EUNOIA JUNIOR COLLEGE
JC2 Preliminary Examination 2025
General Certificate of Education Advanced Level
Higher 2

CANDIDATE NAME	

CIVICS GROUP	2	4	–			INDEX NUMBER	

CHEMISTRY

9729/02

Paper 2 Structured Questions

02 September 2025
2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name, civics group, index number in the spaces at the top of this page.
Write in dark blue or black pen.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

Answer **all** questions in the spaces provided on the Question Paper.
The use of an approved scientific calculator is expected, where appropriate.

A Data Booklet is provided.

The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
Paper 2	
1	**/ 13**
2	**/ 16**
3	**/ 14**
4	**/ 14**
5	**/ 18**
Total	**/ 75**

This document consists of **22** printed pages and **2** blank pages.

1 Mount Ijen in East Java is famous for its rare blue flames, visible at night. The phenomenon occurs when sulfur vapour, from the volcano's cracks burns, producing bright blue flames and sulfur dioxide. In the cool high-altitude air, some of the vapour condenses into solid sulfur.

(a) A team of environmental chemists were authorised to collect solid sulfur deposits near Mount Ijen's crater to investigate volcanic activity.

The chemists burnt the sulfur sample and measured the temperature change for a fixed amount of water placed in a calorimeter. The data from their experiment is shown in Table 1.1.

Table 1.1

mass of solid sulfur powder burnt /g	0.76
mass of water in beaker /g	150
initial temperature of water /°C	29.8
final temperature of water / °C	39.7

(i) Construct an equation to represent the standard enthalpy change of combustion of solid sulfur, S.

..... [1]

(ii) Calculate the enthalpy change of combustion of solid sulfur, S, based on their experiment.

[2]

(iii) During volcanic activity, many sulfur-containing gases such as hydrogen sulfide, H_2S, and sulfur dioxide, SO_2, are released. In the atmosphere, H_2S can oxidise to form SO_2, and subsequently sulfur trioxide, SO_3, may be formed.

$$H_2S(g) + 3/2\ O_2(g) \rightarrow SO_2(g) + H_2O(l) \qquad \Delta H_r = -562\ kJ\ mol^{-1}$$

Use the data given in Table 1.2 to calculate the enthalpy change of combustion of solid sulfur, S.

Table 1.2

compound	ΔH_f / kJ mol^{-1}
$H_2S(g)$	–20.6
$H_2O(l)$	–285.8

[2]

(iv) Comment on the difference in values for the enthalpy change of combustion of solid sulfur determined in **(a)(ii)** and **(a)(iii)**.

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(v) With reference to a relevant chemical equation, explain how the release of sulfur-containing gases during volcanic activity can have a negative impact on the environment.

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..... [2]

(b) Sulfur in volcanic emissions primarily exists as a mixture of two stable isotopes: ^{32}S and ^{34}S.

The chemists analysed volcanic gas samples to determine the isotopes' relative abundance, which reveals the sulfur's origin.

- If the sample was enriched in ^{32}S, it originated from deep mantle degassing.
- If the sample was enriched in ^{34}S, it originated from hydrothermally recycled sources.

(i) 1.994 g of SO_2 evolved at Mount Ijen allowed the chemists to extract 1.00 g of elemental sulfur containing mixture of isotopes, ^{32}S and ^{34}S, for further analysis.

Calculate the percentage by mass of ^{32}S in the elemental sulfur extracted. You may use the chemical formula S to represent elemental sulfur in your calculations.

[3]

(ii) Hence, suggest the likely origin of the sulfur sample.

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..... [1]

While volcanic emissions affect the isotopic fractions of sulfur, the natural isotopic abundance of sulfur in Earth's environment is generally found to be present as follows.

Table 1.3

isotope	relative isotopic mass	percentage abundance / %
^{32}S	31.972	95.02
^{33}S	32.971	0.75
^{34}S	33.968	4.21
^{36}S	35.967	0.02

(iii) Use the data in Table 1.3 to calculate the relative atomic mass of sulfur, giving your answer to two decimal places.

[1]

[Total: 13]

2 Group 17 elements form a range of oxoacids with different oxidation states, such as $HClO_4$.

(a) (i) $HClO_4$ has two central atoms; one chlorine atom and one oxygen atom. In addition, the H atom is bonded to a O atom. Draw the dot-and-cross diagram of $HClO_4$.

[1]

(ii) Use VSEPR to describe and explain the shape and bond angle about central Cl and O atom in $HClO_4$.

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..... [3]

(b) With reference to your answer in **(a)(i)**, explain why HFO_4 does not exist?

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..... [1]

(c) The Latimer diagram of some chlorine species in acidic solution is given in Fig. 2.1.

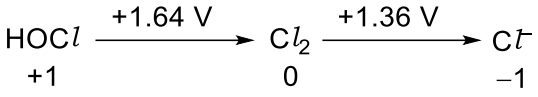

Fig 2.1

In Latimer diagram, oxidation numbers decrease from left to right and the numerical values of $E^{\ominus}$ of two adjacent species in volts. For example, the diagram shows that $E^{\ominus}(HOCl|Cl_2)$ is +1.64 V.

(i) Write a half-equation for the conversion of one mole of HOCl to one mole of Cl^- in acidic solution at 298 K.

..... [1]

(ii) Hess' Law is applicable to $\Delta G^{\ominus}$ in the same manner as $\Delta H^{\ominus}$.
With reference to the *Data Booklet* and Fig. 2.1, calculate $\Delta G^{\ominus}$ for the conversion of one mole HOCl to one mole of Cl^- in acidic solution.

[3]

(iii) Hence, calculate the standard electrode potential for the $HOCl|Cl^-$ half-cell.

[1]

(d) A sample of group 2 metal ethanedioate, MC_2O_4, is analysed to determine the identity of the metal.

A 4.13 g sample of the metal ethanedioate is reacted with excess acidified potassium manganate(VII), $KMnO_4$.

$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$

A 25 cm^3 portion from the remaining solution is reacted with periodate ions, IO_4^-, to produce IO_3^- and MnO_4^-. 22.2 cm^3 of 0.2 mol dm^{-3} of IO_4^- was required to react with the manganese(II) ions.

$$2Mn^{2+} + 5IO_4^- + 3H_2O \rightarrow 2MnO_4^- + 5IO_3^- + 6H^+$$

Deduce the identity of the metal in the metal ethanedioate.

[3]

(e) Periodic acid, HIO_4, is used as a selective oxidant in organic chemistry to split alcohols with two adjacent hydroxy groups into two carbonyl compounds.
An example is shown in Fig. 2.2.

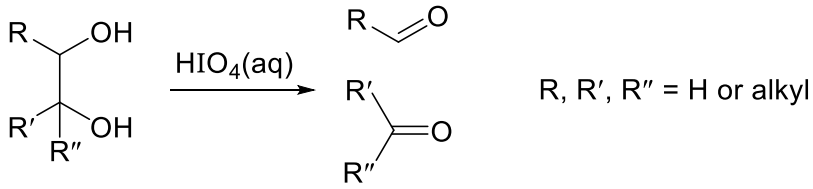

Fig. 2.2

Periodic acid also oxidises hydroxycarbonyl and dicarbonyl compounds by a hydration equilibrium, in which the carbonyl group is first converted into a diol.

$$R_2C{=}O \; + \; H_2O \; \rightleftharpoons \; R_2C(OH)_2 \qquad\qquad R = H \text{ or alkyl}$$

For example:

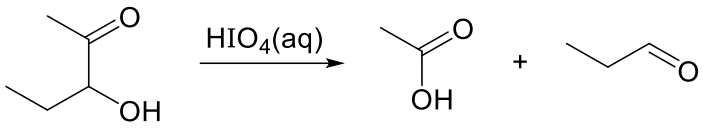

Fig. 2.3

Predict the organic products of the reactions shown in Fig. 2.4.

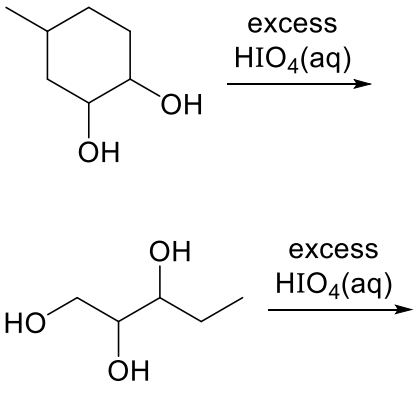

Fig. 2.4

[3]

[Total: 16]

3 **(a)** State whether trichloroethanoic acid or ethanoic acid, is the stronger acid. Explain your answer.

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..... [2]

(b) Phenyl ethanoate is often used as a solvent and as the building block for the synthesis of other chemicals.

(i) One method of its production involves phenol with an appropriate acid chloride via a **two**-step process. Identify the reactant required for each step.

step 1: .....

step 2: .....
[2]

(ii) Give two reasons why phenol does **not** react with carboxylic acids to form esters.

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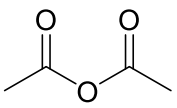
.....[2]

Another method of production involves phenols reacting with a class of compounds known as acid anhydrides. Ethanoic anhydride, $(CH_3CO)_2O$, is an example of a common commercially available acid anhydride.



ethanoic anhydride

Acid anhydrides undergo similar reactions to acid chlorides, and are easier and safer to handle in organic synthesis.

(c) **(i)** Write a balanced chemical equation for the formation of phenyl ethanoate using phenol and ethanoic anhydride.

[1]

(ii) Suggest why acid anhydrides are generally less reactive than acid chlorides towards nucleophiles.

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..... [1]

(d) **R** is formed when an acid anhydride **S**, $C_{14}H_{10}O_3$, reacts with CH_3NH_2.

R is a neutral compound and has the molecular formula C_8H_9NO. **R** reacts with hot $H_2SO_4(aq)$ to produce **P** and CH_3NH_2.

P is not very soluble in water, but dissolves after reacting with an excess of $Na_2CO_3(aq)$.

(i) Name the type of reaction occurring when **R** reacts with hot aqueous sulfuric acid.

..... [1]

(ii) **P** has the molecular formula $C_7H_6O_2$. **P** can be formed when methylbenzene reacts with acidified potassium manganate(VII).

Draw the structure of **P**.

[1]

(iii) Write the equation for the reaction of **P** with an excess of $Na_2CO_3(aq)$.

..... [1]

(iv) Suggest the structures of **R** and **S**.

R	**S**

[2]

(v) Use of the *Data Booklet* is relevant to this question.
Infra-red absorptions are useful in identifying functional groups present in molecules.

Suggest an absorption frequency range which can be used to distinguish between molecule **R** and **P**.

..... [1]

[Total:14]

4 Industrial wastewater is wastewater produced by industrial facilities during manufacturing or other processes. It differs from domestic wastewater due to the presence of a wider range of pollutants and the potential for higher concentrations of contaminants.

(a) An industrial facility discharges wastewater containing $A\ell^{3+}$, Zn^{2+}, and Cu^{2+} ions. To meet environmental standards, the facility designs a treatment process by controlled precipitation to remove these ions from the wastewater.

(i) Table 4.1 shows the K_{sp} values for the hydroxides of the metal ions.
Given that the wastewater initially contains 0.010 mol dm^{-3} of each metal ion, calculate the minimum pH at which copper(II) hydroxide begin to precipitate.

Table 4.1

metal hydroxide	K_{sp}	minimum pH for precipitation
$A\ell(OH)_3$	1.3×10^{-33}	3.70
$Cu(OH)_2$	2.2×10^{-20}	–
$Zn(OH)_2$	3.0×10^{-17}	6.74

[2]

(ii) Based on your calculations in **(a)(i)**, explain how $A\ell^{3+}$, Cu^{2+} and Zn^{2+} ions in the wastewater can be separated in the treatment process.

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.....[1]

(b) Industrial wastewater containing Cu^{2+} ions must be treated before it can be safe for discharge to a sanitary sewer for further treatment. The allowable limit of Cu^{2+} in the discharge is 1 mg per litre.

(i) Calculate the concentration of Cu^{2+} ions in the wastewater when zinc(II) hydroxide starts to precipitate.

[2]

(ii) The industrial wastewater is treated at pH 6.74. Using your answer in **(b)(i)**, deduce if the wastewater is safe for discharge to sanitary sewage for further treatment?

[1]

(c) There may be difficulty in removing Al^{3+} ion from the wastewater when excess sodium hydroxide solution is added.

Explain, with the aid of suitable equation(s), why this is so.

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.....[2]

(d) A sample of the industrial wastewater was found to be pale blue in colour due to contamination by Cu^{2+} ions.

(i) Explain why the solution contaminated with Cu^{2+} is blue in colour.

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(ii) A student took a sample of the solution and added excess concentrated hydrochloric acid. State the type of reaction and describe any observations. Construct a balanced equation for the reaction.

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.....[3]

[total: 14]

5 Energy is crucial for life and bodily functions, stored in the form of adenosine triphosphate, ATP. Renown as “energy currency”, ATP consists of a base, adenine, attached to ribose, to which is attached to a triphosphate group, as shown in Fig. 5.1.

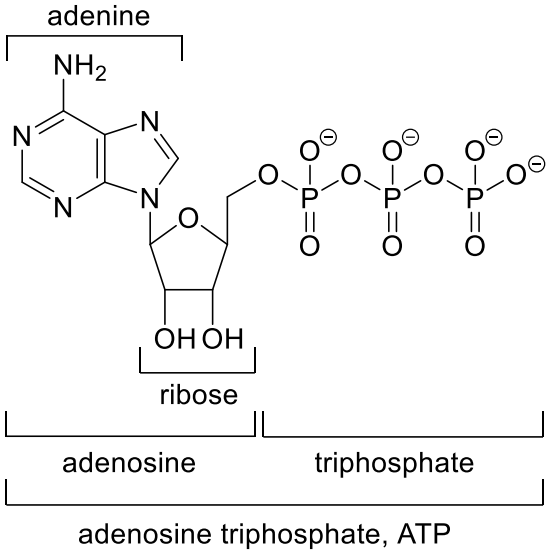

Fig. 5.1

(a) Adenine is made up of a six-membered pyrimidine ring fused with a five-membered imidazole ring, both of which are aromatic and planar.

The imidazole ring specifically contains six π electrons and can exist as an imidazole molecule. Two representations of imidazole molecule are shown in Fig. 5.2.

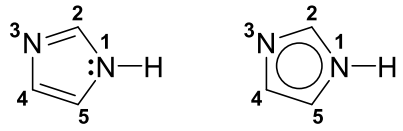

Fig. 5.2

Nitrogen atoms undergo the same type of hybridisation as carbon atoms.

(i) By reference to orbital overlap and the hybridisation of the nitrogen and carbon atoms, suggest how the σ and π bonds are formed in an imidazole molecule.

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..... [3]

(ii) An imidazole molecule is amphoteric as it can function both as an acid and a base.

By considering your answer in **(a)(i)** and its structure or otherwise, suggest and explain:

- The acidic proton is the H atom bonded to N1, not H atoms bonded to carbon atoms.
- N3 acts as the base.

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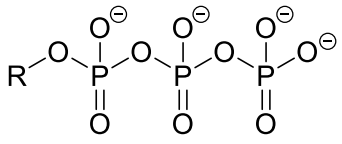
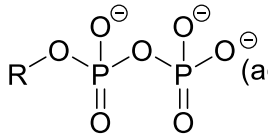
..... [2]

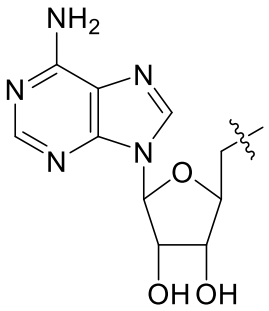
ATP hydrolysis breaks a high-energy P–O bond, releasing energy and forming ADP and HPO_4^{2-}, and is reversible under suitable conditions in reaction 1. The biochemical standard condition (as annotated by the superscript of $^{\ominus\prime}$) applies here where concentrations of all species are defined to be at 1 mol dm^{-3} at pH 7.0, at 37 ºC.

reaction 1  (aq) + $2H_2O(l)$

ATP

 (aq)+ HPO_4^{2-}(aq) + H_3O^+(aq)

ADP

where R = 

$\Delta G^{\ominus\prime}$ = –30.5 kJ mol^{-1}

$\Delta H^{\ominus\prime}$ = –20.5 kJ mol^{-1}

(b) The mechanism of the hydrolysis of ATP proceeds via the following stages:

1. Similar to nucleophilic addition, a nucleophilic attack of water on a phosphorus atom of the terminal phosphate unit while breaking the P=O π bond, forming intermediate 1.
2. The negative charge of the oxygen atom in intermediate 1 is then conferred to reforming of the π-bond in the P=O while another P–O bond involving the phosphorus atom of the terminal phosphate unit is cleaved to form intermediate 2 and ADP.
3. Another water molecule abstracts a proton from intermediate 2.

(i) Suggest why a water molecule is a nucleophile.

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..... [1]

(ii) Complete Fig. 5.3 to suggest the mechanism for this reaction for stages 1 and 2 only. Show the displayed structure of intermediate 2, relevant dipoles, relevant lone pairs of electrons and the movement of electrons by using curly arrows. [3]

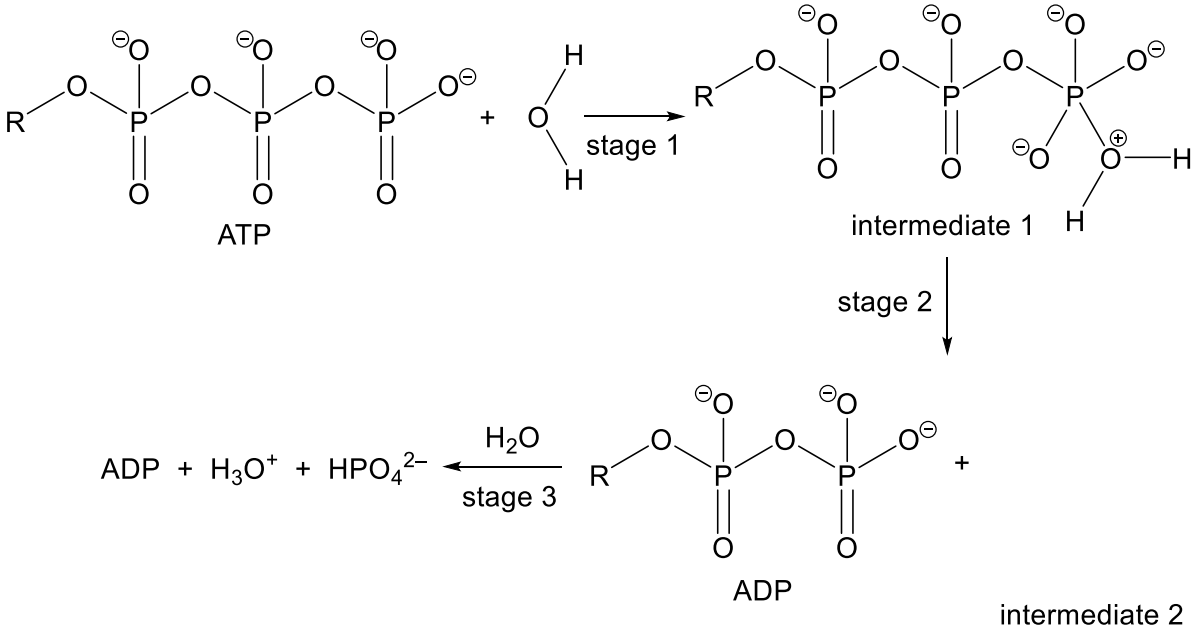

Fig. 5.3

(c) Calculate the entropy change of reaction, $\Delta S^{\ominus\prime}$, at 37 ºC and comment on the sign of $\Delta S^{\ominus\prime}$ obtained.

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..... [2]

(d) Physiological conditions vary depending on the organism, the specific tissue or cell compartment, and the current energy needs for metabolic and other reactions. Table 5.1 shows the concentrations of ATP, ADP and HPO_4^{2-} for various physiological conditions of organism.

Table 5.1

physiological condition of organism	ATP concentration / mol dm^{-3}	ADP concentration / mol dm^{-3}	HPO_4^{2-} concentration / mol dm^{-3}
standard condition	1	1	1
human – resting muscle	8×10^{-3}	9×10^{-6}	4×10^{-3}
human – muscle recovery from severe exercise	8×10^{-3}	7×10^{-6}	1×10^{-3}

(i) Other than concentration to be 1 mol dm^{-3}, state another condition specified by the symbol $^{\ominus}$ when the enthalpy change, entropy change and Gibbs free energy for a reaction are described at 298 K.

..... [1]

(ii) By considering Table 5.1 or otherwise, suggest why the standard condition is not applicable to most physiological conditions.

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..... [1]

(iii) Equation 1 can be used to compute the actual Gibbs free energy change, ΔG due to ATP hydrolysis under physiological condition.

Equation 1 $\Delta G = \Delta G^{\ominus\prime} + RT \ln Q_c$

where Q_c refers to the reaction quotient which has the same expression as K_c.

Using equation 1, Table 5.1 and the *Data Booklet*, calculate the Gibbs free energy change, ΔG due to ATP hydrolysis in reaction 1 for human muscle of athletes recovering from severe physical exertion at 37 ºC at pH = 7.4.

[2]

In the presence of magnesium ions, the Gibbs free energy change of reaction 1 changes. This is shown in Fig. 5.4.

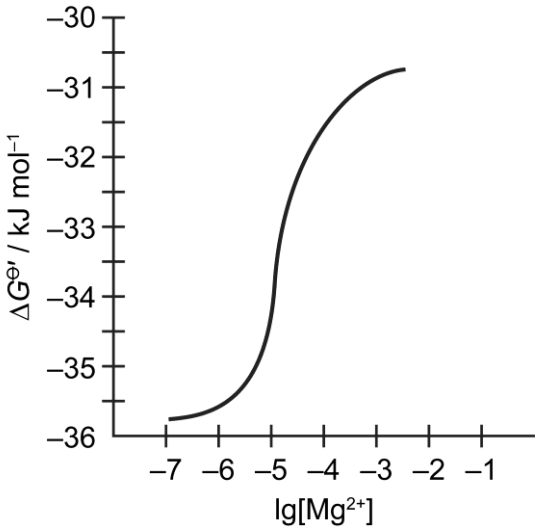

Fig. 5.4

(e) (i) Based on Fig. 5.4, describe how Gibbs free energy change varies with increasing concentration of magnesium ions.

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..... [1]

(ii) ATP can form several complexes with magnesium ions such as the $[MgATP]^{2-}$ complex. The $[MgATP]^{2-}$ complex serves as the substrate for ATPase, the enzyme that catalyses reaction 1.

The rate of reaction 1 using a fixed amount of ATPase is investigated. Experiments are performed using different concentrations of $[MgATP]^{2-}$ complex (substrate) and the rate of each reaction is measured.

Sketch a graph to describe the relationship between the rate of the reaction and substrate concentration, using a fixed amount of ATPase enzyme, in this reaction. Explain your reasoning.

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..... [2]

[Total: 18]

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