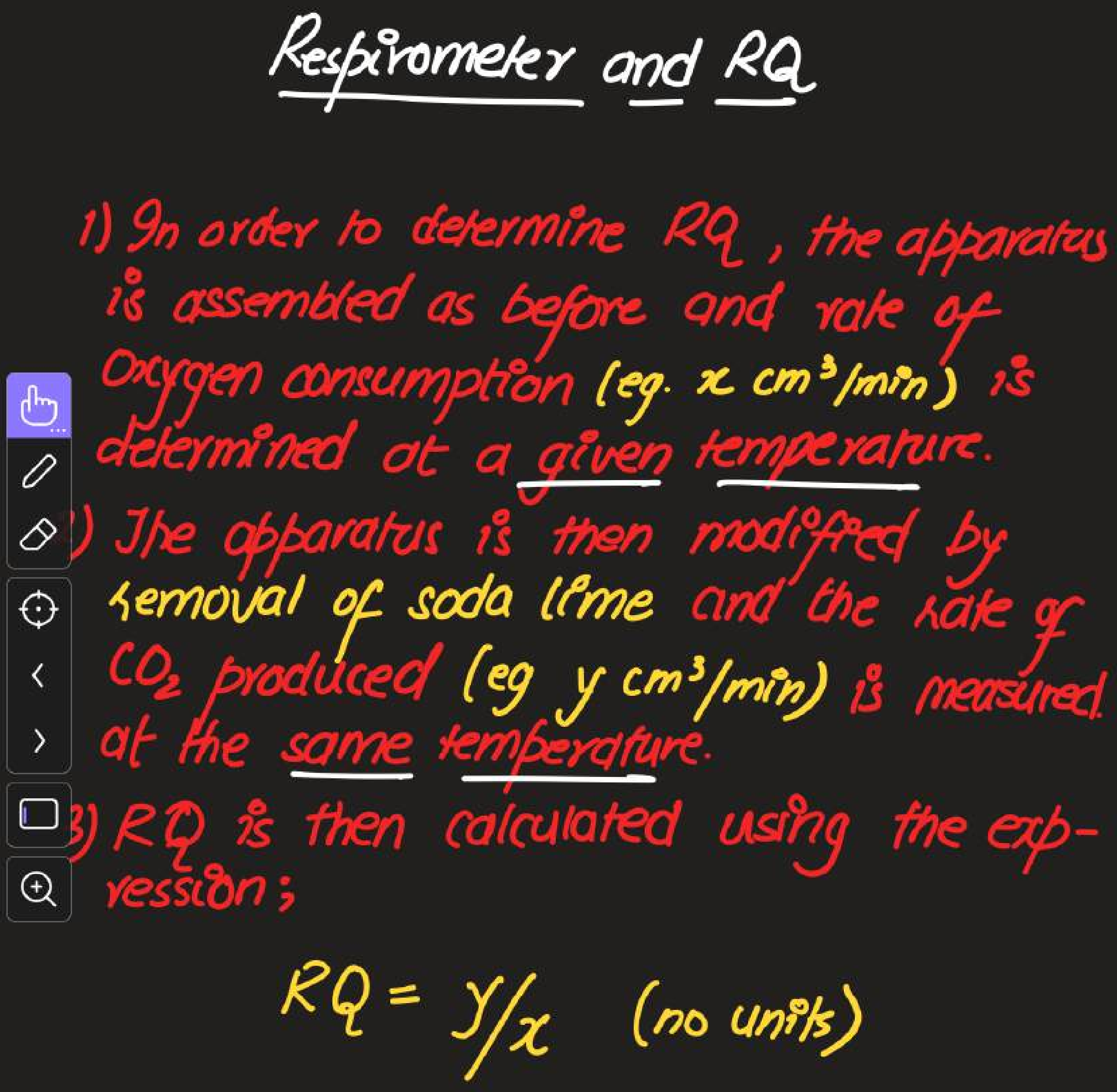
* hence increases rate of respiration.

* for every 10°c rise in temperature, the rate of respiration roughly doubles.
$Q_{10} = 2$



B :-

* Beyond the optimum, enzymes lose their tertiary structure due to disruption of ionic bonds, hydrogen bonds & hydrophobic bonds.
* Enzymes lose their active site which reduces the rate of formation of E-S complexes.
* Hence reduces the rate of respiration



Respirometer and RQ

1) In order to determine RQ, the apparatus is assembled as before and rate of oxygen consumption (eg. x cm³/min) is determined at a given temperature.

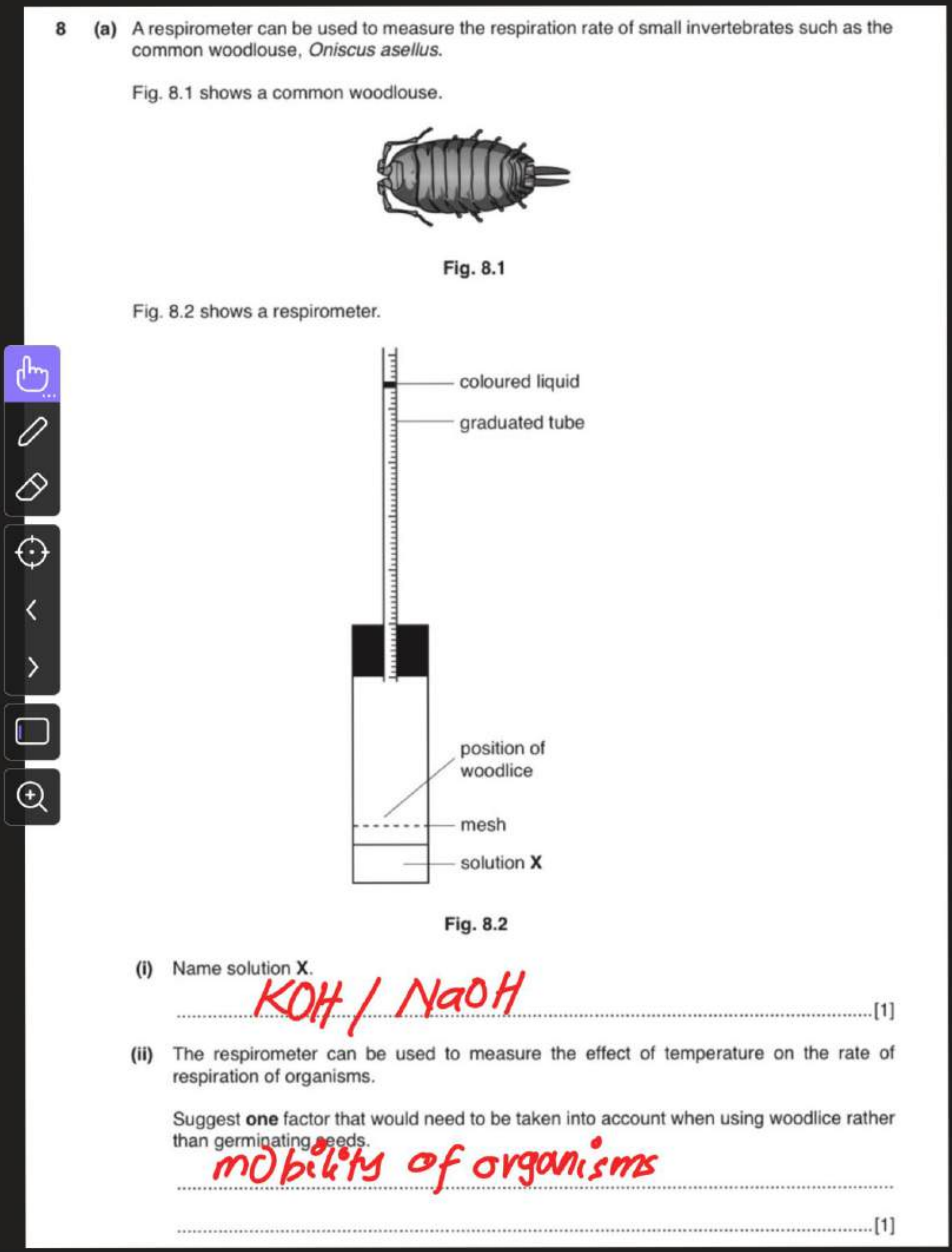
) The apparatus is then modified by removal of soda lime and the rate of CO_2 produced (eg y cm³/min) is measured at the same temperature.

3) RQ is then calculated using the expression;

$$RQ = y/x \quad \text{(no units)}$$

Questions

Question 1



8 (a) A respirometer can be used to measure the respiration rate of small invertebrates such as the common woodlouse, *Oniscus asellus*.

Fig. 8.1 shows a common woodlouse.

Fig. 8.1

Fig. 8.2 shows a respirometer.

Fig. 8.2

(i) Name solution **X**.

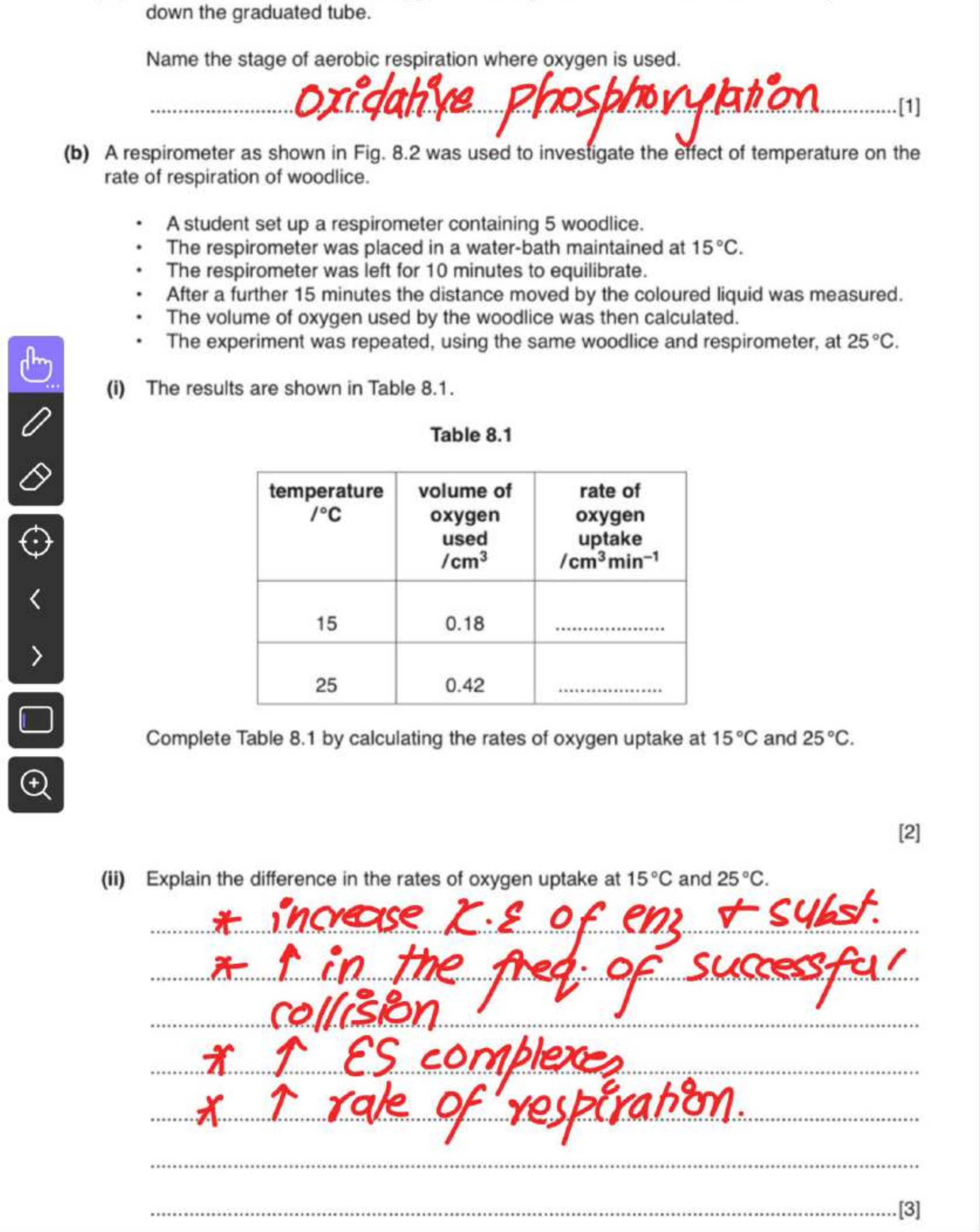
KOH / NaOH ....[1]

(ii) The respirometer can be used to measure the effect of temperature on the rate of respiration of organisms.

Suggest **one** factor that would need to be taken into account when using woodlice rather than germinating seeds.

mobility of organisms ....

..........[1]



(iii) As respiration takes place, oxygen is used by the woodlice and the coloured liquid moves down the graduated tube.

Name the stage of aerobic respiration where oxygen is used.

Oxidative phosphorylation [1]

(b) A respirometer as shown in Fig. 8.2 was used to investigate the effect of temperature on the rate of respiration of woodlice.

- A student set up a respirometer containing 5 woodlice.
- The respirometer was placed in a water-bath maintained at 15 °C.
- The respirometer was left for 10 minutes to equilibrate.
- After a further 15 minutes the distance moved by the coloured liquid was measured.
- The volume of oxygen used by the woodlice was then calculated.
- The experiment was repeated, using the same woodlice and respirometer, at 25 °C.

(i) The results are shown in Table 8.1.

Table 8.1

temperature /°C	volume of oxygen used /cm^3	rate of oxygen uptake /$cm^3 min^{-1}$
15	0.18	....
25	0.42	....

Complete Table 8.1 by calculating the rates of oxygen uptake at 15 °C and 25 °C.

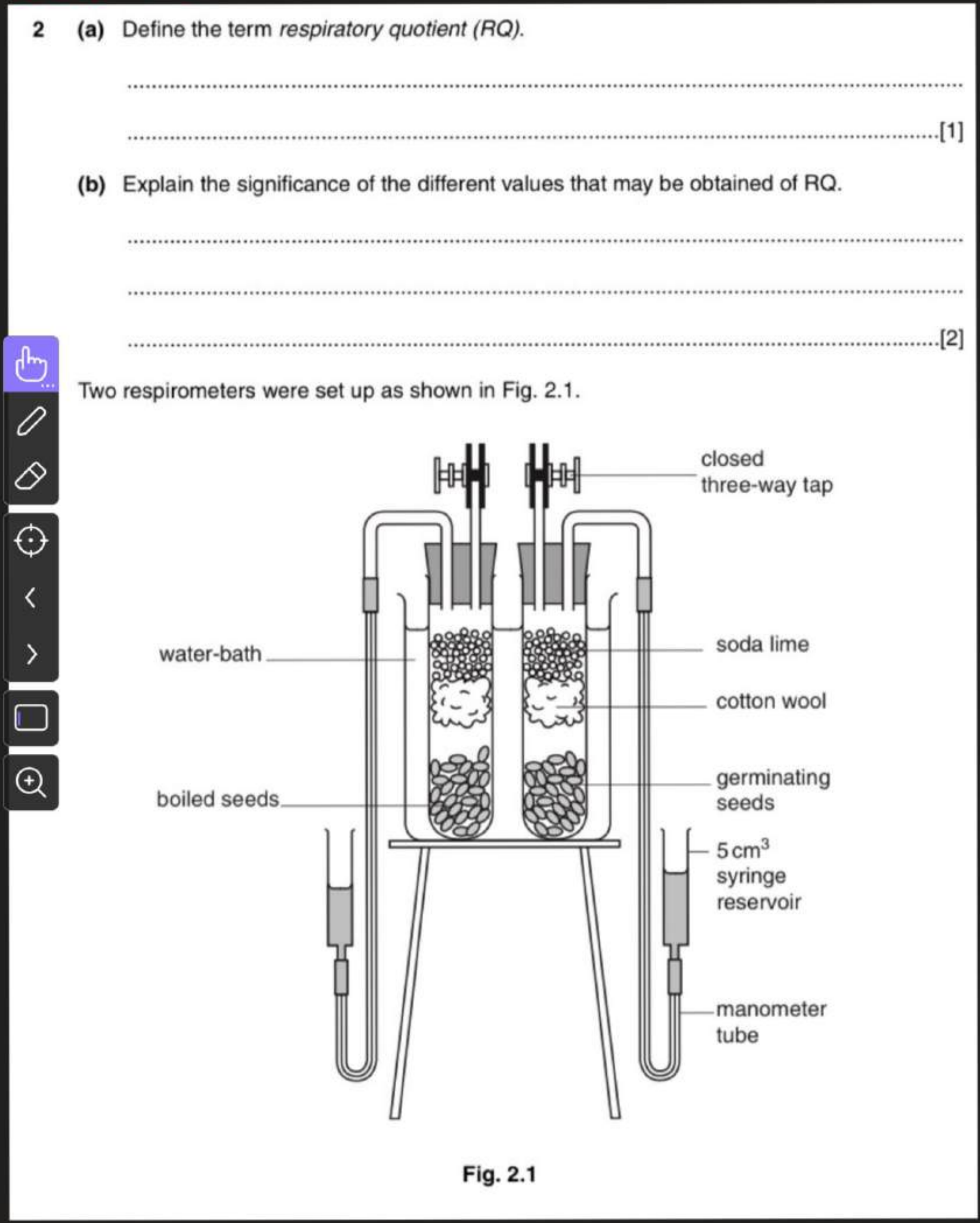
[2]

(ii) Explain the difference in the rates of oxygen uptake at 15 °C and 25 °C.

* increase K.E of enz + subst.
* ↑ in the freq. of successful collision
* ↑ ES complexes
* ↑ rate of respiration.

[3]

Question 2



2 **(a)** Define the term *respiratory quotient (RQ)*.

....

....[1]

(b) Explain the significance of the different values that may be obtained of RQ.

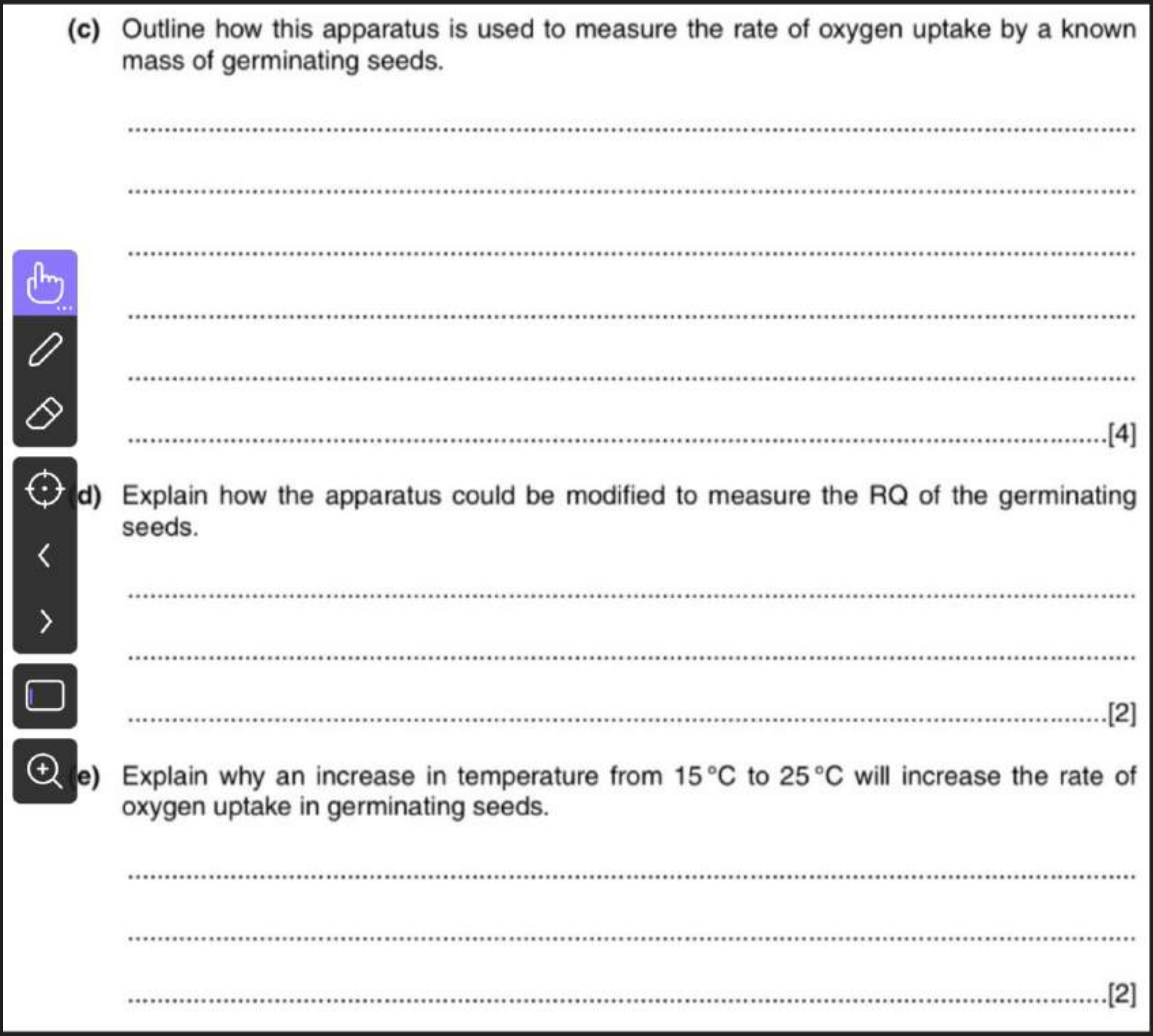
....

....

....[2]

Two respirometers were set up as shown in Fig. 2.1.

Fig. 2.1



(c) Outline how this apparatus is used to measure the rate of oxygen uptake by a known mass of germinating seeds.

....

....

....

....

....

....[4]

d) Explain how the apparatus could be modified to measure the RQ of the germinating seeds.

....

....

....[2]

e) Explain why an increase in temperature from 15 °C to 25 °C will increase the rate of oxygen uptake in germinating seeds.

....

....

....[2]