CAMBRIDGE INTERNATIONAL AS & A LEVEL CHEMISTRY · 9701

CHEMISTRY



EXAM QUESTION PACK

8 REACTION KINETICS

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Chapter 8

Reaction kinetics

8.1 Rate of reaction

410. 9701_m21_qp_12 Q: 10

A large excess of marble chips is reacted with 25 cm^3 of 1.0 mol dm^{-3} hydrochloric acid at 40 °C.

How is the result different when the reaction is repeated with 60 cm^3 of 0.5 mol dm^{-3} hydrochloric acid at 40 °C?

A The reaction is faster and more of the products are made when the reaction is complete.

B The reaction is faster and less of the products are made when the reaction is complete.

C The reaction is slower and more of the products are made when the reaction is complete.

D The reaction is slower and less of the products are made when the reaction is complete.

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411. 9701_s21_qp_12 Q: 11

1 Two chemicals, X and Y, react together in solution to give product Z.

The rate of formation of product Z at the start of the reaction was measured in five experiments, 1–5, using various concentrations of X and Y. The results are shown.

experiment number	starting concentration of X / mol dm^{-3}	starting concentration of Y / mol dm^{-3}	rate of formation of Z at the start / mol dm^{-3} s^{-1}
1	0.10	0.10	0.0001
2	0.10	0.20	0.0004
3	0.10	0.40	0.0016
4	0.20	0.10	0.0001
5	0.40	0.10	0.0001

Which statement is correct?

A The rate of the reaction is directly proportional to the concentration of reagent X.

B The rate of the reaction is directly proportional to the concentration of reagent Y.

C The rate of the reaction is **not** affected by the concentration of reagent X.

D The rate of the reaction is **not** affected by the concentration of reagent Y.

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412. 9701_s17_qp_11 Q: 11

When 4 g of powdered calcium carbonate, M_r = 100, were added to 100 cm^3 of 0.10 mol dm^{-3} hydrochloric acid the volume of carbon dioxide produced was recorded.

time / s	30	60	90	120	150	180	210	240
total volume of carbon dioxide given off / cm^3	40	70	88	101	110	116	120	120

Which row gives the correct explanations about these results?

	why the rate of the reaction changes with time	why the reaction stops
A	fewer collisions between reacting molecules occur	the calcium carbonate is used up
B	fewer collisions between reacting molecules occur	the hydrochloric acid is used up
C	more collisions between reacting molecules occur	the calcium carbonate is used up
D	more collisions between reacting molecules occur	the hydrochloric acid is used up

---

413. 9701_w17_qp_11 Q: 7

Iodine and propanone react according to the following equation.

$$I_2(aq) + CH_3COCH_3(aq) \rightarrow CH_3COCH_2I(aq) + HI(aq)$$

If the concentration of propanone is increased, keeping the total reaction volume constant, the rate of the reaction also increases.

What could be the reason for this?

A A greater proportion of collisions is successful at the higher concentration.

B The particles are further apart at the higher concentration.

C The particles have more energy at the higher concentration.

D There are more collisions between reactant particles per second at the higher concentration.

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414. 9701_w17_qp_12 Q: 10

A large excess of marble chips was reacted with 25 cm^3 of 1.0 mol dm^{-3} hydrochloric acid at 40 °C.

How will the result be different when the reaction is repeated with 60 cm^3 of 0.5 mol dm^{-3} hydrochloric acid at 40 °C?

A The reaction is faster and less of the products are made.

B The reaction is faster and more of the products are made.

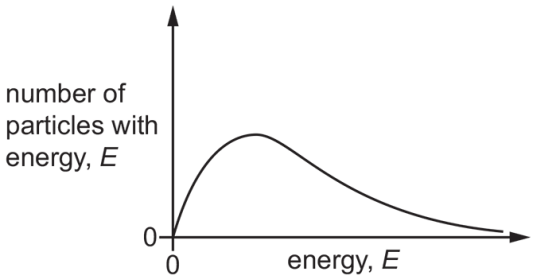
C The reaction is slower and less of the products are made.

D The reaction is slower and more of the products are made.

8.2 Effect of temperature on reaction rates and the concept of activation energy

415. 9701_m22_qp_12 Q: 15

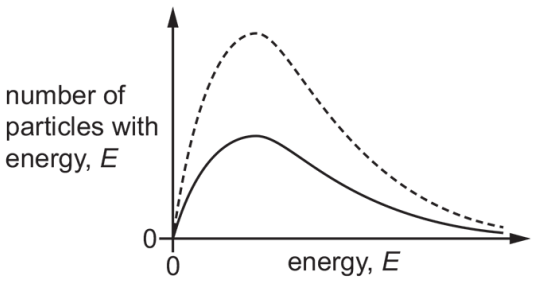
The Boltzmann distribution for one mole of a gas at temperature T is shown.



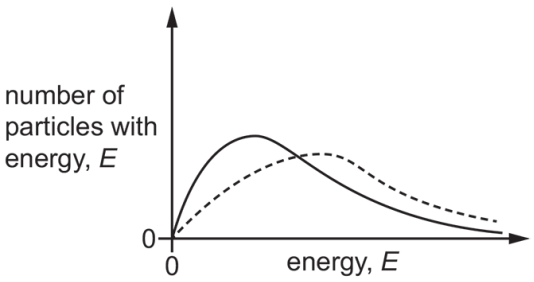
One mole of the same gas is added, and the gas remains at temperature T.

Which dotted curve shows the distribution with the added gas?

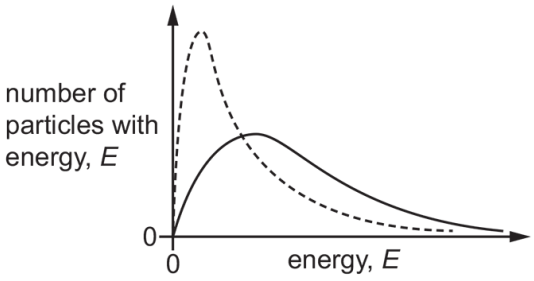
A



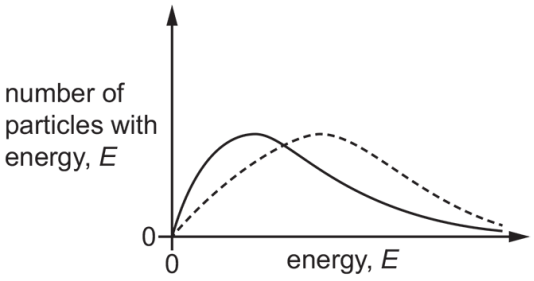
B



C



D



416. 9701_m22_qp_12 Q: 16

In the reaction shown, the concentrations of both X and Y are reduced to half of their original values whilst keeping the total volume of the solution constant.

$$X(aq) + Y(aq) \rightarrow XY(aq)$$

Simultaneously the temperature is increased from 298 K to 348 K.

Which prediction is definitely true?

A A smaller proportion of collisions between particles of X and particles of Y will be successful.

B The average kinetic energy of particles of X and particles of Y will increase.

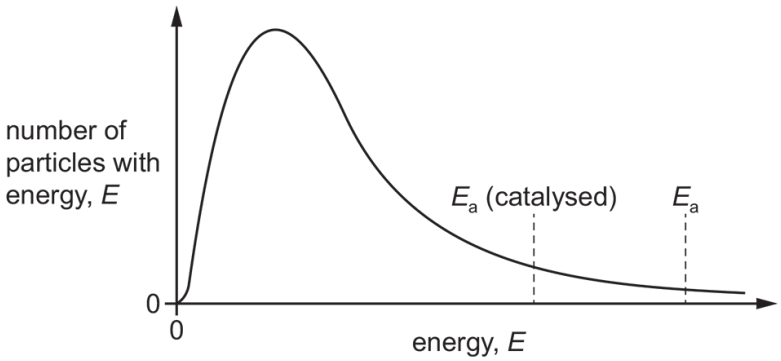
C The rate of the reaction will be unaffected.

D The frequency of collisions between particles of X and particles of Y will halve.

---

417. 9701_m21_qp_12 Q: 11

The Boltzmann distribution curve for a gaseous mixture of ethene and hydrogen is shown. Nickel is an effective catalyst for the reaction that occurs.



How does the diagram appear if the same reaction mixture is at a higher temperature?

A The curve is unchanged.

B The values of both E_a (catalysed) and E_a decrease.

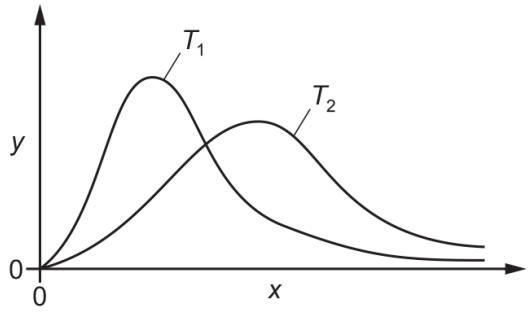
C The values of both E_a (catalysed) and E_a increase.

D The values of both E_a (catalysed) and E_a remain the same.

---

418. 9701_s21_qp_11 Q: 5

The diagram shows the Boltzmann distribution for the same gas at two different temperatures, T_1 and T_2.



What is plotted on the *y*-axis and which line represents the higher temperature?

	plotted on *y*-axis	higher temperature
A	number of molecules	T_1
B	number of molecules	T_2
C	molecular energy	T_1
D	molecular energy	T_2

---

419. 9701_s21_qp_13 Q: 12

The height of the peak of the curve in a Boltzmann distribution represents the number of molecules that have the most probable energy.

A sample of gas has its temperature decreased without changing the number of molecules present.

Which statement correctly describes a feature of the Boltzmann distribution for the gas when the temperature decreases?

A The value of the most probable energy would stay the same.

B The number of molecules with the most probable energy would increase.

C The area under the molecular energy distribution curve would decrease.

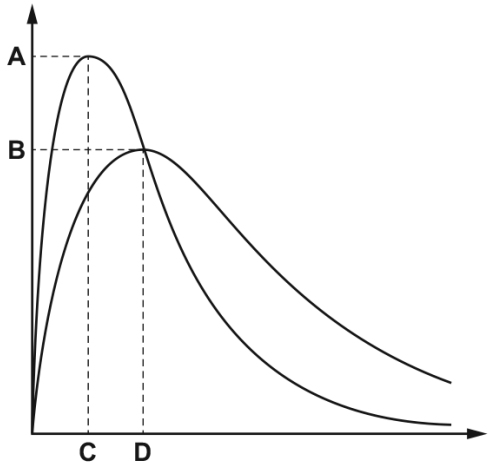
D The number of molecules at the very high energy end of the distribution would stay the same.

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420. 9701_s20_qp_11 Q: 6

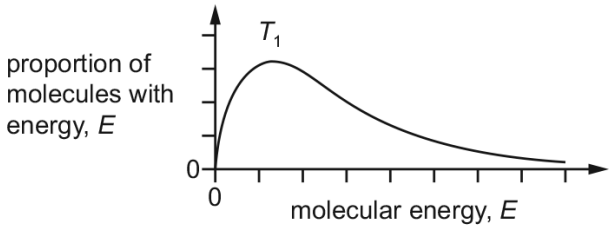
The diagram shows the Boltzmann energy distribution curves for molecules of a sample of a gas at two different temperatures.

Which letter on the axes represents the most probable energy for molecules of the same sample of gas at the **lower** temperature?



421. 9701_m19_qp_12 Q: 1

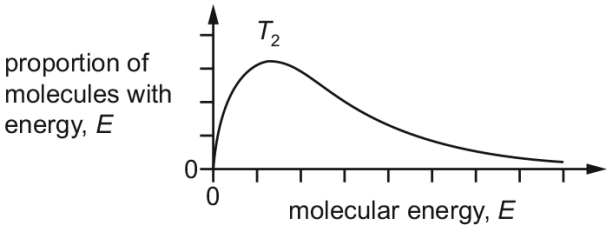
The Boltzmann distribution is shown for a sample of gas at an initial temperature, T_1.



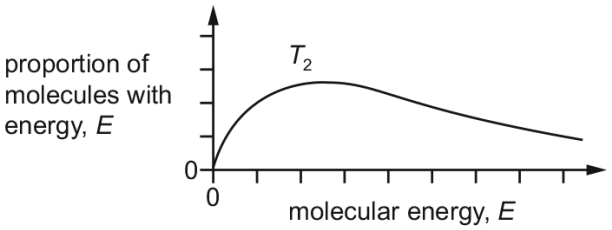
The sample of gas was heated to temperature, T_2.

What is the correct distribution for the higher temperature, T_2?

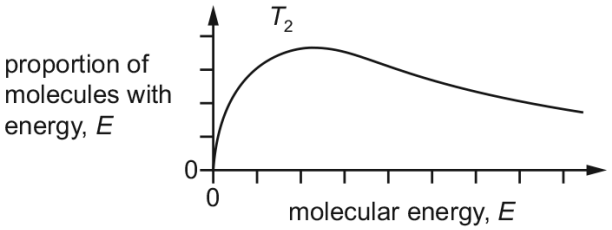
A



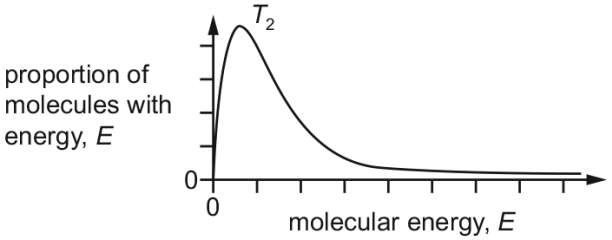
B



C



D



422. 9701_s19_qp_11 Q: 1

The temperature of a sample of an inert gas is increased.

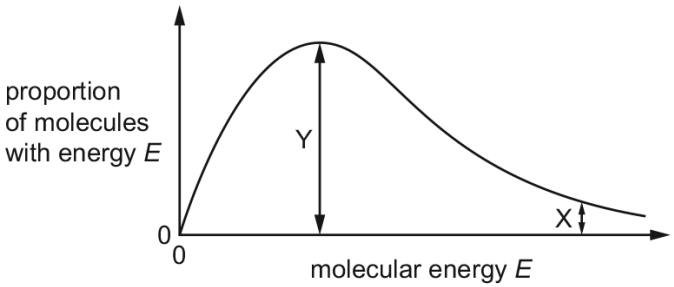
What effect does this have on the number of molecules with the most probable energy and on the number of molecules with high energy?

	number of molecules with the most probable energy	number of molecules with high energy
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

---

423. 9701_s17_qp_13 Q: 11

The diagram shows the Boltzmann distribution of the energy of gaseous molecules at a particular temperature.



Which statement is correct?

A If the temperature of the gas is raised, the height of the maximum of the curve increases.

B If the temperature of the gas is raised, the maximum of the curve moves to the right.

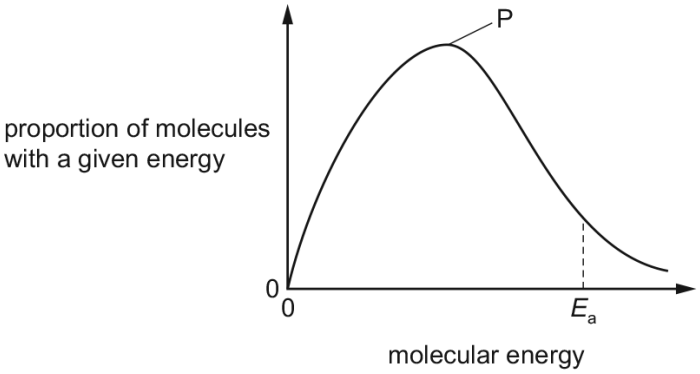
C The length of the line labelled X shows the activation energy for the reaction.

D The length of the line labelled Y shows the enthalpy change of the reaction.

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424. 9701_s16_qp_12 Q: 1

The diagram shows the Boltzmann distribution of energies in 1 mole of a gas. The gas can take part in a reaction with an activation energy, E_a.



Which statement correctly describes the effect of an increase in temperature?

A Peak P will be higher and fewer molecules will have energy > E_a.

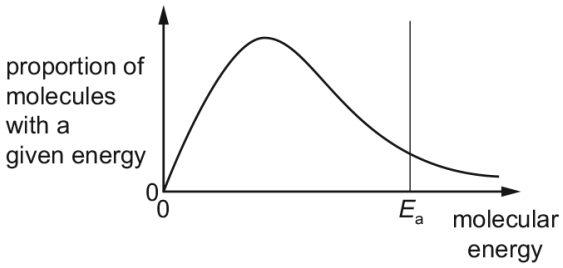
B Peak P will be higher and more molecules will have energy > E_a.

C Peak P will be lower and fewer molecules will have energy > E_a.

D Peak P will be lower and more molecules will have energy > E_a.

425. 9701_w16_qp_11 Q: 1

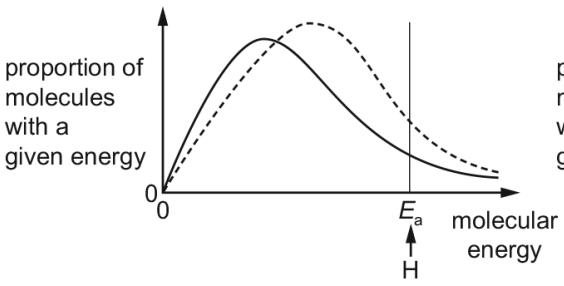
The diagram represents, for a given temperature, the Boltzmann distribution of the kinetic energies of the molecules in a mixture of two gases that react together. The activation energy for the reaction, E_a, is marked.



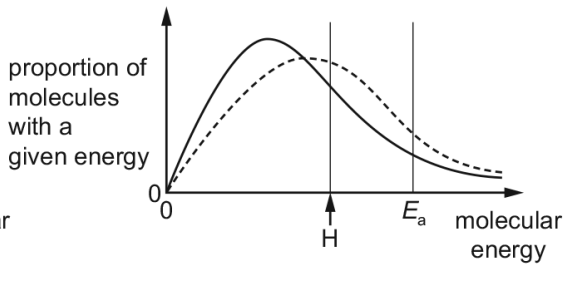
The dotted curves below show the Boltzmann distribution for the same reaction at a higher temperature. On these diagrams, H represents the activation energy at the higher temperature.

Which diagram is correct?

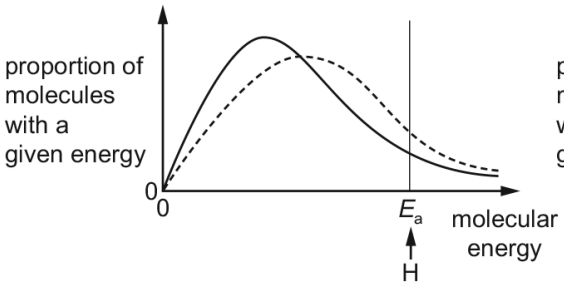
A



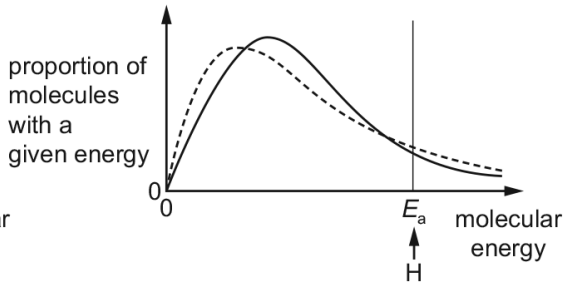
B



C

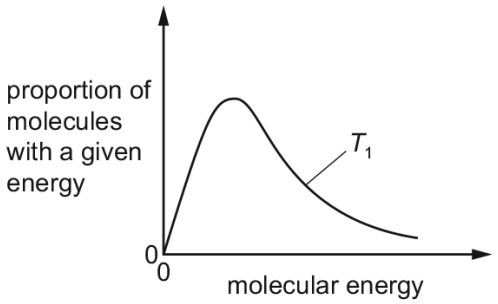


D



426. 9701_w16_qp_12 Q: 1

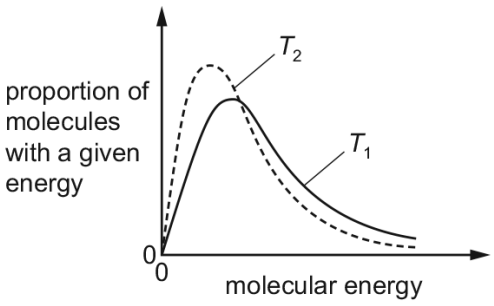
The molecules of a gas at a constant temperature, T_1, have the distribution of molecular energies shown in the diagram.



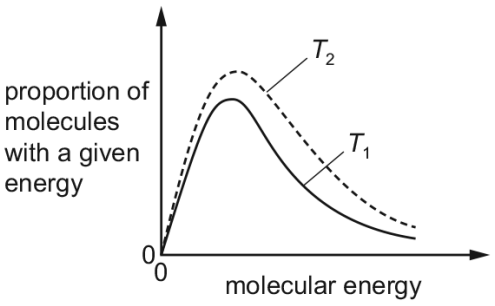
When the temperature is **increased** to T_2, the distribution of molecular energies changes.

Which diagram correctly shows this change?

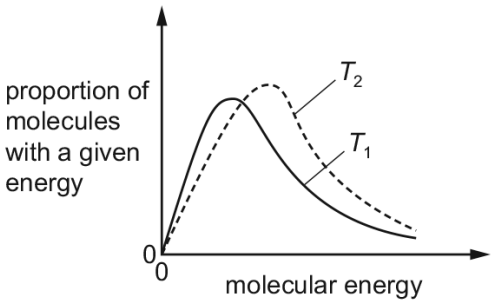
A



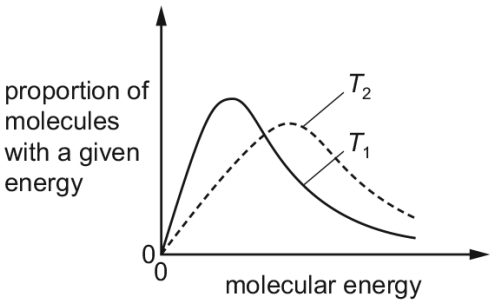
B



C

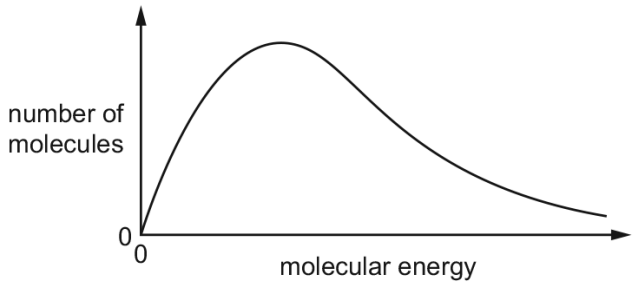


D



427. 9701_s15_qp_12 Q: 11

The Boltzmann distribution below shows the distribution of molecular energies in a sample of a gas at a given temperature.



Which statement correctly describes the change in such a distribution if the temperature is increased?

A Fewer molecules possess the most probable energy value and this value shifts to the left.

B Fewer molecules possess the most probable energy value and this value shifts to the right.

C More molecules possess the most probable energy value and this value shifts to the left.

D The area under the curve of the distribution increases.

---

428. 9701_w15_qp_12 Q: 11

Which row correctly describes what happens when the temperature of a chemical reaction is **decreased**?

	activation energy (E_a)	number of successful collisions
A	decreases	decreases
B	decreases	increases
C	remains the same	decreases
D	remains the same	increases

8.3 Homogeneous and heterogeneous catalysts

429. 9701_s21_qp_11 Q: 11

Which statement about catalysts is correct?

A They change the reaction pathway by increasing the activation energy.

B They increase the rate of reaction by lowering the enthalpy change of the reaction.

C They increase the number of particles that have sufficient energy to react.

D Heterogeneous catalysts are in the same state as the reactant.

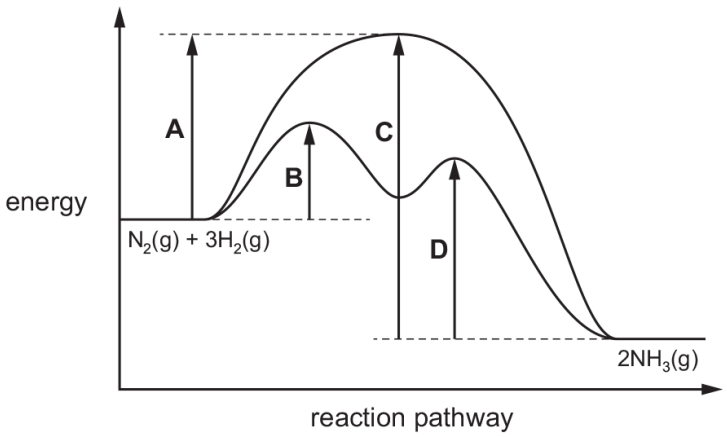
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430. 9701_s21_qp_12 Q: 7

The reaction pathway diagram for the catalysed reaction and the uncatalysed reaction between N_2 and H_2 is shown.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

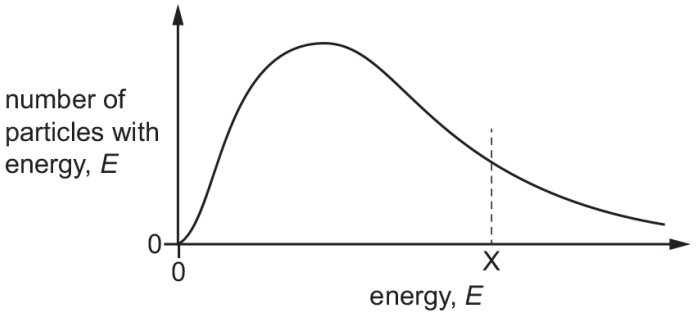
Which letter represents the activation energy for the first step in the decomposition of NH_3 in the presence of a catalyst?



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431. 9701_w21_qp_11 Q: 11

The diagram shows the Boltzmann distribution of energies for a reactant gas. For a particular reaction, the activation energy is X.



Which change to the diagram occurs if an effective catalyst is added at the same temperature?

A More particles will possess higher values of *E*.

B The peak will move to the left.

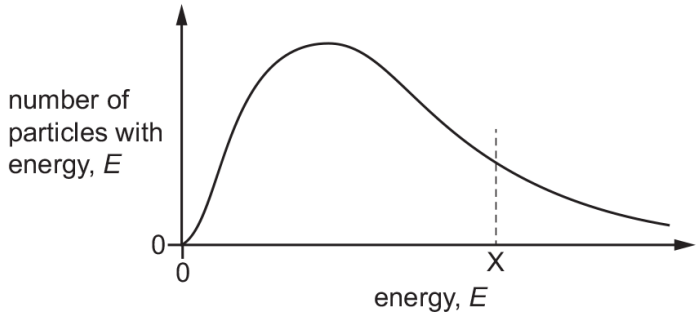
C The peak will move to the right.

D The value of the activation energy decreases.

---

432. 9701_w21_qp_13 Q: 11

The diagram shows the Boltzmann distribution of energies for a reactant gas. For a particular reaction, the activation energy is X.



Which change to the diagram occurs if an effective catalyst is added at the same temperature?

A More particles will possess higher values of *E*.

B The peak will move to the left.

C The peak will move to the right.

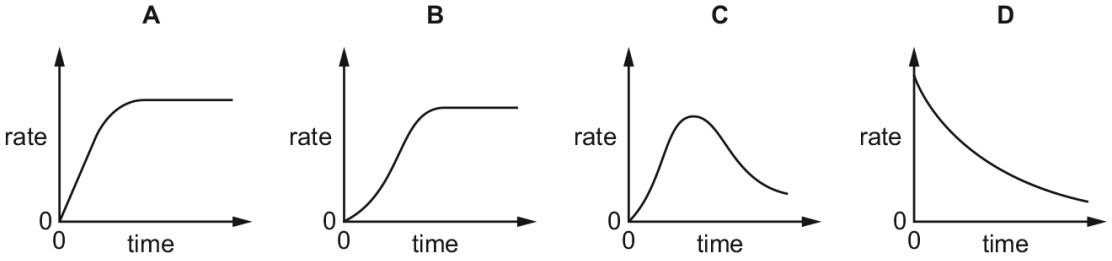
D The value of the activation energy decreases.

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433. 9701_w20_qp_11 Q: 11

An autocatalytic reaction is a reaction in which one of the products catalyses the reaction.

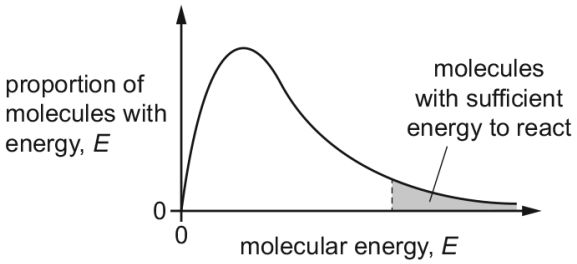
Which curve would be obtained if the rate of an autocatalytic reaction is plotted against time?



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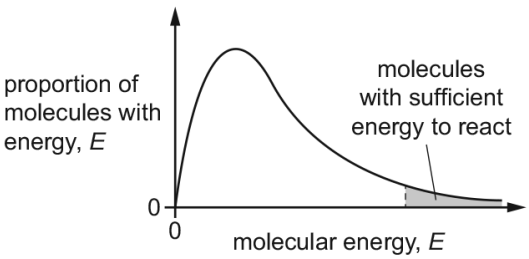
434. 9701_s19_qp_12 Q: 1

The Boltzmann distribution of molecular energies in a sample of aqueous hydrogen peroxide at room temperature is shown.

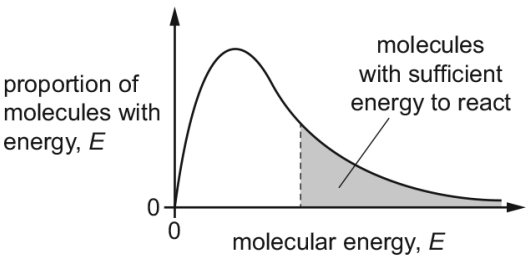


Which diagram shows the Boltzmann distribution of molecular energies of aqueous hydrogen peroxide maintained at room temperature when a catalyst, manganese(IV) oxide, is added?

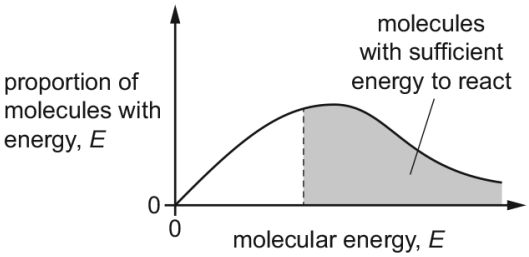
A



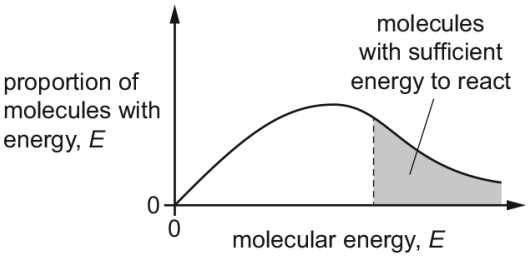
B



C



D



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435. 9701_s19_qp_12 Q: 11

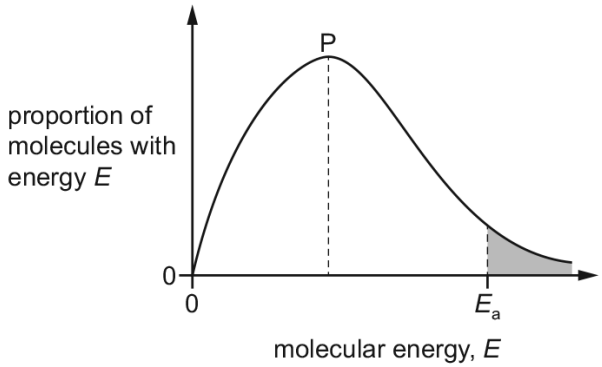
Which row is an example of heterogeneous catalysis?

	reaction	catalyst
A	esterification	sulfuric acid
B	the Contact process	divanadium pentoxide
C	destruction of the ozone layer	chlorine radicals
D	atmospheric formation of sulfur trioxide	nitrogen dioxide

---

436. 9701_w19_qp_11 Q: 1

The diagram shows the Boltzmann distribution of energies in a gas. The gas undergoes a reaction with an activation energy, E_a. The peak of the distribution is labelled P.



If the same reaction is carried out in the presence of a catalyst, which statement is correct?

A The peak P is at a lower height and the position of E_a moves to the left.

B The peak P is at a lower height and the position of E_a moves to the right.

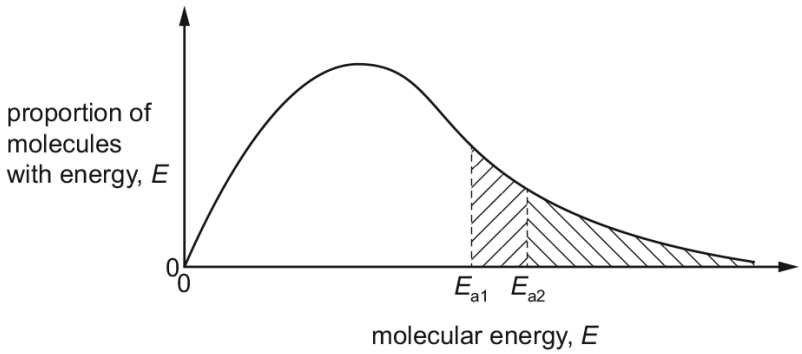
C The peak P remains at the same height and the position of E_a moves to the left.

D The peak P remains at the same height and the position of E_a moves to the right.

---

437. 9701_w19_qp_12 Q: 1

The diagram shows a Boltzmann distribution of the energies of gaseous molecules and the activation energies, E_a, of a reaction with and without a catalyst.



Which statement about this distribution curve is correct?

A If the temperature of the gas is increased, the maximum of the curve becomes higher.

B If the temperature of the gas is increased, the maximum of the curve moves to the left.

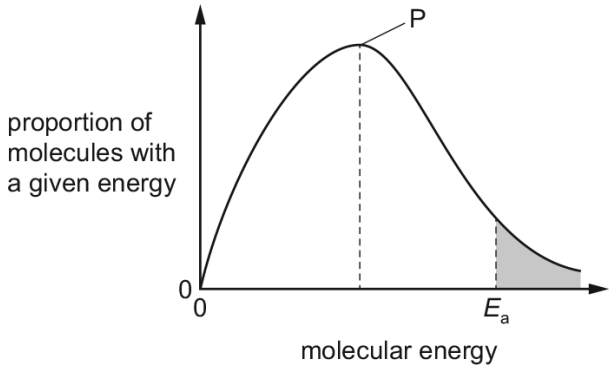
C The fraction of molecules that react in the presence of a catalyst is shown by .

D The fraction of molecules that react in the absence of a catalyst is shown by .

---

438. 9701_s18_qp_11 Q: 4

The diagram shows the Boltzmann distribution of energies in a gas. The gas can take part in a reaction with an activation energy, E_a. The gas is maintained at a constant temperature.



Which statement is correct?

A If a catalyst is added, peak P will be lower and E_a will move to the left.

B If a catalyst is added, peak P will be lower and E_a will move to the right.

C If a catalyst is added, peak P will be the same and E_a will move to the left.

D If a catalyst is added, peak P will be the same and E_a will move to the right.

---

439. 9701_s18_qp_12 Q: 11

A chemical company used a catalyst in a chemical process. The company has now decided not to use the catalyst but to increase the temperature so that the rate of the reaction is the same as it was when the catalyst was used.

Which statement about the new conditions compared to the original conditions is correct?

A The activation energy has been decreased.

B The activation energy has been increased.

C There are fewer successful collisions per unit time.

D There are more successful collisions per unit time.

---

440. 9701_s18_qp_13 Q: 11

The enzyme maltase speeds up the reaction between maltose and water.

$$\text{maltose + water} \xrightarrow{\text{maltase}} \text{glucose}$$

Maltase shows **specificity**.

Which statement describes the **specificity** of maltase?

A Maltase is a biological catalyst and it is a type of protein.

B Maltase is most effective between pH 6.1 and pH 6.8.

C Maltase lowers the activation energies of the reactions it catalyses.

D Maltase only speeds up a small number of chemical reactions.

---

441. 9701_w18_qp_11 Q: 11

Two reactions are shown.

reaction 1 $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

reaction 2 $2O_3(g) \rightleftharpoons 3O_2(g)$

In reaction 1, a finely powdered iron catalyst is used.

In reaction 2, a vaporised tetrachloromethane catalyst in ultraviolet light is used.

Which statement about the catalysts used is correct?

A Both reaction 1 and reaction 2 use a heterogeneous catalyst.

B Both reaction 1 and reaction 2 use a homogeneous catalyst.

C Reaction 1 uses a heterogeneous catalyst and reaction 2 uses a homogeneous catalyst.

D Reaction 1 uses a homogeneous catalyst and reaction 2 uses a heterogeneous catalyst.

---

442. 9701_w18_qp_12 Q: 10

In a chemical system the particles involved have a range of energies. This can be shown on a graph called the Boltzmann distribution.

Which statement correctly explains the effect of a catalyst on the particles in a chemical system?

A A catalyst enables particles with a lower energy to collide successfully.

B A catalyst increases the number of particles with higher energies.

C A catalyst increases the number of particles with the most probable energy value.

D A catalyst increases the value of the most probable particle energy.

---

443. 9701_w18_qp_12 Q: 11

Nitrogen and hydrogen can react together to form ammonia.

The formation of ammonia is exothermic.

The rate and yield of the reaction can be altered by changing the conditions under which the reaction is carried out.

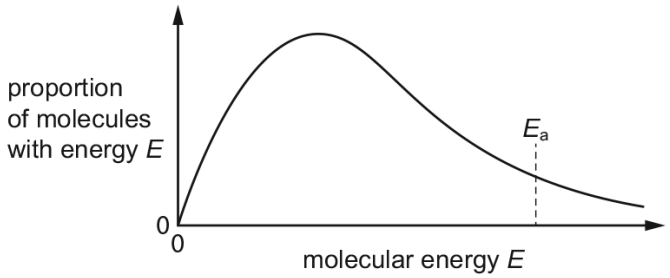
Which row shows the effects of adding iron to the mixture **and** increasing the temperature?

	adding iron	increasing the temperature
A	has no effect on the equilibrium yield	reduces the equilibrium yield
B	increases the equilibrium yield	increases the equilibrium yield
C	increases the equilibrium yield	increases the rate
D	increases the rate	has no effect on the equilibrium yield

---

444. 9701_s17_qp_12 Q: 11

The Boltzmann distribution for the hydrogenation of an alkene at a particular temperature in the absence of a catalyst is shown.



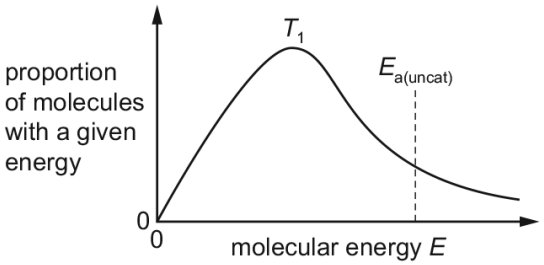
Which row correctly describes the effects of adding nickel to the reaction vessel?

	the shape of the Boltzmann distribution	activation energy, E_a
A	changes	decreases
B	changes	increases
C	does not change	decreases
D	does not change	increases

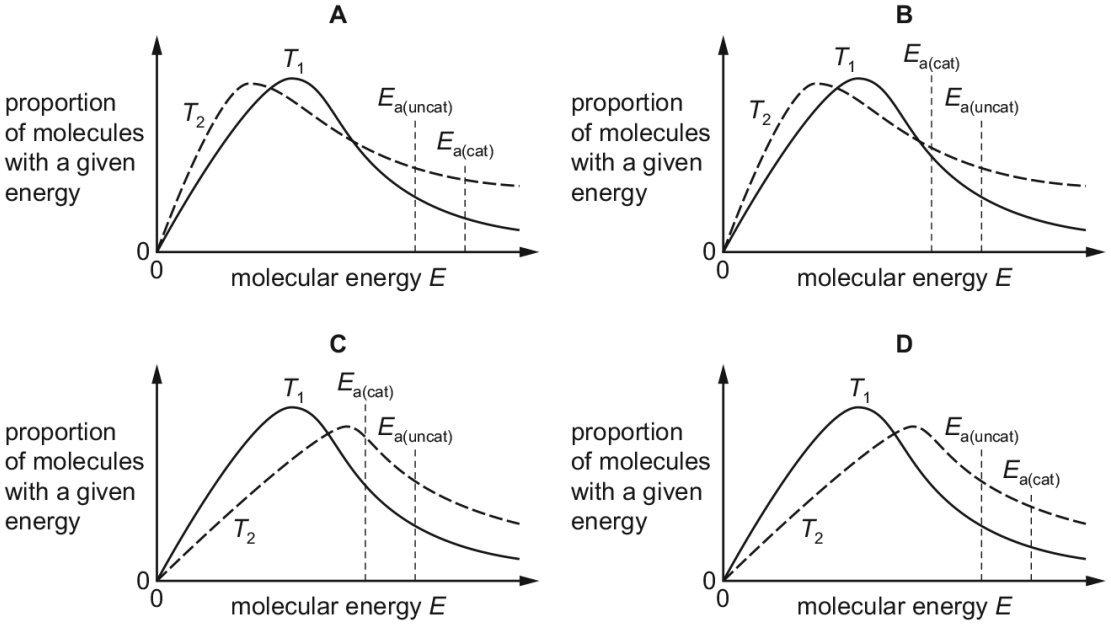
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445. 9701_w17_qp_11 Q: 10

The diagram shows the distribution of molecular energies in a sample of gas at a temperature T_1. The activation energy for an uncatalysed reaction of this gas, $E_{a(uncat)}$, is shown.



Which diagram correctly shows the new distribution and new activation energy, $E_{a(cat)}$, when the temperature is increased to T_2, and a catalyst is used that increases the rate of the reaction?



---

446. 9701_w17_qp_12 Q: 11

Which change alters the activation energy of a given reaction?

A adding a suitable catalyst

B changing the particle size of the reactants

C changing the pressure at which the reaction is carried out

D changing the temperature at which the reaction is carried out

---

447. 9701_s16_qp_11 Q: 11

Enzymes are biological catalysts. Many enzymes show specificity. An example of an enzyme which shows specificity is glucokinase. Glucokinase is involved in the metabolism of glucose.

What does specificity mean in this context?

A Glucokinase is most effective as a catalyst over a narrow pH range.

B Glucokinase is most effective as a catalyst over a narrow range of temperatures.

C Glucokinase only operates on a narrow range of substrate molecules.

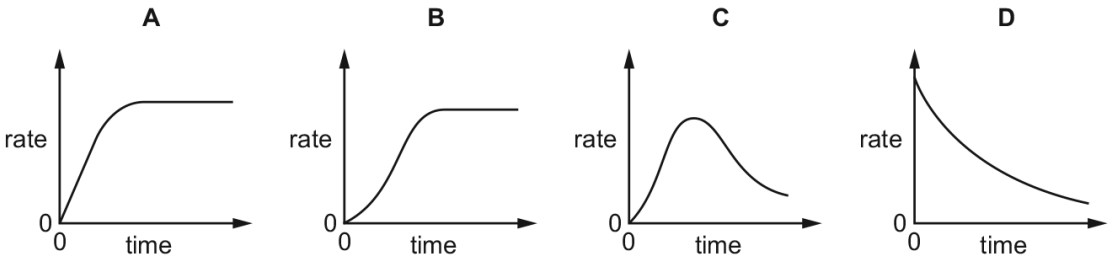
D Glucokinase provides an alternative route for the reactions it catalyses.

---

448. 9701_w16_qp_11 Q: 11

An autocatalytic reaction is a reaction in which one of the products catalyses the reaction.

Which curve would be obtained if the rate of an autocatalytic reaction is plotted against time?

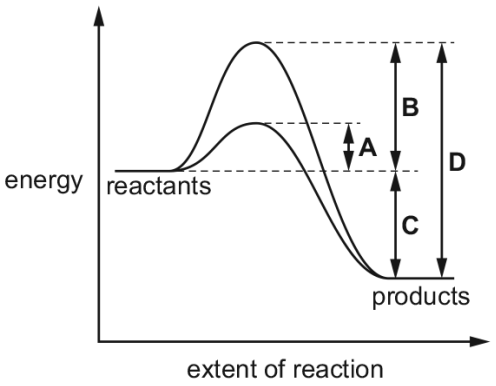


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449. 9701_w16_qp_12 Q: 2

The diagram shows the pathways of a reaction, with and without a catalyst.

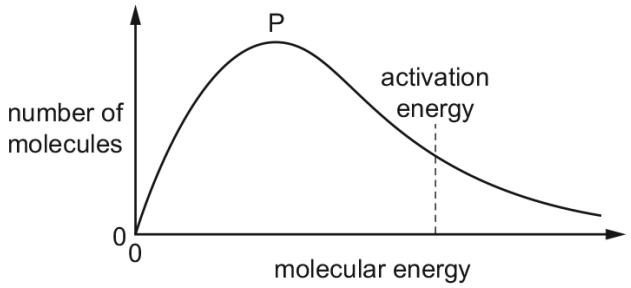
Which letter represents the overall energy change for the reaction?



---

450. 9701_s15_qp_11 Q: 1

The diagram shows a Boltzmann distribution of molecular energies for a gaseous mixture. The distribution has a peak, labelled P on the diagram.



What happens when an effective catalyst is added to the mixture?

A The height of the peak decreases and the activation energy moves to the right.

B The height of the peak decreases and the activation energy moves to the left.

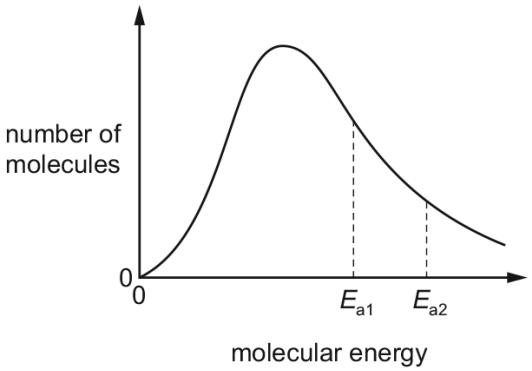
C The height of the peak remains the same and the activation energy moves to the right.

D The height of the peak remains the same and the activation energy moves to the left.

---

451. 9701_s15_qp_13 Q: 1

The diagram shows the Boltzmann energy distribution curve for molecules of a mixture of two gases at a given temperature. For a reaction to occur the molecules must collide together with sufficient energy.



E_a is used to represent the activation energy for the reaction between the gases. Of the two values shown, one is the activation energy for a catalysed reaction, the other for an uncatalysed reaction.

Which statement about $\boldsymbol{E_{a1}}$ is correct?

A E_{a1} corresponds to a catalysed reaction with fewer effective collisions than the uncatalysed reaction.

B E_{a1} corresponds to an uncatalysed reaction with fewer effective collisions than the catalysed reaction.

C E_{a1} corresponds to a catalysed reaction with a greater number of effective collisions than the uncatalysed reaction.

D E_{a1} corresponds to an uncatalysed reaction with a greater number of effective collisions than the catalysed reaction.

Chapter 8

Reaction kinetics

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8.1 Effect of temperature: on reaction rates, rate constants; activation energy

32. 9701_m21_qp_22 Q: 1

The rate of chemical reactions is affected by changes in temperature and pressure.

(a) (i) Draw a curve on the axes to show the Boltzmann distribution of energy of particles in a sample of gaseous krypton atoms at a given temperature.

Label the curve **T1** and label the axes.



[2]

(ii) On the diagram in **(a)(i)**, draw a second curve to show the distribution of energies of the krypton atoms at a higher temperature.

Label the second curve **T2**. [1]

(b) The Boltzmann distribution assumes that the particles behave as an ideal gas.

(i) State **two** assumptions of the kinetic theory as applied to an ideal gas.

1 .....

.....

2 .....

.....

[2]

(ii) 2.00 g of krypton gas, Kr(g), is placed in a sealed 5.00 dm^3 container at 120 °C.

Calculate the pressure, in Pa, of Kr(g) in the container.
Assume Kr(g) behaves as an ideal gas.

Show your working.

pressure = ... Pa [3]

(iii) State and explain the conditions at which krypton behaves most like an ideal gas.

.....

.....

.....

..... [2]

(c) Krypton reacts with fluorine in the presence of ultraviolet light to make krypton difluoride, $KrF_2(g)$.

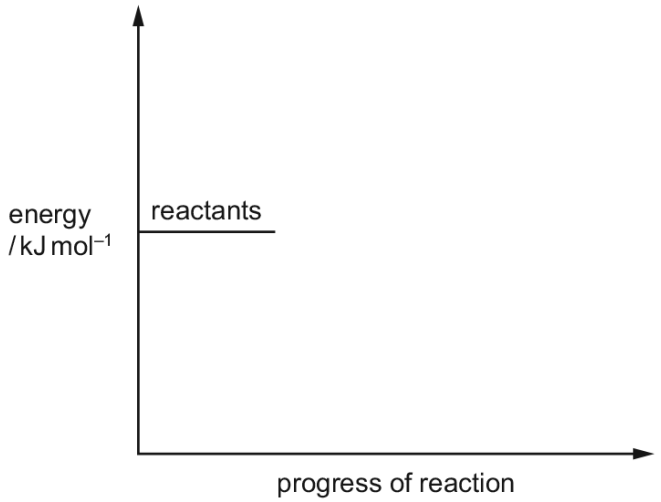
$$Kr(g) + F_2(g) \rightarrow KrF_2(g)$$

activation energy for the reaction, $E_a = +385\,kJ\,mol^{-1}$

enthalpy change of formation of KrF_2, $\Delta H_f = +60.2\,kJ\,mol^{-1}$

(i) Use this information to complete the reaction profile diagram for the formation of KrF_2. Label E_a and ΔH_f on the diagram.

Assume the reaction proceeds in one step.



[2]

(ii) Explain, in terms of activation energy, E_a, and the collision of particles, how an increase in temperature affects the rate of a chemical reaction.

.....

.....

.....

..... [2]

[Total: 14]

33. 9701_s17_qp_22 Q: 3

The hydrogen halides, HC*l*, HBr and HI, can undergo thermal decomposition.
In a sealed container an equilibrium is established according to the equation shown.

$$2HX(g) \rightleftharpoons H_2(g) + X_2(g) \qquad \text{(where X = C}l\text{, Br or I)}$$

(a) Some bond energies are shown in the table.

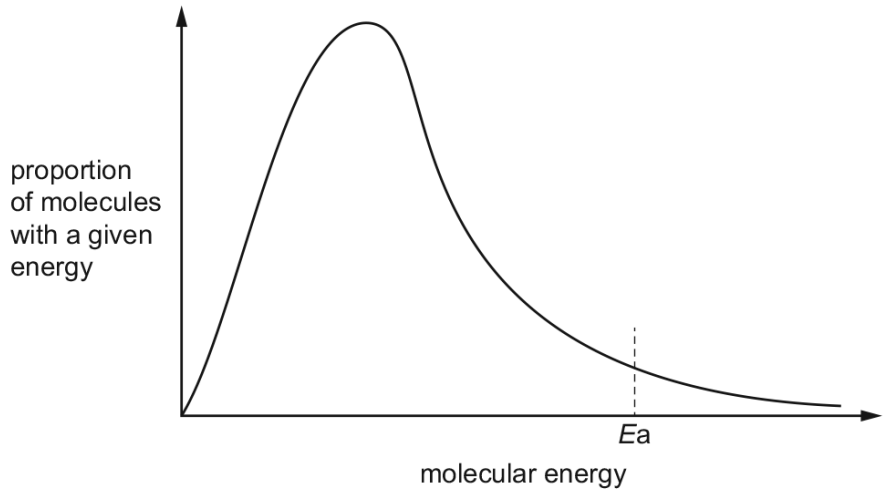
	bond energy / kJ mol^{-1}
H–Br	366
H–H	436
Br–Br	193

Use these data to calculate a value for the enthalpy change, ΔH, for the thermal decomposition of hydrogen bromide, HBr, according to the equation shown.

ΔH = ... kJ mol^{-1} [1]

(b) At a temperature of 700 K a sample of HBr is approximately 10% decomposed. Changing the temperature affects both the rate of decomposition of HBr and the percentage that decomposes.

The Boltzmann distribution for a sample of HBr at 700 K is shown. *E*a represents the activation energy for the reaction.



(i) Using the same axes, sketch a second curve to indicate the Boltzmann distribution at a higher temperature. [2]

(ii) With reference to the curves, state and explain the effect of increasing temperature on the **rate** of decomposition of HBr.

.....

.....

.....

..... [3]

(iii) The decomposition of HBr is endothermic.

State the effect of increasing temperature on the **percentage** of HBr that decomposes. Use Le Chatelier's principle to explain your answer.

.....

.....

.....

..... [3]

(iv) At 700 K HBr is approximately 10% decomposed but hydrogen iodide, HI, is approximately 20% decomposed.

Explain this difference with reference to bond strengths and the factors that affect them.

.....

.....

.....

..... [3]

(c) At temperatures above 1500 K, HCl will decompose.

A sample of 0.300 mol of HCl decomposed in a sealed container.

The resulting equilibrium mixture was found to contain 1.50×10^{-2} mol of Cl_2.

(i) Calculate the amounts, in mol, of H_2 and HCl present in the equilibrium mixture.

H_2 = ... mol

HCl = ... mol
[2]

(ii) Calculate the mole fraction of each gas in the equilibrium mixture.

mole fraction of HCl = ...

mole fraction of H_2 = ...

mole fraction of Cl_2 = ...
[1]

(d) In another experiment under different conditions, an equilibrium mixture was produced with mole fractions for each species as shown.

species	mole fraction
HCl	0.88
H_2	0.06
Cl_2	0.06

(i) Write the expression for the equilibrium constant, K_p, for the decomposition of HCl.

$$2HCl(g) \rightleftharpoons H_2(g) + Cl_2(g)$$

K_p =

[1]

(ii) Explain why the total pressure of the system does **not** need to be known for K_p to be calculated for this experiment.

.....

..... [1]

(iii) Calculate the value of K_p for this experiment.

K_p = ... [1]

[Total: 18]

34. 9701_w17_qp_21 Q: 1

Ammonia, NH_3, is manufactured from nitrogen and hydrogen by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\,kJ\,mol^{-1}$$

(a) Some bond energies are given.

N≡N = 944 kJ mol^{-1}
H–H = 436 kJ mol^{-1}

(i) Explain the meaning of the term *bond energy*.

.....

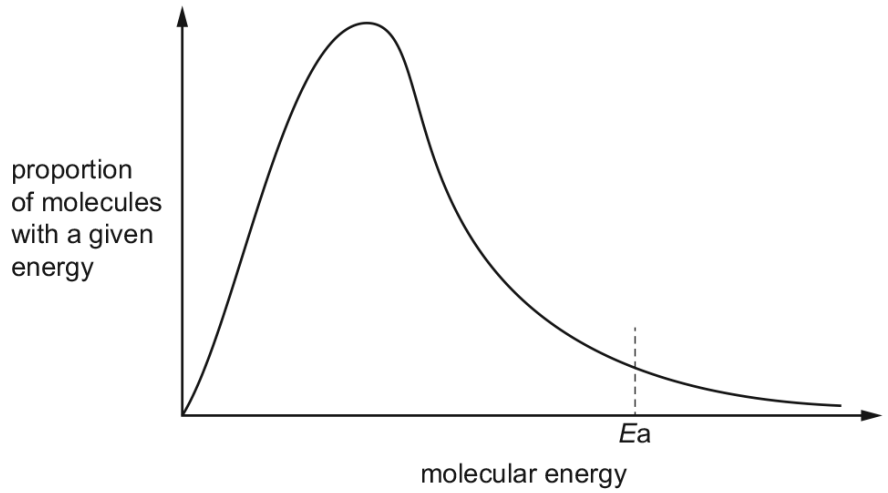
..... [2]

(ii) Use the data to calculate a value for the N–H bond energy.
You must show your working.

N–H bond energy = ... kJ mol^{-1} [2]

(b) The Haber process is usually carried out at a temperature of approximately 400 °C in the presence of a catalyst. Changing the temperature affects both the rate of production of ammonia and the yield of ammonia.

The Boltzmann distribution for a mixture of nitrogen and hydrogen at 400 °C is shown.
*E*a represents the activation energy for the reaction.



(i) Using the same axes, sketch a second curve to indicate the Boltzmann distribution at a higher temperature. [2]

(ii) **With reference to the Boltzmann distribution**, state and explain the effect of increasing temperature on the rate of production of ammonia.

.....

.....

.....

..... [3]

(iii) State and explain the effect of increasing temperature on the yield of ammonia.
Use Le Chatelier's principle to explain your answer.

.....

.....

.....

..... [3]

(c) At a pressure of 2.00×10^7 Pa, 1.00 mol of nitrogen, $N_2(g)$, was mixed with 3.00 mol of hydrogen, $H_2(g)$. The final equilibrium mixture formed contained 0.300 mol of ammonia, $NH_3(g)$.

(i) Calculate the amounts, in mol, of $N_2(g)$ and $H_2(g)$ in the equilibrium mixture.

$N_2(g)$ = ... mol

$H_2(g)$ = ... mol
[2]

(ii) Calculate the partial pressure of ammonia, pNH_3, in the equilibrium mixture.

Give your answer to **three** significant figures.

pNH_3 = ... Pa [3]

(d) In another equilibrium mixture the partial pressures are as shown.

substance	partial pressure / Pa
$N_2(g)$	2.20×10^6
$H_2(g)$	9.62×10^5
$NH_3(g)$	1.40×10^4

(i) Write the expression for the equilibrium constant, K_p, for the production of ammonia from nitrogen and hydrogen.

K_p =

[1]

(ii) Calculate the value of K_p for this reaction.

State the units.

K_p = ...

units = ...

[2]

(iii) This reaction is repeated with the same starting amounts of nitrogen and hydrogen. The same temperature is used but the container has a smaller volume.

State the effects, if any, of this change on the yield of ammonia and on the value of K_p.

effect on yield of ammonia .....

effect on value of K_p .....

[2]

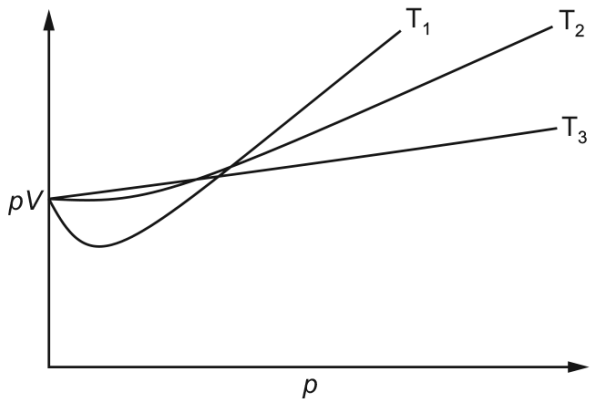
[Total: 22]

8.2 Homogeneous and heterogeneous catalysts including enzymes

35. 9701_S15_qp_21 Q: 2

The relationship $pV = nRT$ can be derived from the laws of mechanics by assuming ideal behaviour for gases.

(a) The graph represents the relationship between pV and p for a real gas at three different temperatures, T_1, T_2 and T_3.



(i) Draw **one** line on the graph to show what the relationship should be for the same amount of an **ideal** gas. [1]

(ii) State and explain, with reference to the graph, which of T_1, T_2 or T_3 is the lowest temperature.

.....

..... [1]

(iii) Explain your answer to **(ii)** with reference to intermolecular forces.

.....

..... [1]

(iv) State and explain the effect of pressure on the extent to which a gas deviates from ideal behaviour.

.....

.....

.....

..... [2]

(b) A flask with a volume of 100 cm^3 was first weighed with air filling the flask, and then with another gas, **Y**, filling the flask. The results, measured at 26 °C and 1.00×10^5 Pa, are shown.

Mass of flask containing air = 47.930 g

Mass of flask containing **Y** = 47.989 g

Density of air = 0.00118 g cm^{-3}

Calculate the relative molecular mass, M_r, of **Y**.

M_r of **Y** = ... [4]

(c) Although nitrogen gas makes up about 79% of the atmosphere it does not easily form compounds.

(i) Explain why nitrogen is so unreactive.

.....

..... [1]

(ii) Explain why the conditions in a car engine lead to the production of oxides of nitrogen.

.....

..... [1]

(iii) Give an equation for a reaction involved in the removal of nitrogen monoxide, NO, from a car's exhaust gases, in the catalytic converter.

..... [1]

One of the main reasons for reducing the amounts of oxides of nitrogen in the atmosphere is their contribution to the formation of acid rain.

(iv) Write an equation for the formation of nitric acid from nitrogen dioxide, NO_2, in the atmosphere.

..... [1]

(v) Write equations showing the catalytic role of nitrogen monoxide, NO, in the oxidation of atmospheric sulfur dioxide, SO_2.

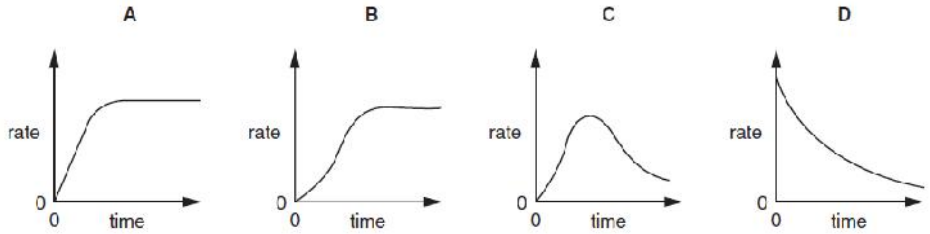
.....

..... [2]

[Total: 15]

1.

Which curve is obtained if the rate of reaction is plotted against time for an autocatalytic reaction (i.e. a reaction in which one of the products catalyses the reaction)?



[2002 M/J (11)]

2.

A piece of zinc foil dissolved completely in 20 cm^3 of a dilute sulphuric acid solution and the volume of hydrogen evolved was noted at equal, short time intervals. Another piece of zinc foil of the same surface area and mass was added to 40 cm^3 of the same solution of dilute sulphuric acid.

How will the initial rate of reaction and the total volume of hydrogen evolved in this second experiment compare to the first experiment?

	initial rate of reaction	*total volume of hydrogen evolved*
A	no change	decrease
B	no change	no change
C	increase	no change
D	increase	increase

[2002 O/N (12)]

3.

It is often said that the rate of a typical reaction is roughly doubled by raising the temperature by 10 °C.

What explains this observation?

A Raising the temperature by 10 °C doubles the average energy of each molecule.

B Raising the temperature by 10 °C doubles the average velocity of the molecules.

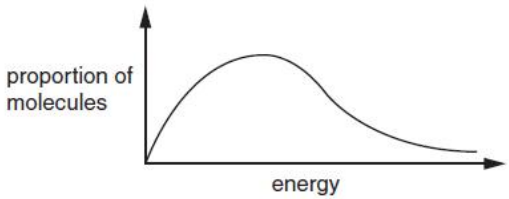
C Raising the temperature by 10 °C doubles the number of molecular collisions in a given time.

D Raising the temperature by 10 °C doubles the number of molecules having more than a certain minimum energy.

[2003 M/J (12)]

4.

The diagram represents the Boltzmann distribution of molecular energies at a given temperature.



As temperature increases, which statements are correct?

1 The maximum of the curve is displaced to the right.

2 The proportion of molecules with energies **above** any given value increases.

3 The proportion of molecules **with** any given energy increases.

[2003 O/N (33)]

5.

Which statements about the properties of a catalyst are correct?

1 A catalyst increases the average kinetic energy of the reacting particles.

2 A catalyst increases the rate of the reverse reaction.

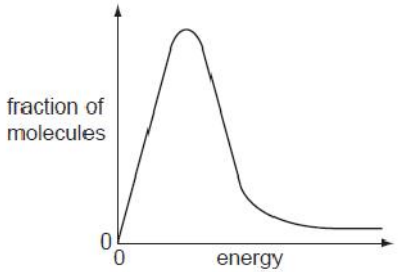
3 A catalyst has no effect on the enthalpy change $\Delta H^{\ominus}$ of the reaction.

[2004 M/J (33)]

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6.

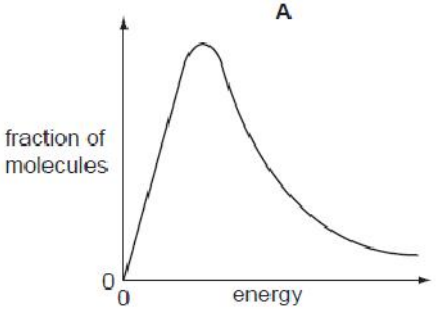
The diagram shows the Boltzmann distribution for air at room temperature.



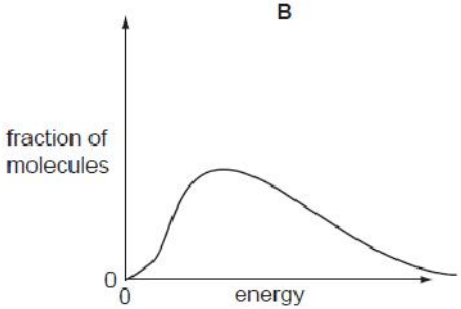
Air inside a car engine can reach a temperature of about 500 °C, enabling nitrogen to react with oxygen to form nitrogen oxides.

What would be the Boltzmann distribution for the air inside this car engine?

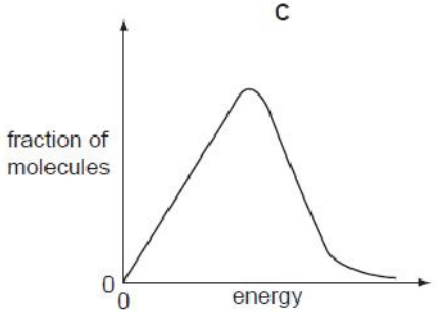
A



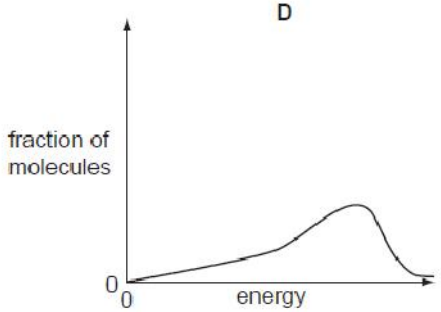
B



C



D



[2004 O/N (12)]

7.

What factors can affect the value of the activation energy of a reaction?

1 the presence of a catalyst

2 changes in temperature

3 changes in concentration of the reactants

[2004 O/N (33)]

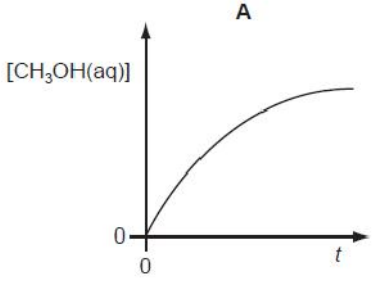
8.

The reaction represented by the following equation was carried out.

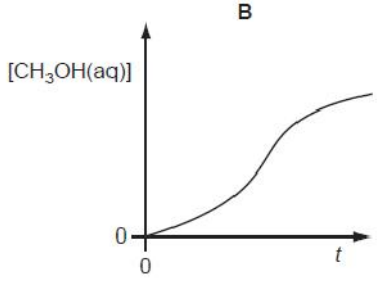
$$HCO_2CH_3(aq) + NaOH(aq) \rightarrow HCO_2Na(aq) + CH_3OH(aq)$$

Which graph best shows the relationship between $[CH_3OH(aq)]$ and t, the time from mixing of the reactants?

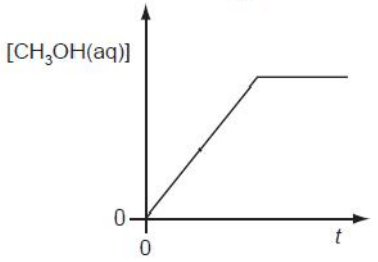
A



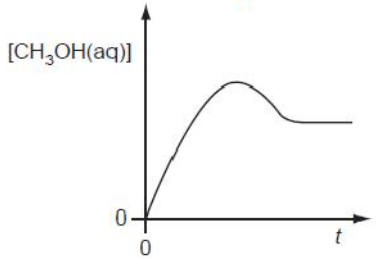
B



C



D



[2005 M/J (11)]

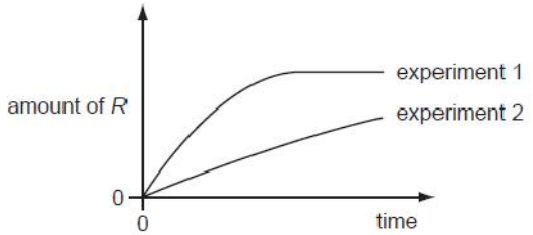
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9.

The stoichiometry of a catalysed reaction is shown by the equation below.

$$P(g) + Q(g) \rightleftharpoons R(g) + S(g)$$

Two experiments were carried out in which the production of R was measured against time. The results are shown in the diagram below.



Which changes in the conditions from experiment 1 to experiment 2 might explain the results shown?

1 Less of P was used.

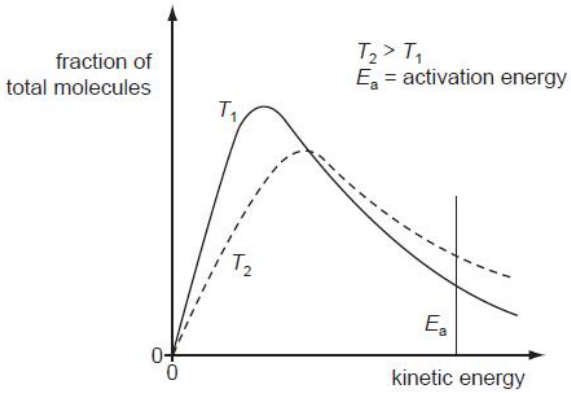
2 A different catalyst was used.

3 Product S was continuously removed from the reaction vessel.

[2005 M/J (34)]

10.

The distribution of molecular kinetic energies within a gas at temperature T_1 and T_2 are shown in the diagram.



Which statement correctly explains why a small increase in temperature leads to a significant increase in the rate of a gaseous reaction?

A The frequency of collisions between molecules is greater at a higher temperature.

B The activation energy of the reaction is less when the gases are at a higher temperature.

C The frequency of collisions between molecules with kinetic energy greater than the activation energy is greater at higher temperature.

D The proportion of molecules with more kinetic energy than the activation energy is lower at a higher temperature.

[2005 O/N (11)]

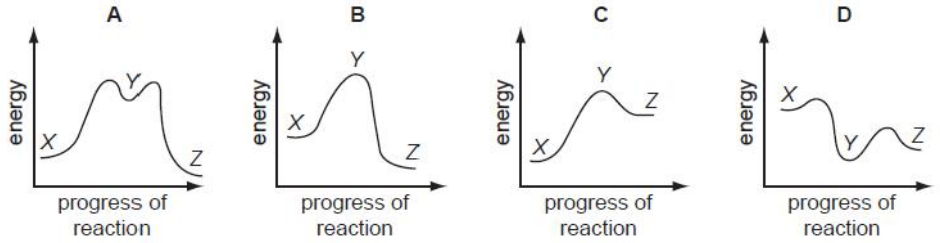
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11.

In the conversion of compound *X* into compound *Z*, it was found that the reaction proceeded by way of compound *Y*, which could be isolated. The following steps were involved.

$X \rightarrow Y$; ΔH, positive
$Y \rightarrow Z$; ΔH, negative

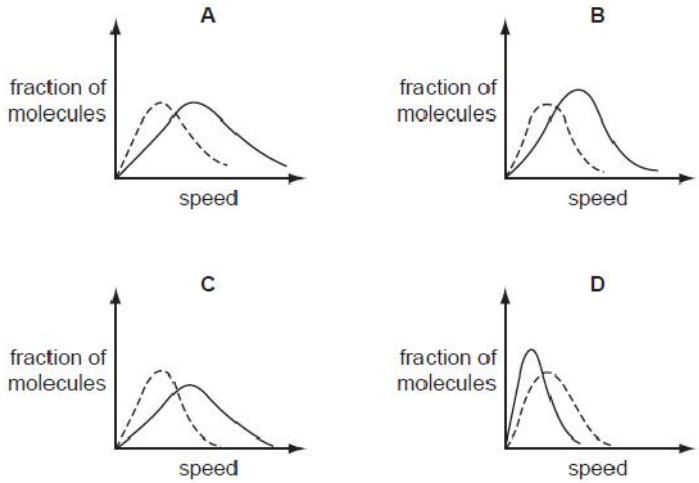
Which reaction profile fits these data?



[2006 M/J (8)]

12.

Which solid-line curve most accurately represents the distribution of molecular speeds in a gas at 500K if the dotted-line curve represents the corresponding distribution for the same gas at 300K?

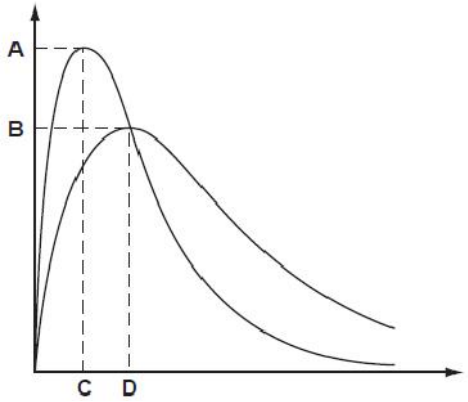


[2006 M/J (12)]

13.

The diagram shows the Maxwell-Boltzmann energy distribution curves for molecules of a sample of a gas at two different temperatures.

Which letter on the axes represents the most probable energy of the molecules at the lower temperature?



[2006 O/N (12)]

14.

A reversible reaction is catalysed.

Which statements about the effects of the catalyst on this system are correct?

1 The catalyst alters the mechanism of the reaction.

2 The catalyst reduces the energy of activation (the energy barrier) for both the forward and the backward reaction.

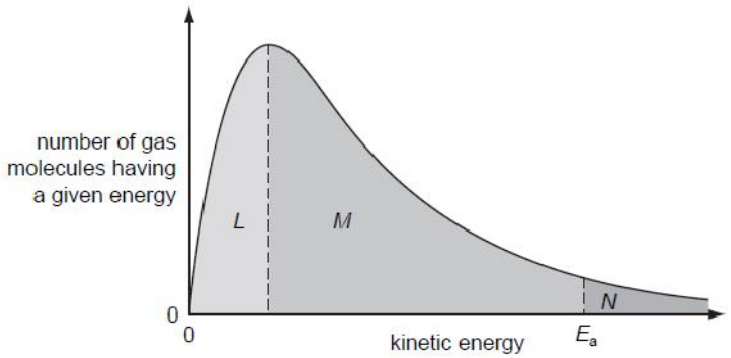
3 The catalyst alters the composition of the equilibrium mixture.

[2006 O/N (33)]

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15.

The Boltzmann distribution shows the number of molecules having a particular kinetic energy at constant temperature.



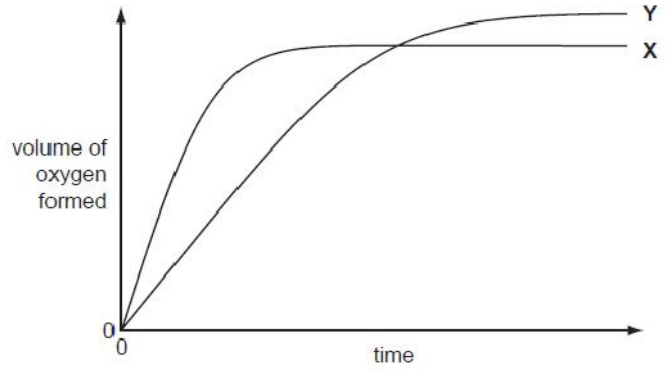
If the temperature is decreased by 10 °C, what happens to the size of the areas labelled *L*, *M* and *N*?

	L	*M*	*N*
A	decreases	decreases	decreases
B	decreases	increases	decreases
C	increases	decreases	decreases
D	increases	decreases	increases

[2007 M/J (10)]

16.

In the diagram, curve **X** was obtained by observing the decomposition of 100 cm^3 of 1.0 mol dm^{-3} hydrogen peroxide, catalysed by manganese(IV) oxide.



Which alteration to the original experimental conditions would produce curve **Y**?

A adding water

B adding some 0.1 mol dm^{-3} hydrogen peroxide

C using less manganese(IV) oxide

D lowering the temperature

[2007 M/J (11)]

17.

Many crude oils contain sulphur as H_2S. During refining, by the Claus process, the H_2S is converted into solid sulphur, which is then removed.

reaction I $2H_2S(g) + 3O_2(g) \rightarrow 2H_2O(l) + 2SO_2(g)$

reaction II $2H_2S(g) + SO_2(g) \rightarrow 2H_2O(l) + 3S(s)$

Which statements about the Claus process are correct?

1 H_2S is oxidised in reaction I.

2 SO_2 oxidises H_2S in reaction II.

3 SO_2 behaves as a catalyst.

[2007 M/J (33)]

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18.
It is often said that the rate of a typical reaction is roughly doubled by raising the temperature by 10 °C.

What explains this observation?

A Raising the temperature by 10 °C doubles the average kinetic energy of each molecule.

B Raising the temperature by 10 °C doubles the average velocity of the molecules.

C Raising the temperature by 10 °C doubles the number of molecular collisions in a given time.

D Raising the temperature by 10 °C doubles the number of molecules having more than a certain minimum energy.

[2007 O/N (11)]

19.
Which statements are correct about the activation energy of a reaction?

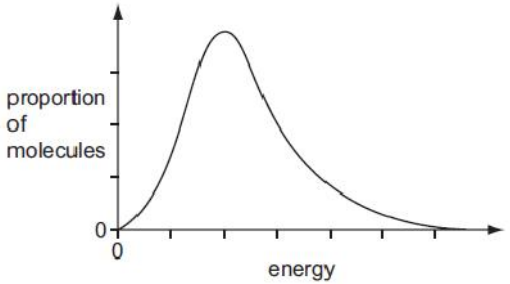
1 It is different for the forward and back reactions in an exothermic process.

2 It is low for a reaction that takes place slowly.

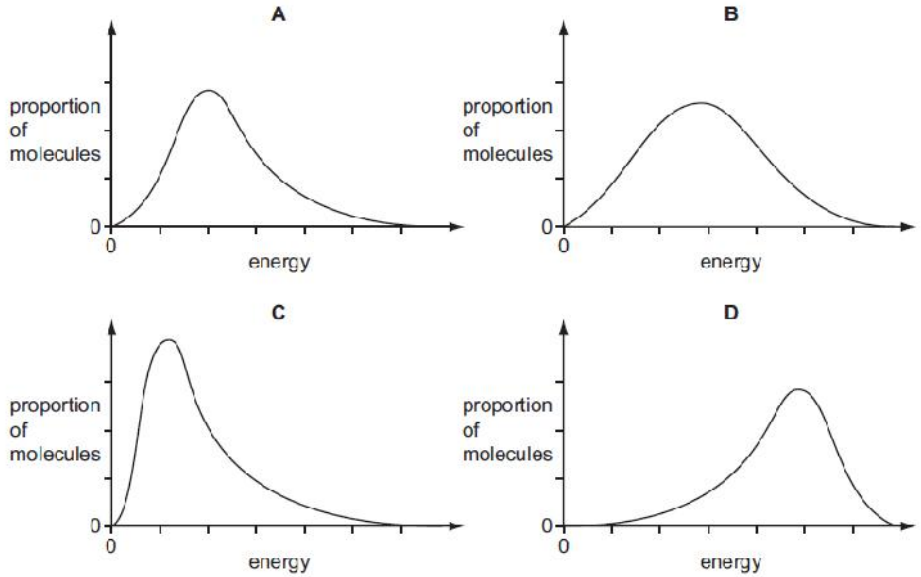
3 It is unaffected by the presence of a catalyst.

[2007 O/N (34)]

20.
The molecular energy distribution curve represents the variation in energy of the molecules of a gas at room temperature.



Which curve applies for the same gas at a lower temperature?



[2008 M/J (12)]

21.
Which statements about the properties of a catalyst are correct?

1 A catalyst increases the average kinetic energy of the reacting particles.

2 A catalyst increases the rate of the reverse reaction.

3 A catalyst has no effect on the enthalpy change of the reaction.

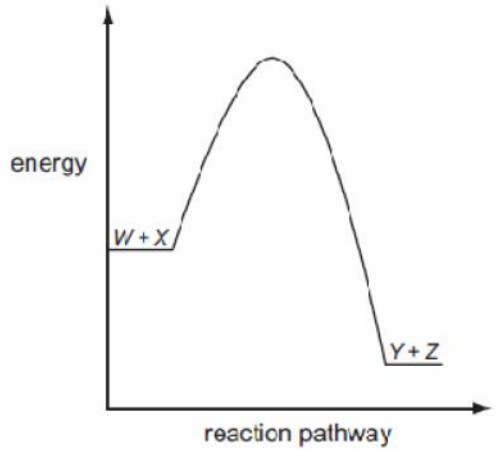
[2008 M/J (33)]

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22.

The diagram represents the reaction pathway for the following reaction.

$W(g) + X(g) \rightarrow Y(g) + Z(g)$



What statement can be made about the reverse reaction, $Y(g) + Z(g) \rightarrow W(g) + X(g)$?

A It will have a larger activation energy and a positive ΔH.

B It will have a larger activation energy and a negative ΔH.

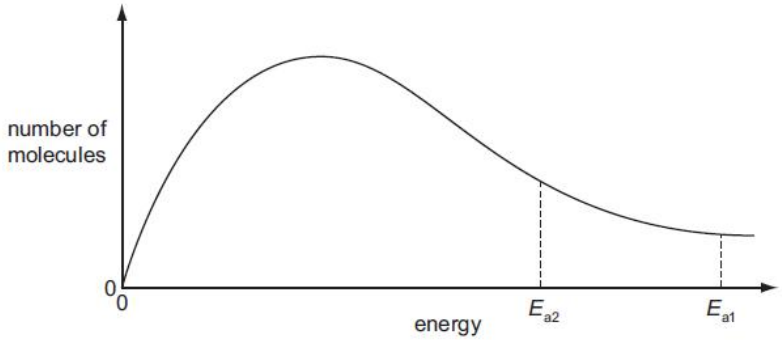
C It will have a smaller activation energy and a positive ΔH.

D It will have a smaller activation energy and a negative ΔH.

[2008 O/N (9)]

23.

The diagram shows the Maxwell-Boltzmann energy distribution curve for molecules of a mixture of two gases at a given temperature. For a reaction to occur the molecules must collide together with sufficient energy.



E_a is the activation energy for the reaction between the gases. Of the two values shown, one is for a catalysed reaction, the other for an uncatalysed one.

Which pair of statements is correct when a catalyst is used?

A	E_{a1}	catalysed reaction fewer effective collisions	E_{a2}	uncatalysed reaction more effective collisions
B	E_{a1}	uncatalysed reaction fewer effective collisions	E_{a2}	catalysed reaction more effective collisions
C	E_{a1}	catalysed reaction more effective collisions	E_{a2}	uncatalysed reaction fewer effective collisions
D	E_{a1}	uncatalysed reaction more effective collisions	E_{a2}	catalysed reaction fewer effective collisions

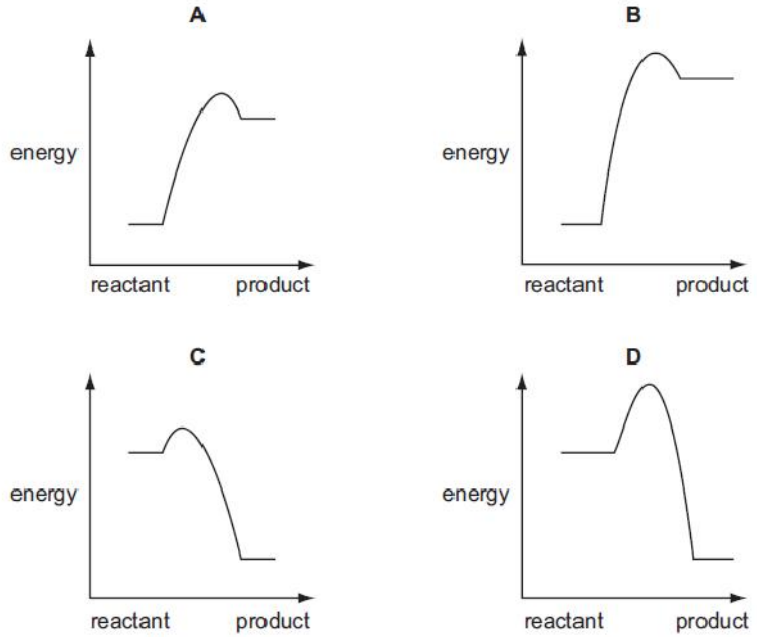
[2009 M/J (10)]

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24.
Four reactions of the type shown are studied at the same temperature.

$$X(g) + Y(g) \rightarrow Z(g)$$

Which is the correct reaction pathway diagram for the reaction that would proceed **most** rapidly and with the **highest** yield?



[2009 O/N-11 (10)]

25.
Why does a mixture of hydrogen gas and bromine gas react together faster at a temperature of 500 K than it does at a temperature of 400 K?

1 A higher proportion of effective collisions occurs at 500 K.

2 Hydrogen molecules and bromine molecules collide more frequently at 500 K.

3 The activation energy of the reaction is lower at 500 K.

[2009 O/N-11 (34)]

26.
$Na_2S_2O_3$ reacts with dilute HC*l* to give a pale yellow precipitate. If 1 cm^3 of 0.1 mol dm^{-3} HC*l* is added to 10 cm^3 of 0.02 mol dm^{-3} $Na_2S_2O_3$ the precipitate forms slowly.

If the experiment is repeated with 1 cm^3 of 0.1 mol dm^{-3} HC*l* and 10 cm^3 of 0.05 mol dm^{-3} $Na_2S_2O_3$ the precipitate forms more quickly.

Why is this?

A The activation energy of the reaction is lower when 0.05 mol dm^{-3} $Na_2S_2O_3$ is used.

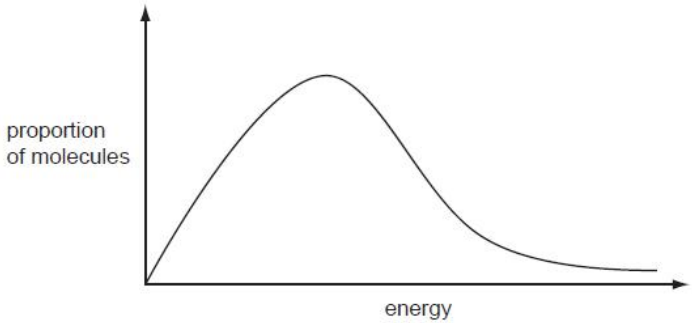
B The reaction proceeds by a different pathway when 0.05 mol dm^{-3} $Na_2S_2O_3$ is used.

C The collisions between reactant particles are more violent when 0.05 mol dm^{-3} $Na_2S_2O_3$ is used.

D The reactant particles collide more frequently when 0.05 mol dm^{-3} $Na_2S_2O_3$ is used.

[2010 M/J-11 (12)]

27.
The diagram represents the Boltzmann distribution of molecular energies at a given temperature.



Which of the factors that affect the rate of a reaction can be explained using such a Boltzmann distribution?

1 increasing the concentration of reactants

2 increasing the temperature

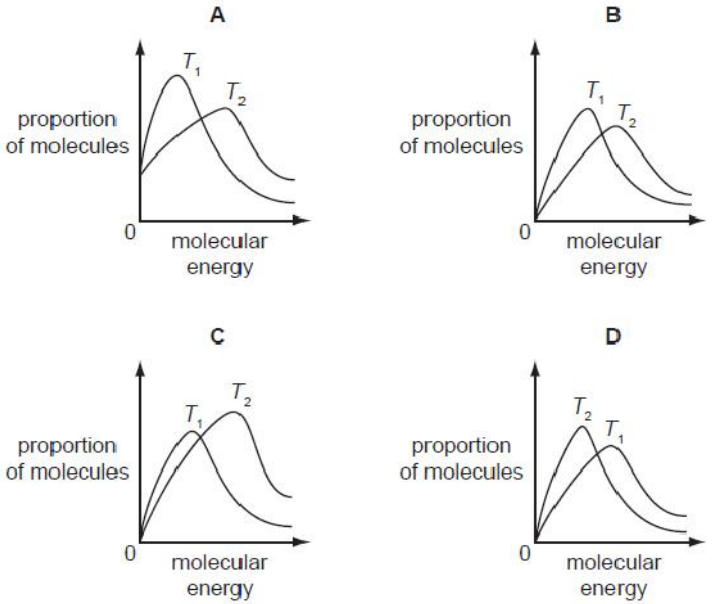
3 the addition of a catalyst

[2010 O/N-11 (32)]

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28.

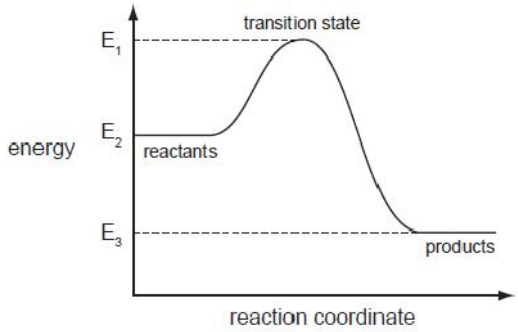
Which diagram correctly represents the Boltzmann distribution of molecular energies at two temperatures T_1 and T_2, where $T_1 = 300\,K$ and $T_2 = 310\,K$?



[2010 O/N-12 (2)]

29.

The reaction pathway diagram below illustrates the energies of reactants, products and the transition state of a reaction.



Which expression represents the activation energy of the forward reaction?

A $E_1 - E_2$ **B** $E_1 - E_3$ **C** $E_2 - E_3$ **D** $(E_1 - E_2) - (E_2 - E_3)$

[2010 O/N-12 (6)]

30.

A student puts 10 cm^3 of 0.100 mol dm^{-3} sulfuric acid into one test-tube and 10 cm^3 of 0.100 mol dm^{-3} ethanoic acid into another test-tube. He then adds 1.0 g (an excess) of magnesium ribbon to each test-tube and takes suitable measurements. Both acids have the same starting temperature.

Neither reaction is complete after 2 minutes, but both are complete after 20 minutes.

Which statements are correct?

1 After 2 minutes, the sulfuric acid is at a higher temperature than the ethanoic acid.

2 After 2 minutes, the sulfuric acid has produced more gas than the ethanoic acid.

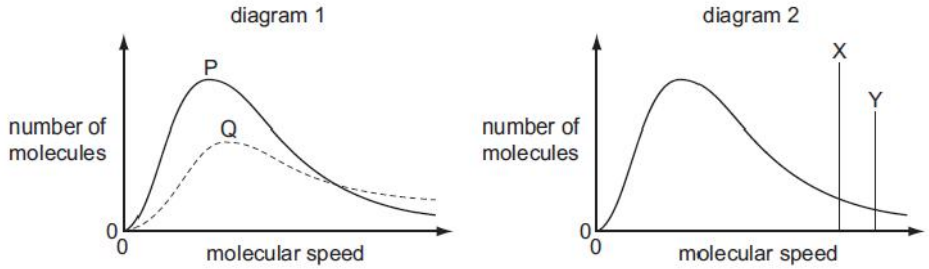
3 After 20 minutes, the sulfuric acid has produced more gas than the ethanoic acid.

[2010 O/N-12 (34)]

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31.

Different Boltzmann distributions are shown in the diagrams.



In diagram 1, one curve P or Q corresponds to a temperature higher than that of the other curve.

In diagram 2, one line X or Y corresponds to the activation energy for a catalysed reaction and the other line corresponds to the activation energy of the same reaction when uncatalysed.

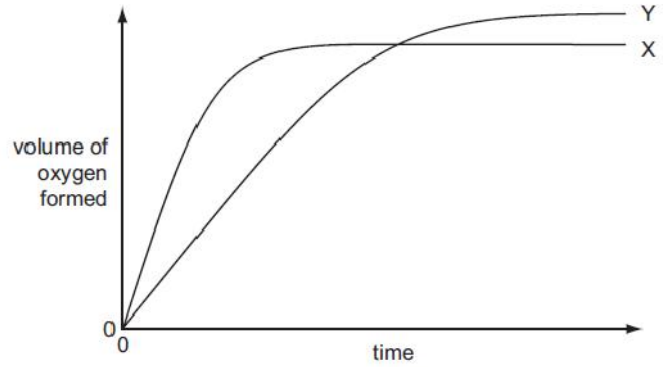
Which combination gives the correct curve and line?

	higher temperature	presence of catalyst
A	P	X
B	P	Y
C	Q	X
D	Q	Y

[2011 M/J-11 (4)]

32.

In the diagram, curve X was obtained by observing the decomposition of 100 cm^3 of 1.0 mol dm^{-3} hydrogen peroxide, catalysed by manganese(IV) oxide.



Which alteration to the original experimental conditions would produce curve Y?

A adding some 0.1 mol dm^{-3} hydrogen peroxide

B adding water

C lowering the temperature

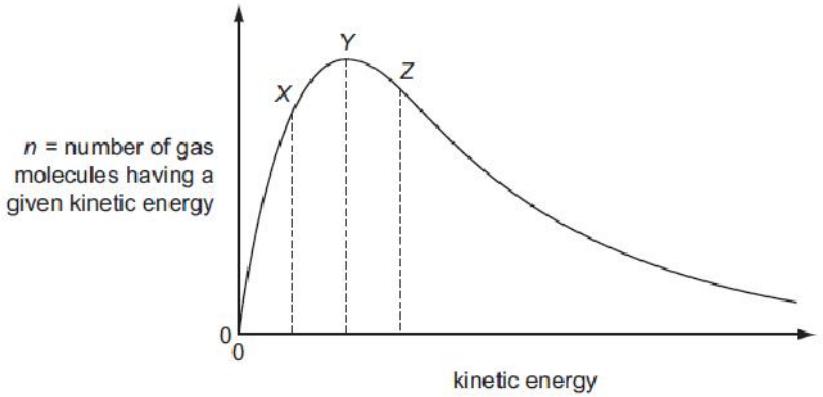
D using less manganese(IV) oxide

[2011 M/J-11 (6)]

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33.

The Boltzmann distribution for a gas at constant temperature is shown below.



If the temperature of the gas is **reduced** by 10 °C the graph changes shape.

What happens to the values of *n* for the points marked *X*, *Y* and *Z*?

	X	*Y*	*Z*
A	higher	lower	higher
B	higher	lower	lower
C	lower	higher	lower
D	lower	lower	lower

[2011 M/J-12 (6)]

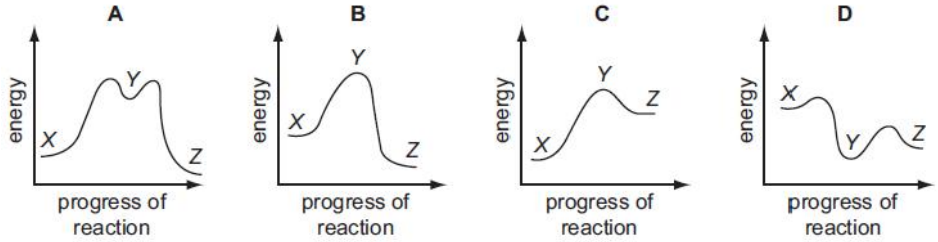
34.

In the conversion of compound *X* into compound *Z*, it was found that the reaction proceeded by way of compound *Y*, which could be isolated. The following steps were involved.

$X \rightarrow Y$; ΔH, positive

$Y \rightarrow Z$; ΔH, negative

Which reaction profile fits these data?



[2011 M/J-12 (9)]

35.

Solid calcium carbonate is added to 100 cm^3 of dilute hydrochloric acid and the rate of the reaction is measured. 100 cm^3 of distilled water is then added to a second 100 cm^3 portion of the acid, and the experiment repeated under the same conditions.

Why does the addition of water decrease the rate of the reaction?

1 Adding water reduces the frequency of collisions between reactant molecules.

2 Adding water reduces the proportion of effective collisions between reactant molecules.

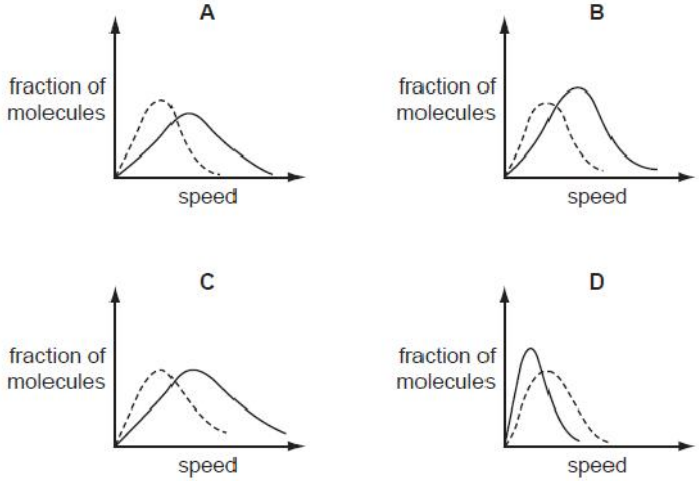
3 Adding water reduces the proportion of reactant molecules possessing the activation energy.

[2011 M/J-12 (31)]

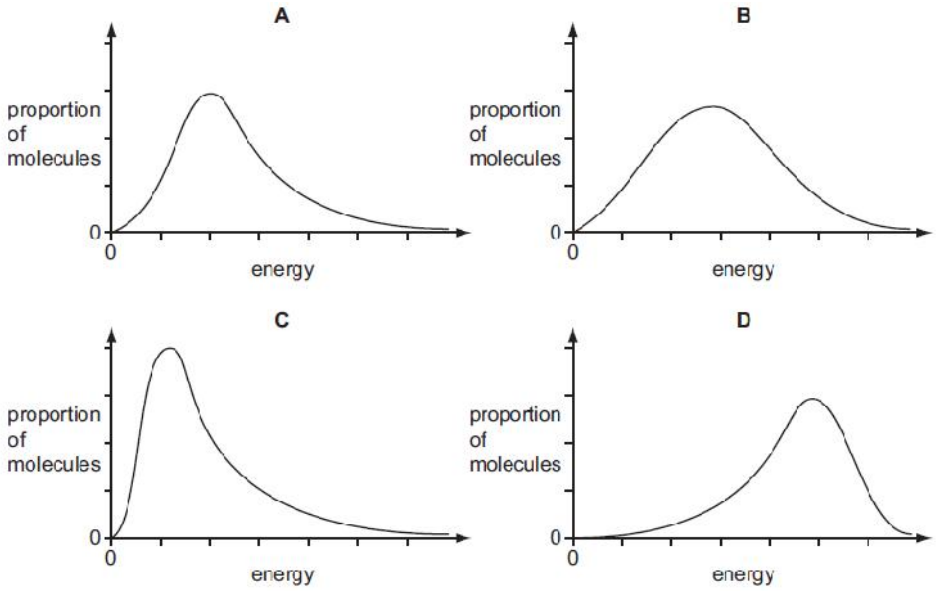
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36.

Which solid-line curve most accurately represents the distribution of molecular speeds in a gas at 500K if the dotted-line curve represents the corresponding distribution for the same gas at 300K?



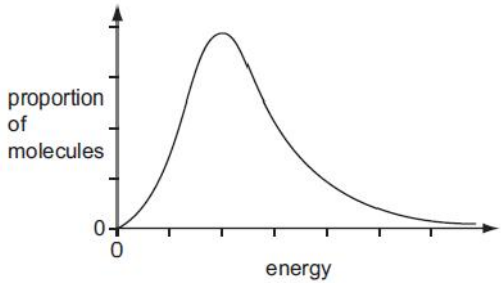
[2011 O/N-11 (11)]



[2012 M/J-12 (1)]

37.

The molecular energy distribution curve represents the variation in energy of the molecules of a gas at room temperature.



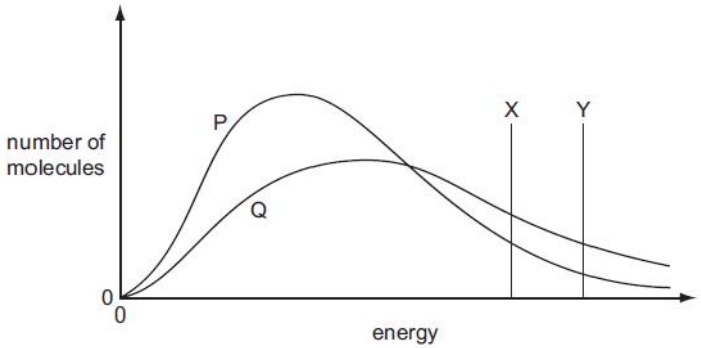
Which curve applies for the same gas at a lower temperature?

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38.

The gaseous compound Z decomposes on heating.

In the diagram below, Boltzmann distributions for Z at two different temperatures P and Q are shown. The lines X and Y indicate activation energies for the decomposition of Z with and without a catalyst.



Which curve and which line describe the decomposition of Z at a higher temperature and with a catalyst present?

	higher temperature	catalyst present
A	P	X
B	P	Y
C	Q	X
D	Q	Y

[2012 O/N-13 (8)]

39.

Why does the rate of a gaseous reaction increase when the pressure is increased at a constant temperature?

A More particles have energy that exceeds the activation energy.

B The particles have more space in which to move.

C The particles move faster.

D There are more frequent collisions between particles.

[2013 M/J-11 (8)]

40.

Which factor can affect the value of the activation energy of a reaction?

A changes in concentration of the reactants

B decrease in temperature

C increase in temperature

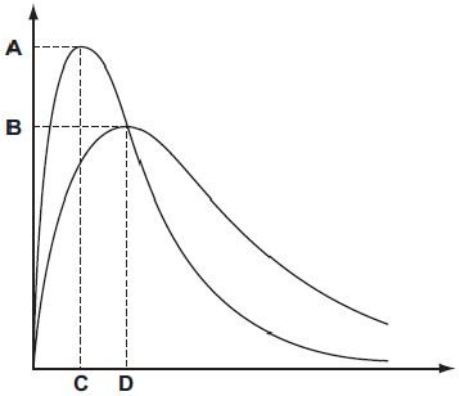
D the presence of a catalyst

[2013 M/J-12 (4)]

41.

The diagram shows the Maxwell-Boltzmann energy distribution curves for molecules of a sample of a gas at two different temperatures.

Which letter on the axes represents the most probable energy of the molecules at the **lower** temperature?

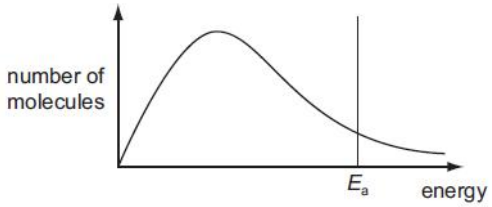


[2013 M/J-12 (5)]

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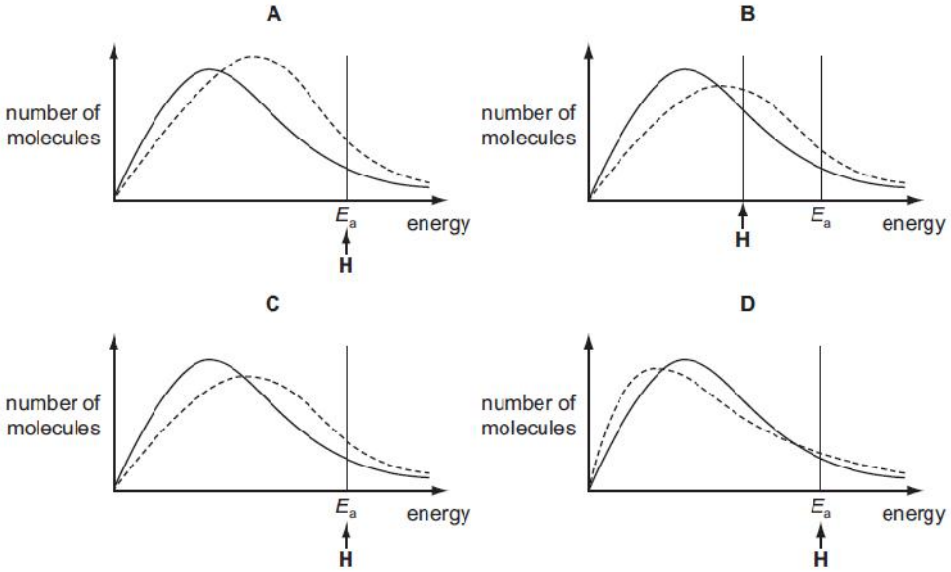
42.

The diagram represents, for a given temperature, the Boltzmann distribution of the kinetic energies of the molecules in a mixture of two gases that will react together. The activation energy for the reaction, E_a, is marked.



The dotted curves below show the Boltzmann distribution for the same reaction at a higher temperature. On these diagrams, **H** represents the activation energy at the higher temperature.

Which diagram is correct?

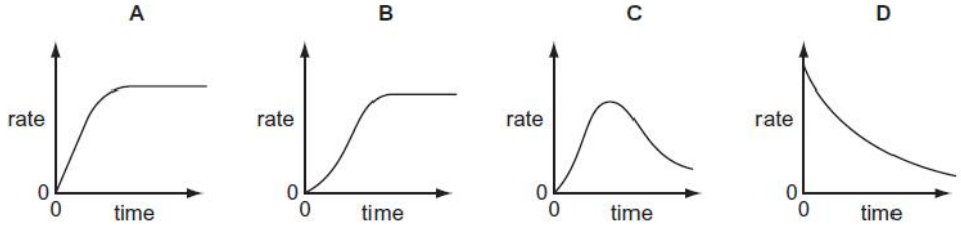


[2013 M/J-13 (4)]

43.

An autocatalytic reaction is a reaction in which one of the products catalyses the reaction.

Which curve was obtained if the rate of reaction was plotted against time for an autocatalytic reaction?



[2013 O/N-11 (5)]

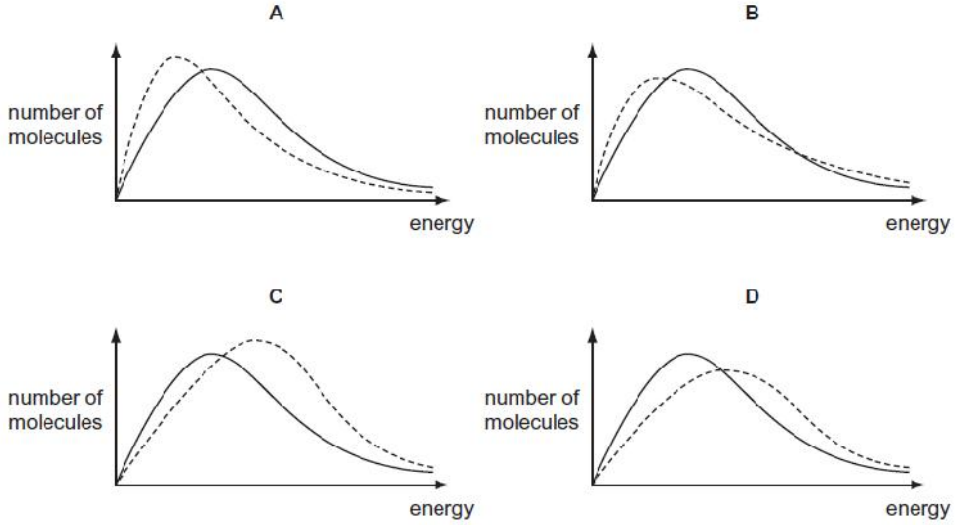
44.

The diagrams below show the Boltzmann distribution for air at two temperatures.

The solid line represents the distribution at –20 °C.

The dotted line represents the distribution at –10 °C.

Which diagram is correct?



[2013 O/N-11 (6)]

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45.

$Na_2S_2O_3$ reacts with dilute HC*l* to give a pale yellow precipitate. If 1 cm^3 of 0.1 mol dm^{-3} HC*l* is added to 10 cm^3 of 0.02 mol dm^{-3} $Na_2S_2O_3$ the precipitate forms slowly.

If the experiment is repeated with 1 cm^3 of 0.1 mol dm^{-3} HC*l* and 10 cm^3 of 0.05 mol dm^{-3} $Na_2S_2O_3$ the precipitate forms more quickly.

Why is this?

A The activation energy of the reaction is lower when 0.05 mol dm^{-3} $Na_2S_2O_3$ is used.

B The collisions between reactant particles are more violent when 0.05 mol dm^{-3} $Na_2S_2O_3$ is used.

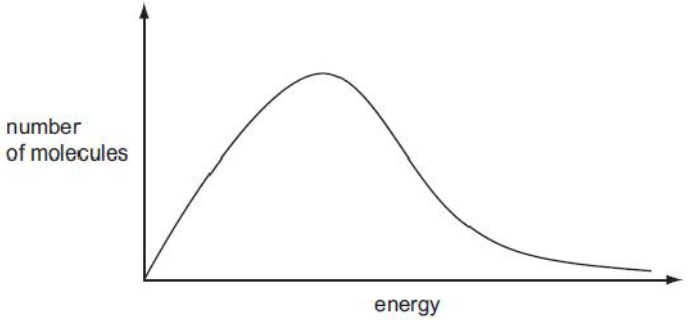
C The reactant particles collide more frequently when 0.05 mol dm^{-3} $Na_2S_2O_3$ is used.

D The reaction proceeds by a different pathway when 0.05 mol dm^{-3} $Na_2S_2O_3$ is used.

[2013 O/N-13 (5)]

46.

The diagram represents the Boltzmann distribution of molecular energies at a given temperature.



Which of the factors that affect the rate of a reaction can be explained using such a Boltzmann distribution?

1 increasing the concentration of reactants

2 increasing the temperature

3 the addition of a catalyst

[2013 O/N-13 (32)]

47.

When making sparkler fireworks, a mixture of barium nitrate powder with aluminium powder, water and glue is coated onto wires and allowed to dry. At this stage, the following exothermic reaction may occur.

$$16Al + 3Ba(NO_3)_2 + 36H_2O \rightarrow 3Ba(OH)_2 + 16Al(OH)_3 + 6NH_3$$

Which conditions would be best to reduce the rate of this reaction during the drying process, and would also keep the aluminium and barium nitrate unchanged?

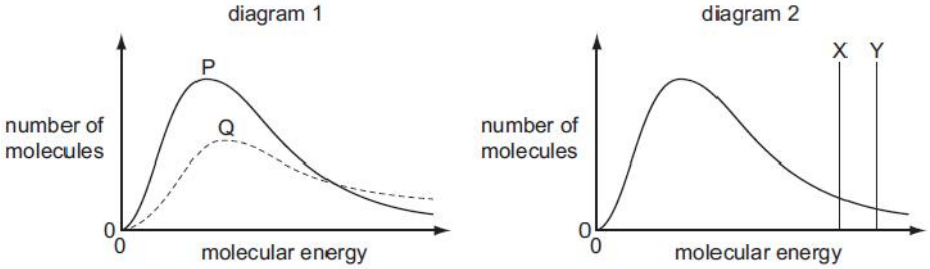
	temperature / K	pH
A	298	7
B	298	14
C	398	7
D	398	14

[2014 M/J-11 (8)]

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48.

Boltzmann distributions are shown in the diagrams.



In diagram 1, one curve, P or Q, corresponds to a temperature higher than that of the other curve.

In diagram 2, one line, X or Y, corresponds to the activation energy in the presence of a catalyst and the other line corresponds to the activation energy of the same reaction in the absence of a catalyst.

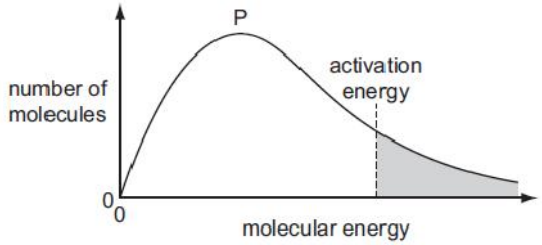
Which combination gives the correct curve and line?

	higher temperature	presence of catalyst
A	P	X
B	P	Y
C	Q	X
D	Q	Y

[2014 M/J-11 (11)]

49.

The diagram shows a Boltzmann distribution of molecular energies for a gaseous mixture. The distribution has a peak, labelled P on the diagram.



What happens when the temperature of the mixture increases?

A The height of the peak, P, decreases and the activation energy moves to the left.

B The height of the peak, P, decreases and the activation energy moves to the right.

C The height of the peak, P, decreases and the activation energy does not change.

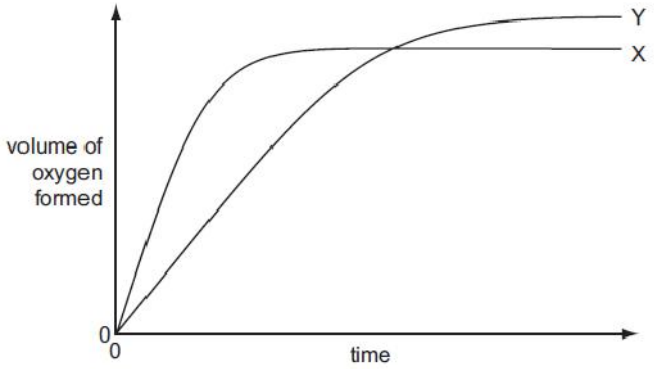
D The height of the peak, P, increases and the activation energy moves to the left.

[2014 M/J-12 (1)]

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50.

In the diagram, curve X was obtained by observing the decomposition of 100 cm^3 of 1.0 mol dm^{-3} hydrogen peroxide, catalysed by manganese(IV) oxide.



Which alteration to the original experimental conditions would produce curve Y?

A adding more manganese(IV) oxide

B adding some 0.1 mol dm^{-3} hydrogen peroxide

C adding water

D raising the temperature

[2014 M/J-12 (5)]

51.

The reaction

$$E + F \rightleftharpoons G + H$$

is catalysed by platinum.

Which statements about the properties of the catalyst are correct?

1 The catalyst has no effect on the enthalpy change of the reaction.

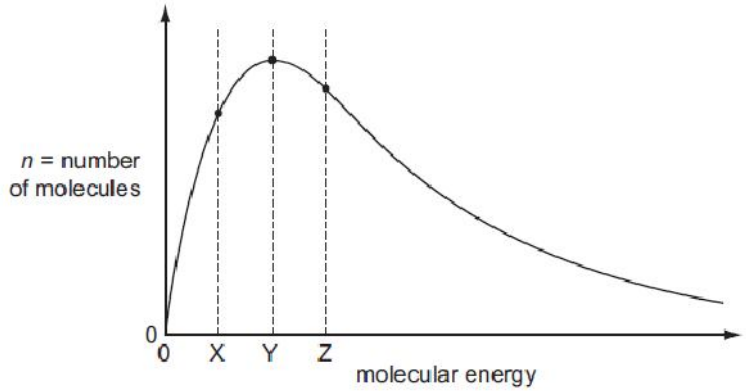
2 The catalyst increases the rate of the reverse reaction.

3 The catalyst increases the average kinetic energy of the reacting particles.

[2014 M/J-12 (32)]

52.

The Boltzmann distribution for a gas at constant temperature is shown below.



If the temperature of the gas is **reduced** by 10 °C the graph changes shape.

What happens to the values of *n* for the molecular energies X, Y and Z?

	X	Y	Z
A	higher	lower	higher
B	higher	lower	lower
C	lower	higher	lower
D	lower	lower	lower

[2014 M/J-13 (1)]

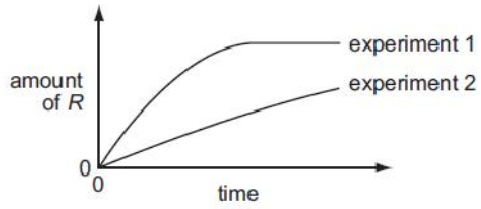
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53.

The stoichiometry of a catalysed reaction is shown by the equation below.

$$P(g) + Q(g) \rightleftharpoons R(g) + S(l)$$

Two experiments were carried out in which the rate of production of *R* was measured. The results are shown in the diagram below.



Which changes in the conditions might explain the results shown?

1 A lower pressure was used in experiment 2.

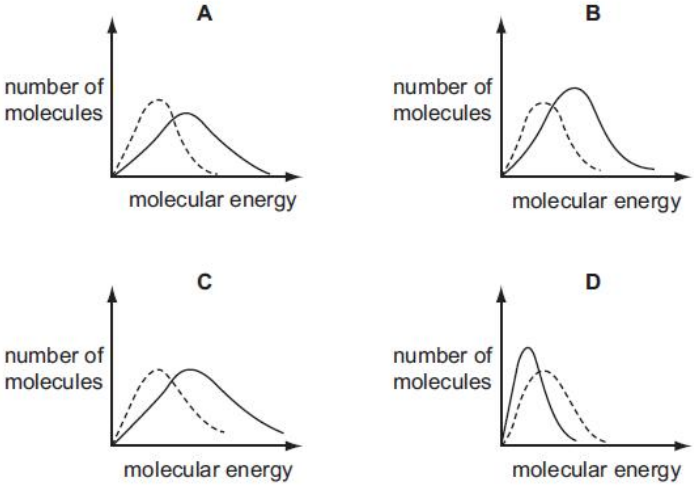
2 A different catalyst was used in experiment 2.

3 Product *S* was continuously removed from the reaction vessel in experiment 2.

[2014 M/J-13 (34)]

54.

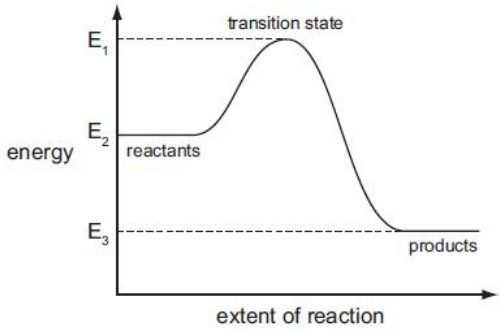
Which solid-line curve most accurately represents the distribution of molecular energies in a gas at 500 K if the dotted-line curve represents the corresponding distribution for the same gas at 300 K?



[2014 O/N-11 (1)]

55.

The reaction pathway diagram below illustrates the energies of the reactants, the products and the transition state of a reaction.



Which expression represents the activation energy of the forward reaction?

A $E_1 - E_2$ **B** $E_2 - E_1$ **C** $E_2 - E_3$ **D** $E_3 - E_2$

[2014 O/N-11 (8)]

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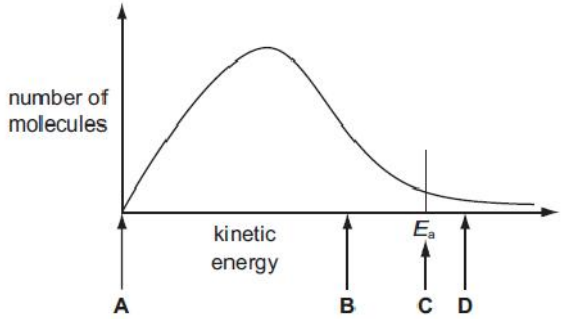
56.

The diagram below represents, for a given temperature, the Boltzmann distribution of the kinetic energy of the molecules in a mixture of two gases that react slowly together.

The activation energy for the reaction, E_a, is marked.

When the reaction is catalysed, the rate of reaction increases a little.

What will be the position of E_a for the catalysed reaction?



[2014 O/N-13 (1)]

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Reaction Kinetics - 2021

1. Nov/2020/Paper_41/No.1

Nitrogen monoxide, NO, reacts with oxygen to form nitrogen dioxide, NO_2.

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$$

The rate equation for the forward reaction is shown.

$$\text{rate} = k[NO]^2[O_2]$$

(a) Complete the following table.

the order of reaction with respect to [NO]	
the order of reaction with respect to $[O_2]$	
the overall order of reaction	

[1]

(b) Two separate experiments are carried out at 30 °C to determine the rate of the forward reaction.

experiment	$[NO]$ / mol dm^{-3}	$[O_2]$ / mol dm^{-3}	rate / mol dm^{-3} s^{-1}
1	0.00300	0.00200	1.51×10^{-4}
2		0.00500	6.05×10^{-5}

(i) Use the data for experiment 1 to calculate the value of the rate constant, *k*. State the units of *k*.

k = ... units = ...

[2]

(ii) Calculate the value of [NO] in experiment 2.

[NO] = ... mol dm^{-3} [1]

(c) Define the term *rate-determining step*.

..... [1]

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(d) Peroxodisulfate ions, $S_2O_8^{2-}$, react with iodide ions, I^-.

$$S_2O_8^{2-} + 2I^- \rightarrow 2SO_4^{2-} + I_2$$

The rate equation for the reaction in the absence of any catalyst is shown.

$$\text{rate} = k[S_2O_8^{2-}][I^-]$$

(i) Suggest equations for a two-step mechanism for this reaction, stating which of the two steps is the rate-determining step.

step 1 .....

step 2 .....

rate-determining step = ...

[2]

(ii) A large excess of peroxodisulfate ions is mixed with iodide ions. Immediately after mixing, $[I^-] = 0.00780\,\text{mol dm}^{-3}$. Under the conditions used, the half-life of $[I^-]$ is 48 seconds.

Calculate the iodide ion concentration 192 seconds after the peroxodisulfate and iodide ions are mixed.

iodide ion concentration = ... mol dm^{-3} [1]

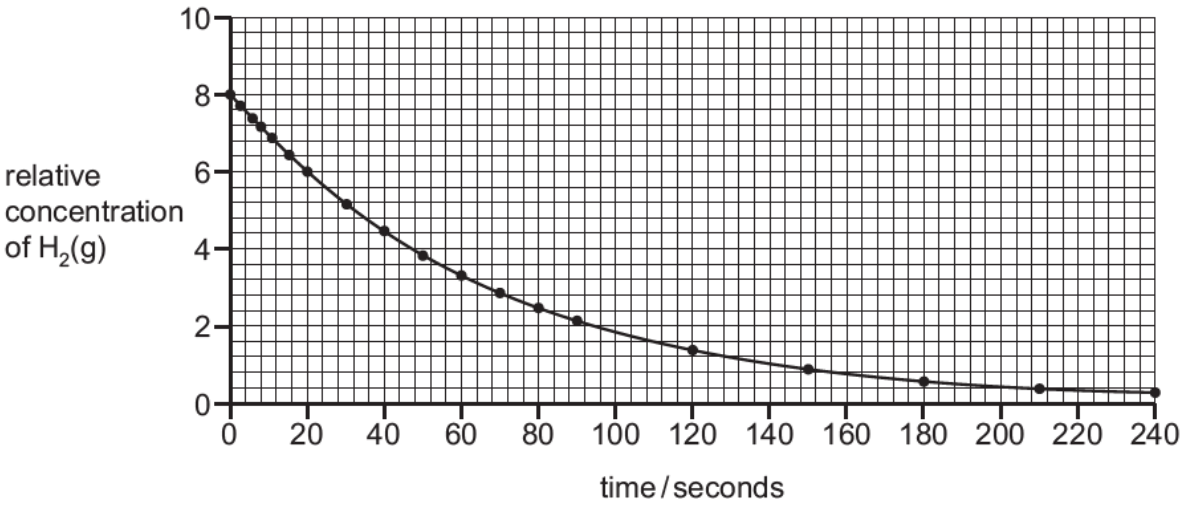
[Total: 8]

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2. Nov/2020/Paper_42/No.1

The rate of the reaction $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$ is studied.

(a) A small amount of $H_2(g)$ is mixed with a large excess of $I_2(g)$ at a temperature of 400 K and the reaction is monitored. The graph obtained is shown.



(i) Suggest why a large excess of $I_2(g)$ is used in this experiment.

.....

[1]

(ii) The reaction is first order with respect to $H_2(g)$.

Use data from the graph to confirm this statement.

.....

.....

.....

.....

[2]

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(b) Three separate experiments were carried out at 400 K with different starting concentrations of $H_2(g)$ and $I_2(g)$. The results are shown in the table.

experiment	$[H_2(g)]$ / mol dm^{-3}	$[I_2(g)]$ / mol dm^{-3}	rate of reaction / mol dm^{-3} s^{-1}
1	1.0×10^{-2}	1.0×10^{-2}	2.0×10^{-17}
2	1.0×10^{-1}	1.0×10^{-1}	2.0×10^{-15}
3	5.0×10^{-1}	5.0×10^{-1}	5.0×10^{-14}

(i) Use the data, and the order of reaction with respect to $H_2(g)$ given in **(a)(ii)**, to deduce the order of reaction with respect to $I_2(g)$.

Explain your answer, giving data in support of your explanation.

.....

.....

.....

..... [3]

(ii) Use information from **(a)(ii)** and your answer to **(b)(i)** to write the rate equation for the forward reaction.

rate = ... [1]

(iii) Use your rate equation and data from experiment 1 to calculate the value of the rate constant, *k*, for the forward reaction at 400 K. Include units for *k*.

k = ... units = ...
[2]

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(c) At 400 K the rate constant for the forward reaction is approximately 1000 times greater than the rate constant for the backward reaction. The overall orders of the forward and backward reactions are the same.

forward reaction	$H_2(g) + I_2(g) \rightarrow 2HI(g)$
backward reaction	$2HI(g) \rightarrow H_2(g) + I_2(g)$

(i) Use this information to explain what will happen if equal concentrations of HI(g), $H_2(g)$ and $I_2(g)$ are mixed at 400 K.

You should comment on:

- the relative initial rates of the forward and backward reactions
- the position of the equilibrium reached.

.....

.....

..... [1]

(ii) At 700 K the rate constant for the forward reaction is approximately 50 times greater than the rate constant for the backward reaction.

Use this information and the information in **(c)(i)** to deduce the signs of the ΔH values of the forward and backward reactions. Explain your answer.

.....

.....

.....

..... [2]

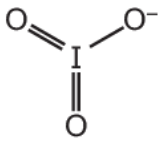
[Total: 12]

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1. March/2021/Paper_42/No.3

Iodates are compounds that contain the IO_3^- anion.

(a) The IO_3^- anion is shown.



Explain, with reference to the qualitative model of electron-pair repulsion, why the IO_3^- anion has a pyramidal shape.

.....

.....

..... [1]

(b) The reaction of iodine and hot aqueous sodium hydroxide is similar to that of chlorine and hot aqueous sodium hydroxide. Sodium iodate, $NaIO_3$, is formed as one of the products.

Suggest an equation for the reaction of iodine and hot aqueous sodium hydroxide.

..... [1]

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(c) The decomposition of hydrogen peroxide, H_2O_2, is catalysed by acidified IO_3^-.

H_2O_2 reduces acidified IO_3^- as shown.

$$5H_2O_2 + 2H^+ + 2IO_3^- \rightarrow I_2 + 5O_2 + 6H_2O$$

This reaction is followed by the oxidation of I_2 by H_2O_2.

half-equation	$E^\ominus$/V
$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O$	+1.77
$IO_3^- + 6H^+ + 5e^- \rightleftharpoons \frac{1}{2}I_2 + 3H_2O$	+1.19
$O_2 + 2H^+ + 2e^- \rightleftharpoons H_2O_2$	+0.68

(i) Use the data to show that the separate reactions of H_2O_2 with IO_3^- and with I_2 are both feasible under standard conditions.

In your answer, give the equation for the reaction of H_2O_2 with I_2.

.....

.....

.....

.....

.....

..... [3]

(ii) Write the overall equation for the decomposition of H_2O_2 catalysed by acidified IO_3^-.

..... [1]

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(d) A student collects some data for the reaction of H_2O_2 with acidified IO_3^-, as shown in the table.

experiment	$[H_2O_2]$ / mol dm^{-3}	$[IO_3^-]$ / mol dm^{-3}	$[H^+]$ / mol dm^{-3}	initial rate of reaction / mol dm^{-3} s^{-1}
1	0.0500	0.0700	0.025	1.47×10^{-5}
2	0.100	0.0700	0.050	2.94×10^{-5}
3	0.100	0.140	0.025	5.88×10^{-5}
4	0.150	0.140	0.025	8.82×10^{-5}

(i) Use the data to determine the order of reaction with respect to $[H_2O_2]$, $[IO_3^-]$ and $[H^+]$.

Show your reasoning.

order with respect to $[H_2O_2]$ = ...

.....

.....

.....

order with respect to $[IO_3^-]$ = ...

.....

.....

.....

order with respect to $[H^+]$ = ...

.....

.....

.....

[3]

(ii) Use your answer to **(d)(i)** to write the rate equation for this reaction.

rate = ... [1]

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(iii) Calculate the value of the rate constant, k, using data from experiment 4 and your answer to **(d)(ii)**.

Give the units of k.

k = ...

units = ...
[2]

(e) $Pb(IO_3)_2$ is only sparingly soluble in water at 25 °C.

The solubility product, K_{sp}, of $Pb(IO_3)_2$ is 3.69×10^{-13} mol^3 dm^{-9} at 25 °C.

(i) Write an expression for the solubility product of $Pb(IO_3)_2$.

K_{sp} =

[1]

(ii) Calculate the solubility, in mol dm^{-3}, of $Pb(IO_3)_2$ at 25 °C.

solubility = ... mol dm^{-3} [2]

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(f) NH_4IO_3 is an unstable compound that readily decomposes when warmed. The decomposition reaction is shown.

$$NH_4IO_3(s) \rightarrow \tfrac{1}{2}N_2(g) + \tfrac{1}{2}O_2(g) + \tfrac{1}{2}I_2(g) + 2H_2O(l) \qquad \Delta H = -154.6\,kJ\,mol^{-1}$$

(i) Use the data in the table to calculate the entropy change of reaction, ΔS, of the decomposition of $NH_4IO_3(s)$.

compound	S / $J\,K^{-1}\,mol^{-1}$
$NH_4IO_3(s)$	42
$N_2(g)$	192
$O_2(g)$	205
$I_2(g)$	261
$H_2O(l)$	70

ΔS = ... $J\,K^{-1}\,mol^{-1}$ [2]

(ii) This reaction is feasible at all temperatures.

Explain why, using the data in **(f)** and your answer to **(f)(i)**.

.....

.....

..... [1]

[Total: 18]

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2. June/2021/Paper_41/No.5

Dinitrogen pentoxide, N_2O_5, is dissolved in an inert solvent (solv) and the rate of decomposition of N_2O_5 is investigated. This reaction produces nitrogen dioxide, which remains in solution, and oxygen gas.

$$N_2O_5(solv) \rightarrow 2NO_2(solv) + \tfrac{1}{2}O_2(g)$$

(a) Suggest what measurements could be used to follow the rate of this reaction from the given information.

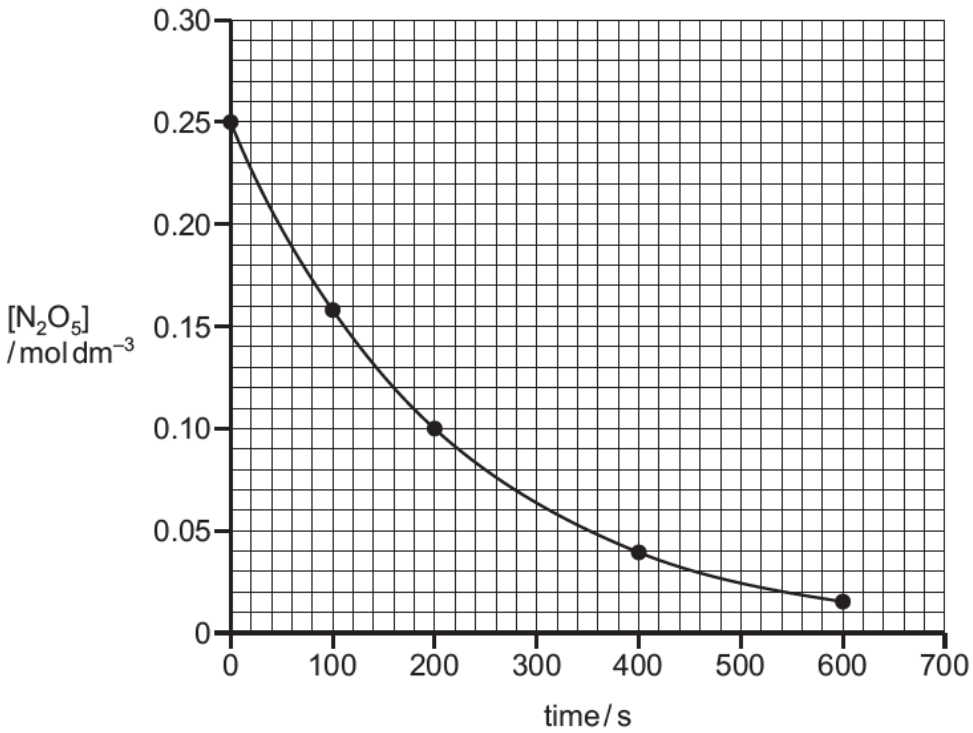
.....

..... [1]

(b) In a separate experiment, the rate of the decomposition of $N_2O_5(g)$ is investigated.

$$N_2O_5(g) \rightarrow 2NO_2(g) + \tfrac{1}{2}O_2(g)$$

The graph shows the results obtained.



The reaction is first order with respect to N_2O_5. This can be confirmed from the graph using half-lives.

(i) Explain the term *half-life of a reaction*.

.....

..... [1]

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(ii) Determine the half-life of this reaction. Show your working on the graph.

half-life = ... s [1]

(iii) Suggest the effect on the half-life of this reaction if the initial concentration of N_2O_5 is halved.

..... [1]

(c) (i) Use the graph in **5(b)** to determine the rate of reaction at 200 s. Show your working.

rate = ...

units = ...
[2]

The rate equation for this reaction is shown.

$$\text{rate} = k[N_2O_5]$$

(ii) Use your answer to **(c)(i)** to calculate the value of the rate constant, k, for this reaction and state its units.

k = ... units ..... [1]

(d) Nitrogen dioxide reacts with ozone, O_3, as shown.

$$2NO_2 + O_3 \rightarrow N_2O_5 + O_2$$

The rate equation for this reaction is rate = $k[NO_2][O_3]$.

Suggest a possible two-step mechanism for this reaction.

.....

..... [2]

[Total: 9]

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3. June/2021/Paper_42/No.7

(a) In aqueous solution, chlorine dioxide, ClO_2, reacts with hydroxide ions as shown.

$$2ClO_2 + 2OH^- \rightarrow ClO_3^- + ClO_2^- + H_2O$$

A series of experiments is carried out using different concentrations of ClO_2 and OH^-. The table shows the results obtained.

experiment	$[ClO_2]$ / mol dm^{-3}	$[OH^-]$ / mol dm^{-3}	initial rate / mol dm^{-3} min^{-1}
1	0.020	0.030	7.20×10^{-4}
2	0.020	0.120	2.88×10^{-3}
3	0.050	0.030	4.50×10^{-3}

(i) Explain the term *order of reaction*.

.....

..... [1]

(ii) Use the data in the table to determine the order of reaction with respect to each reactant, ClO_2 and OH^-.

Explain your reasoning.

.....

.....

.....

.....

.....

..... [2]

(iii) Use your answer to **(a)(ii)** to construct the rate equation for this reaction.

rate = ... [1]

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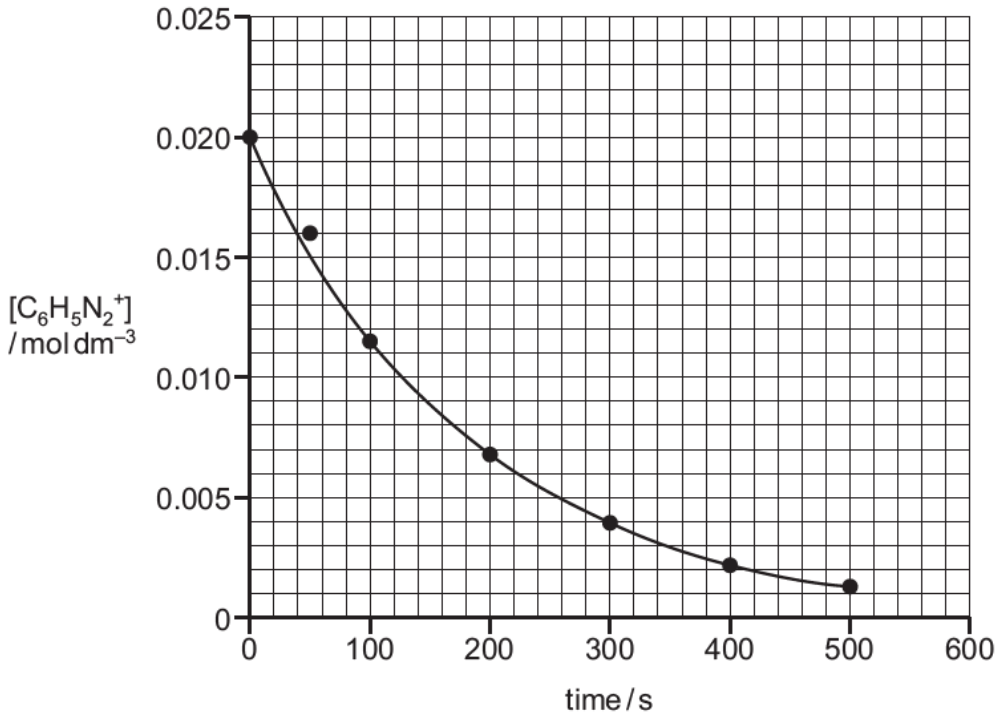
(iv) Use your rate equation and the data from experiment 1 to calculate the rate constant, k, for this reaction.
Include the units of k.

k = ... units ..... [2]

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(b) The decomposition of benzenediazonium ions, $C_6H_5N_2^+$, using a large excess of water, is a first-order reaction.

The graph shows the results obtained.



(i) Draw the structure of the organic product formed in this reaction.

[1]

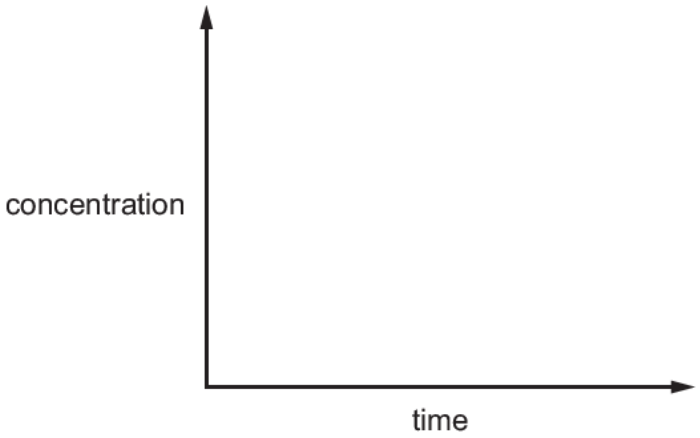
(ii) Use the graph to determine the rate of reaction at 100 s. Show your working.

rate = ... $mol\,dm^{-3}\,s^{-1}$ [1]

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(c) Sketch a concentration–time graph for a **zero-order** reaction.

Use your graph to suggest how successive half-lives for a zero-order reaction vary as the concentration of a reactant decreases. Indicate this by placing a tick (✓) in the appropriate box in the table.



successive half-lives decrease	no change in successive half-lives	successive half-lives increase

[1]

[Total: 9]

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Reaction Kinetics - 2022 June A2 Chemistry 9701

1. June/2022/Paper_41/No.2(c)

(c) Manganese(IV) oxide, MnO_2, acts as a heterogeneous catalyst in the decomposition of hydrogen peroxide, H_2O_2.

(i) Explain what is meant by a heterogeneous catalyst.

.....

..... [1]

(ii) Describe the mode of action of a heterogeneous catalyst in a reaction.

.....

.....

.....

..... [3]

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2. June/2022/Paper_41/No.3(a, b)

(a) The rate of reaction between 2-chloro-2-methylpropane, $(CH_3)_3CCl$, and methanol is investigated. When a large excess of methanol is used, the overall reaction is first order.

$$(CH_3)_3CCl + CH_3OH \rightarrow (CH_3)_3COCH_3 + HCl$$

Fig. 3.1 shows the results obtained.

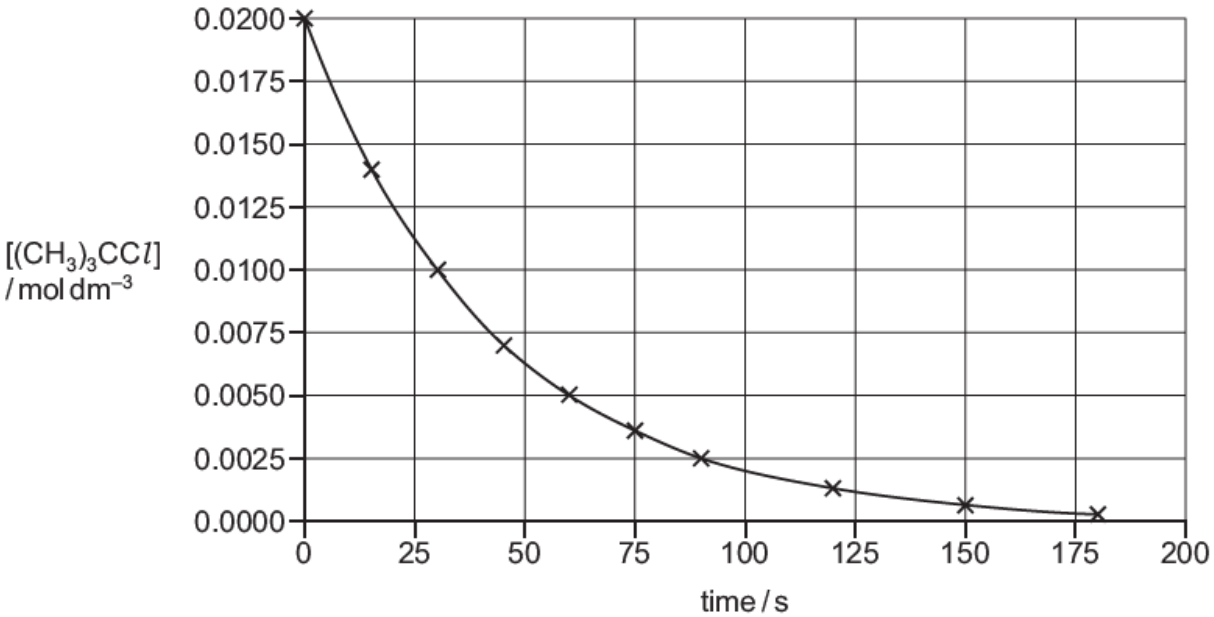


Fig. 3.1

(i) Use the graph to determine the rate of reaction at 40 s. Show all your working.

rate = ... mol dm^{-3} s^{-1} [1]

(ii) Use the graph to show that the overall reaction is first order. Explain your answer.

.....

.....

..... [2]

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(b) In a different reaction, which is also a first order reaction, 75% of the reactant is consumed in 320 s.

Calculate the rate constant, k, for this reaction. State the units for k.

k = ... units = ... [2]

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1. Nov/2023/Paper_9701/41/No.1

Fluorine reacts with chlorine dioxide, ClO_2, as shown.

$$F_2(g) + 2ClO_2(g) \rightarrow 2FClO_2(g)$$

The rate of the reaction is first order with respect to the concentration of F_2 and first order with respect to the concentration of ClO_2. No catalyst is involved.

(a) (i) Suggest a two-step mechanism for this reaction.

step 1 →

step 2 →

[2]

(ii) Identify the rate-determining step in this mechanism. Explain your answer.

.....

..... [1]

(b) When the rate of the reaction is measured in $mol\,dm^{-3}\,s^{-1}$ the numerical value of the rate constant, *k*, is 1.22 under certain conditions.

(i) Complete the rate equation for this reaction, stating the overall order of the reaction.

rate =

overall order of reaction =

[1]

(ii) Use your rate equation in **(i)** to calculate the rate of the reaction when the concentrations of F_2 and ClO_2 are both $2.00 \times 10^{-3}\,mol\,dm^{-3}$.

rate = ... $mol\,dm^{-3}\,s^{-1}$ [1]

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(c) Under different conditions, and in the presence of a large excess of ClO_2, the rate equation is as shown.

$$\text{rate} = k_1[F_2]$$

The half-life, $t_{\frac{1}{2}}$, of the concentration of F_2 is 4.00 s under these conditions.

(i) Calculate the numerical value of k_1, giving its units.

Give your answer to **three** significant figures.

k_1 = ... units .....
[2]

(ii) An experiment is performed under these conditions in which the starting concentration of F_2 is 0.00200 mol dm^{-3}.

Draw a graph on the grid in Fig. 1.1 to show how the concentration of F_2 changes over the first 12 s of the reaction.

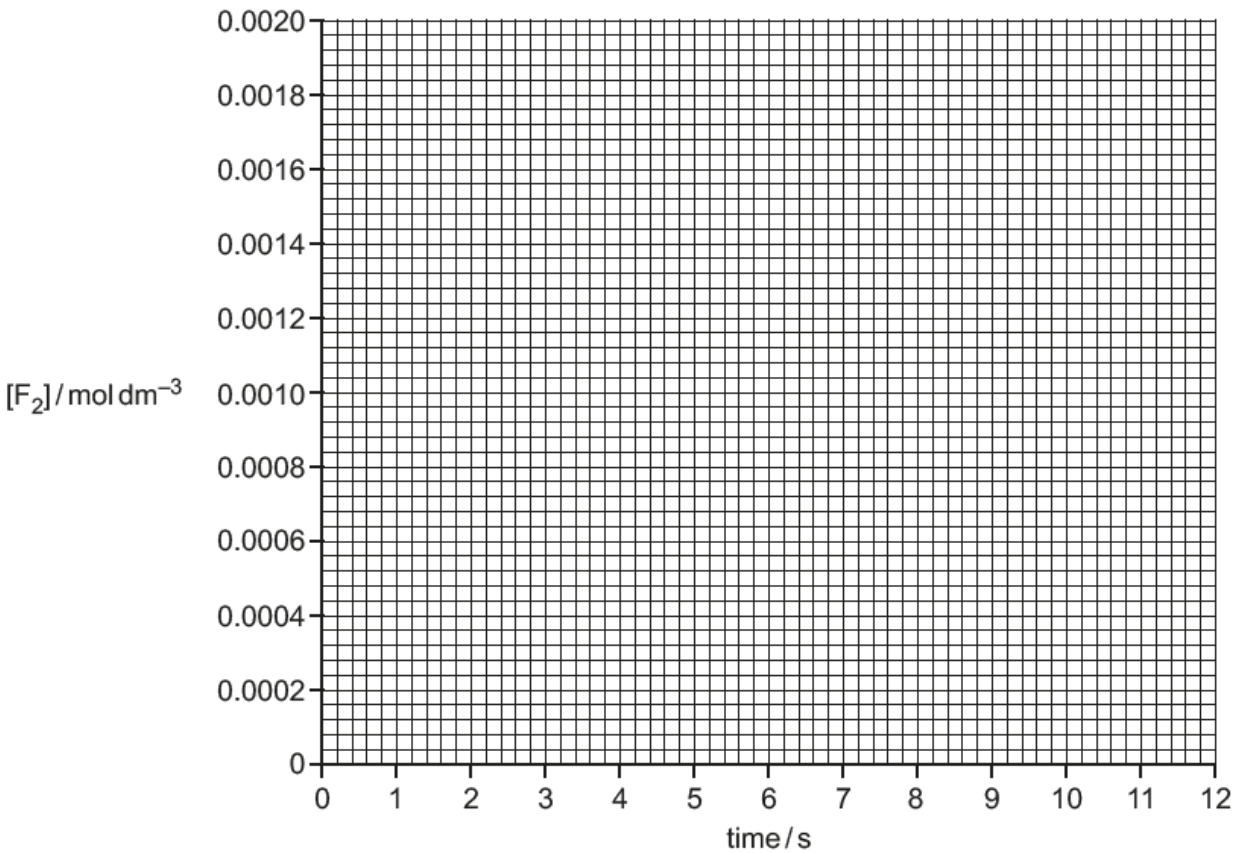


Fig. 1.1

[1]

(iii) Use your graph in Fig. 1.1 to find the rate of the reaction when the concentration of F_2 is 0.00100 mol dm^{-3}. Show your working on the graph.

rate = ... mol dm^{-3} s^{-1} [1]

[Total: 9]

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2. Nov/2023/Paper_9701/41/No.3(d)

(d) The decomposition of $H_2O_2(aq)$ is catalysed by aqueous iron(III) chloride and by silver metal.

Identify which of these two catalysts is acting as a homogeneous catalyst.

Explain your answer.

homogeneous catalyst .....

explanation .....

[1]

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3. Nov/2023/Paper_9701/42/No.1

Propanone, CH_3COCH_3, reacts with iodine, I_2, in the presence of an acid catalyst.

$$CH_3COCH_3 + I_2 \rightarrow CH_3COCH_2I + H^+ + I^-$$

The rate equation for this reaction is shown.

$$\text{rate} = k[CH_3COCH_3][H^+]$$

(a) Complete Table 1.1 to describe the order of the reaction.

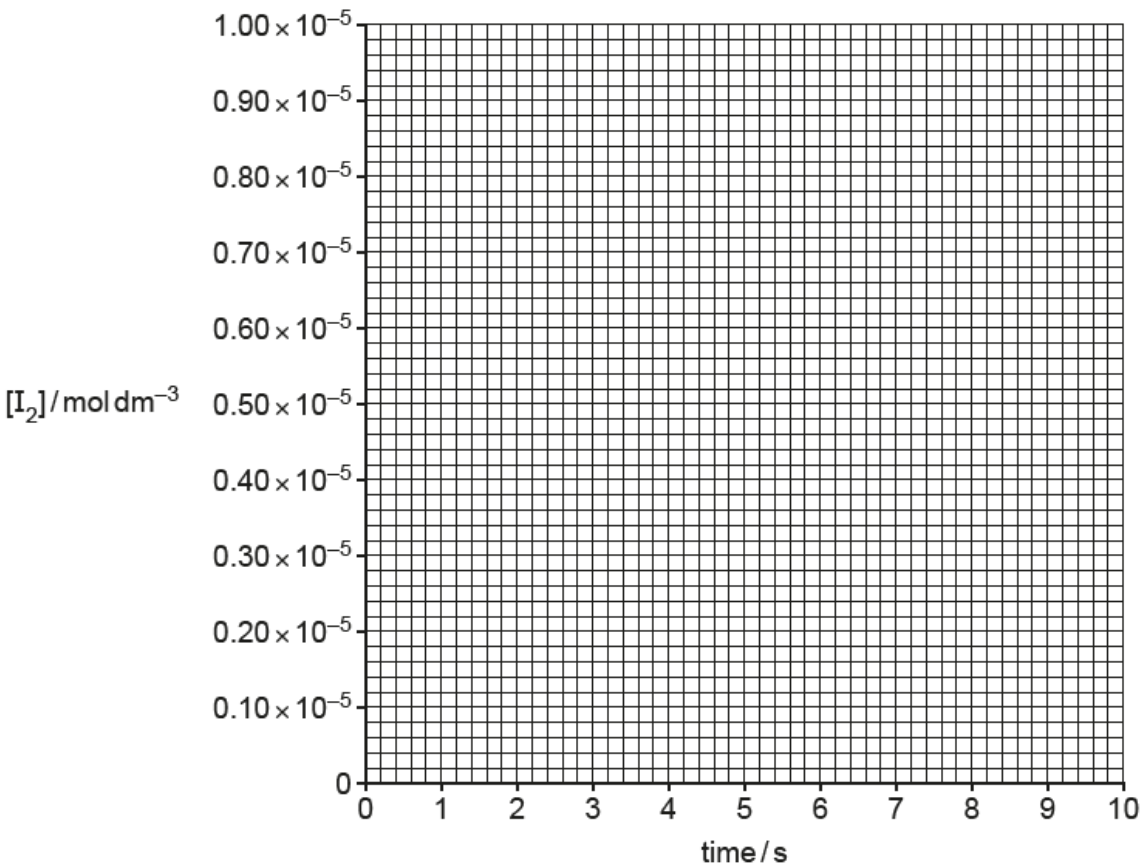
Table 1.1

order of the reaction with respect to $[CH_3COCH_3]$	
order of the reaction with respect to $[I_2]$	
order of the reaction with respect to $[H^+]$	
overall order of the reaction	

[2]

(b) An experiment is performed using a large excess of CH_3COCH_3 and a large excess of $H^+(aq)$. The initial concentration of I_2 is 1.00×10^{-5} mol dm^{-3}. The initial rate of decrease in the I_2 concentration is 2.27×10^{-7} mol dm^{-3} s^{-1}.

(i) Use the axes to draw a graph of $[I_2]$ against time for the first 10 seconds of the reaction.



[1]

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(ii) State whether it is possible to calculate the numerical value of the rate constant, k, for this reaction from your graph. Explain your answer.

.....

..... [1]

(c) The experiment is repeated at a different temperature. The initial concentrations of H^+ ions, I_2 and CH_3COCH_3 are all $0.200\,mol\,dm^{-3}$.

The value of k at this temperature is $2.31 \times 10^{-5}\,mol^{-1}\,dm^3\,s^{-1}$.

Calculate the initial rate of this reaction.

rate = ... $mol\,dm^{-3}\,s^{-1}$ [1]

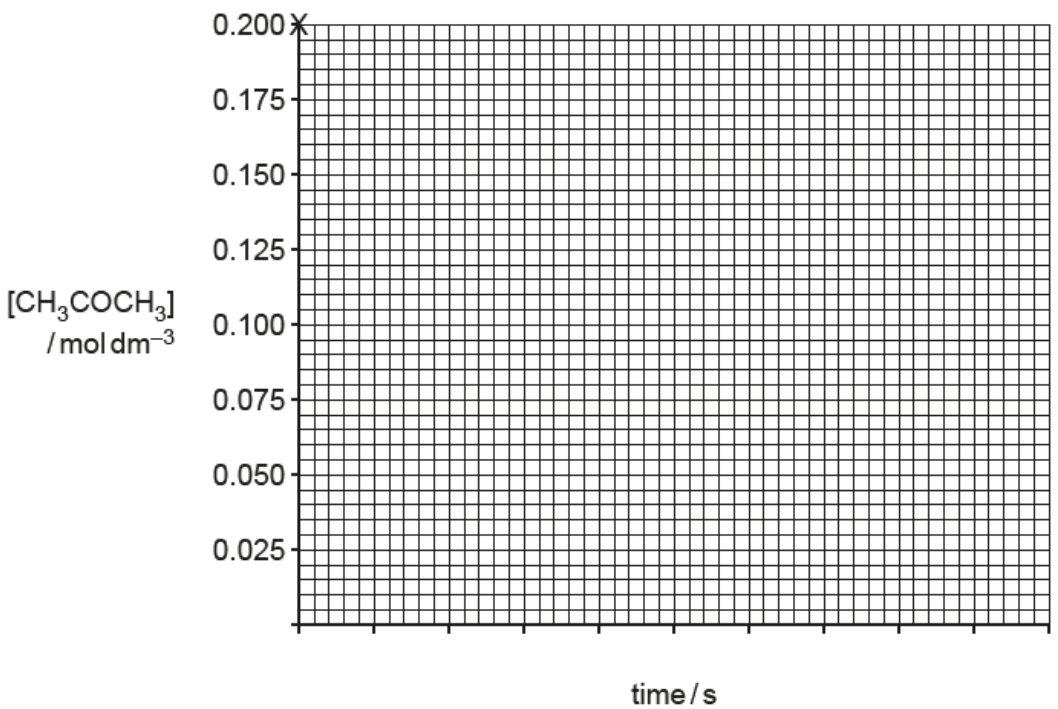
(d) The experiment is repeated using an excess of $H^+(aq)$. The new rate equation is shown.

$$rate = k_1[CH_3COCH_3]$$

(i) The value of k_1 is $1.1 \times 10^{-3}\,s^{-1}$. Calculate the value of the half-life, $t_{\frac{1}{2}}$.

$t_{\frac{1}{2}}$ = ... s [1]

(ii) Use your answer to **(i)** to draw a graph of $[CH_3COCH_3]$ against time for this reaction. The initial value of $[CH_3COCH_3]$ on your graph should be $0.200\,mol\,dm^{-3}$. The final value of $[CH_3COCH_3]$ on your graph should be $0.0250\,mol\,dm^{-3}$.



[1]

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(e) A four-step mechanism is suggested for the overall reaction.

$CH_3COCH_3 + I_2 \rightarrow CH_3COCH_2I + H^+ + I^-$ rate = $k[CH_3COCH_3][H^+]$

Part of this mechanism is shown.

step 1: $CH_3COCH_3 + H^+ \rightarrow CH_3C^+(OH)CH_3$

step 2: $CH_3C^+(OH)CH_3 \rightarrow CH_3C(OH)=CH_2 + H^+$

step 3: $\rightarrow$

step 4: $CH_3C^+(OH)CH_2I \rightarrow CH_3COCH_2I + H^+$

(i) Write an equation for step 3.

..... [1]

(ii) Suggest the slowest step of the mechanism. Explain your answer.

.....

..... [1]

(iii) Identify one conjugate acid-conjugate base pair in the mechanism.

conjugate acid ..... conjugate base ..... [1]

[Total: 10]

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4. June/2023/Paper_9701/41/No.5(a)

(a) The exhaust systems of most modern gasoline-fuelled cars contain a catalytic converter with three metal catalysts.

These metals act as heterogeneous catalysts.

(i) Name **three** metal catalysts used in catalytic converters.

1 ..... 2 ..... 3 ..... [1]

(ii) Explain what is meant by a heterogeneous catalyst.

.....

..... [1]

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(a) Aqueous acidified iodate(V) ions, IO_3^-, react with iodide ions, as shown.

$$IO_3^- + 6H^+ + 5I^- \rightarrow 3I_2 + 3H_2O$$

The initial rate of this reaction is investigated. Table 3.1 shows the results obtained.

Table 3.1

experiment	$[IO_3^-]$/mol dm^{-3}	$[H^+]$/mol dm^{-3}	$[I^-]$/mol dm^{-3}	initial rate/mol dm^{-3} min^{-1}
1	0.0400	0.0150	0.0250	4.20×10^{-2}
2	0.120	to be calculated	0.0125	7.09×10^{-2}

The rate equation for this reaction is rate = $k[IO_3^-][H^+]^2[I^-]^2$.

(i) Explain what is meant by order of reaction.

.....

.....

..... [1]

(ii) Complete Table 3.2.

Table 3.2

the order of reaction with respect to $[IO_3^-]$	
the order of reaction with respect to $[H^+]$	
the order of reaction with respect to $[I^-]$	
the overall order of reaction	

[1]

(iii) Use your answer to **(a)(ii)** to sketch lines in Fig. 3.1 to show the relationship between the initial rates and the concentrations of $[IO_3^-]$ and $[I^-]$.

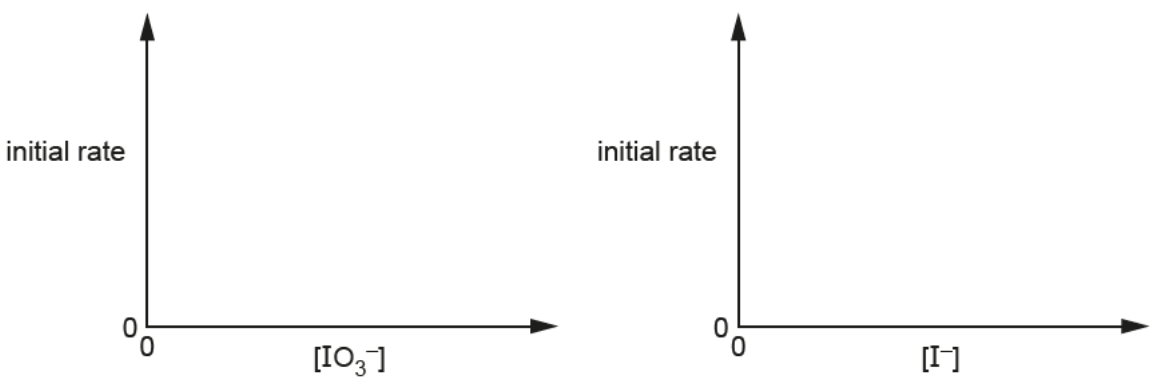


Fig. 3.1

[1]

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(iv) Use data from Table 3.1 to calculate the rate constant, k, for this reaction.

Include the units of k.

k = ... units ..... [2]

(v) Use data from Table 3.1 to calculate the concentration of hydrogen ions, $[H^+]$, in experiment 2.

$[H^+]$ = ... $mol\,dm^{-3}$ [1]

(vi) This reaction is repeated in two separate experiments.

The experiments are carried out at the same temperature and with the same concentrations of I^- and IO_3^-.

One experiment takes place at pH 1.0 and the other experiment takes place at pH 2.0.

Calculate the value of $\frac{\text{rate at pH 1.0}}{\text{rate at pH 2.0}}$.

value of $\frac{\text{rate at pH 1.0}}{\text{rate at pH 2.0}}$ = ... [1]

(b) In aqueous solution, iron(III) ions react with iodide ions, as shown.

$$2Fe^{3+} + 2I^- \longrightarrow 2Fe^{2+} + I_2$$

The initial rate of reaction is first order with respect to Fe^{3+} and second order with respect to I^-.

The mechanism for this reaction has three steps.

Each step involves only **two** ions reacting together.

Suggest equations for the **three** steps of this mechanism. Identify the rate-determining step.

step 1 .....

step 2 .....

step 3 .....

rate-determining step = ...

[3]

[Total: 10]

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6. June/2023/Paper_9701/42/No.4

(a) In aqueous solution, iron(III) ions react with iodide ions, as shown.

$$2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$$

A series of experiments is carried out using different concentrations of Fe^{3+} and I^-, as shown in Table 4.1.

Table 4.1

experiment	$[Fe^{3+}]$ / mol dm^{-3}	$[I^-]$ / mol dm^{-3}	initial rate / mol dm^{-3} s^{-1}
1	0.0400	0.0200	2.64×10^{-4}
2	0.1200	0.0200	7.92×10^{-4}
3	0.0800	0.0400	2.11×10^{-3}

(i) Explain what is meant by overall order of reaction.

.....

.....

..... [1]

(ii) Use the data in Table 4.1 to deduce the order of reaction with respect to Fe^{3+} and with respect to I^-.

Explain your reasoning.

.....

.....

.....

..... [2]

(iii) Use your answer to **(a)(ii)** to construct the rate equation for this reaction.

rate = [1]

(iv) Use your answer to **(a)(iii)** and the data from experiment 1 to calculate the rate constant, *k*, for this reaction. Include the units of *k*.

k = ... units ..... [2]

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(v) Describe qualitatively the effect of an increase in temperature on the rate constant and on the rate of this reaction.

.....

..... [1]

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(b) In aqueous solution, iodide ions react with acidified hydrogen peroxide, as shown.

$$2I^- + H_2O_2 + 2H^+ \rightarrow I_2 + 2H_2O$$

The initial rate of reaction is found to be first order with respect to I^-, first order with respect to H_2O_2 and zero order with respect to H^+.

Fig. 4.1 shows a possible four-step mechanism for this reaction.

step 1	$H_2O_2 + I^- \rightarrow IO^- + H_2O$
step 2	$H^+ + IO^- \rightarrow HIO$
step 3	$HIO + I^- \rightarrow I_2 + OH^-$
step 4	$OH^- + H^+ \rightarrow H_2O$

Fig. 4.1

(i) Suggest which of the steps, 1, 2, 3 or 4, in this mechanism is the rate-determining step.

Explain your answer.

.....

.....

..... [1]

(ii) Identify a step in Fig. 4.1 that involves a redox reaction.

Explain your answer in terms of oxidation numbers.

.....

.....

..... [1]

(iii) Suggest the role of HIO in this mechanism.

Explain your reasoning.

.....

.....

..... [1]

[Total: 10]

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7. March/2023/Paper_9701/42/No.2(c, d)

(c) $H_2PO_2^-(aq)$ reacts with $OH^-(aq)$.

$$H_2PO_2^-(aq) + OH^-(aq) \rightarrow HPO_3^{2-}(g) + H_2(g)$$

Table 2.1 shows the results of a series of experiments used to investigate the rate of this reaction.

Table 2.1

experiment	$[H_2PO_2^-(aq)]$ / mol dm^{-3}	$[OH^-(aq)]$ / mol dm^{-3}	volume of H_2 produced in 60 s / cm^3
1	0.40	2.00	6.4
2	0.80	2.00	12.8
3	1.20	1.00	4.8

(i) The volume of H_2 was measured under room conditions.

Use the molar volume of gas, V_m, and the data from experiment 1 to calculate the rate of reaction in mol dm^{-3} s^{-1}.

rate of reaction = ... mol dm^{-3} s^{-1} [1]

(ii) The rate equation was found to be:

$$\text{rate} = k\,[H_2PO_2^-(aq)]\,[OH^-(aq)]^2$$

Show that the data in Table 2.1 is consistent with the rate equation.

.....

.....

.....

.....

..... [2]

(iii) State the units of the rate constant, k, for the reaction.

..... [1]

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(iv) The experiment is repeated using a large excess of $OH^-(aq)$.

Under these conditions, the rate equation is:

$$\text{rate} = k_1 [H_2PO_2^-(aq)]$$

$k_1 = 8.25 \times 10^{-5} s^{-1}$

Calculate the value of the half-life, $t_{\frac{1}{2}}$, of the reaction.

$t_{\frac{1}{2}}$ = ... s [1]

(v) Describe how an increase in temperature affects the value of the rate constant, k_1.

.....

..... [1]

(d) A student suggests that the reaction between $H_2PO_2^-(aq)$ and $OH^-(aq)$ might happen more quickly in the presence of a heterogeneous catalyst.

Describe the mode of action of a heterogeneous catalyst.

.....

.....

.....

..... [2]

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Reaction Kinetics – 2021 AS

1. Nov/2021/Paper_11/No.31

Which changes can be used to measure the rates of chemical reactions?

1 the decrease in concentration of a reactant per unit time

2 the rate of appearance of a product

3 the increase in total volume of gas per unit time at constant pressure

2. Nov/2021/Paper_11/No.33

Ethylene glycol, $HOCH_2CH_2OH$, is used as a de-icer. It allows ice to melt at temperatures below 0 °C.

Which statements are correct?

1 Ethylene glycol disrupts the extensive network of hydrogen bonds in ice.

2 Ethylene glycol molecules form hydrogen bonds with other ethylene glycol molecules.

3 Ethylene glycol molecules will dissolve in the water formed from the ice.

3. Nov/2021/Paper_13/No.31

Which changes can be used to measure the rates of chemical reactions?

1 the decrease in concentration of a reactant per unit time

2 the rate of appearance of a product

3 the increase in total volume of gas per unit time at constant pressure

4. Nov/2021/Paper_13/No.32

Iron reacts with steam to produce hydrogen and an oxide of iron.

$$3Fe(s) + 4H_2O(g) \rightleftharpoons Fe_3O_4(s) + 4H_2(g)$$

A system containing all four substances is at equilibrium.

Which changes will decrease the mass of Fe present at equilibrium?

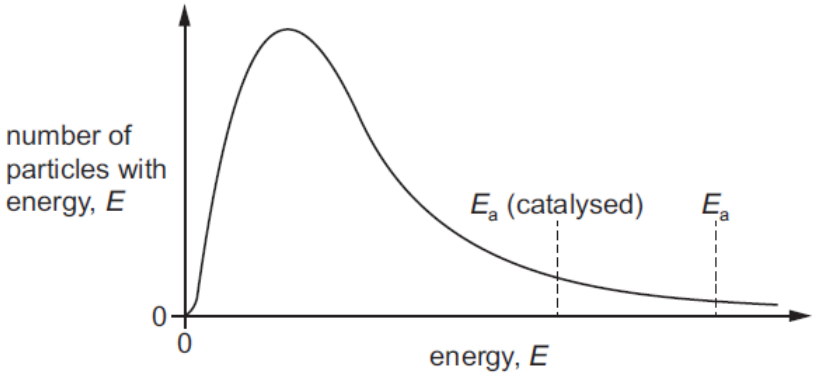
1 addition of steam at constant pressure

2 increase in overall pressure

3 addition of an effective catalyst

5. March/2021/Paper_12/No.11

The Boltzmann distribution curve for a gaseous mixture of ethene and hydrogen is shown. Nickel is an effective catalyst for the reaction that occurs.



How does the diagram appear if the same reaction mixture is at a higher temperature?

A The curve is unchanged.

B The values of both E_a (catalysed) and E_a decrease.

C The values of both E_a (catalysed) and E_a increase.

D The values of both E_a (catalysed) and E_a remain the same.

6. March/2021/Paper_12/No.33

Many gases do **not** obey the general gas equation at high pressures.

Why is this?

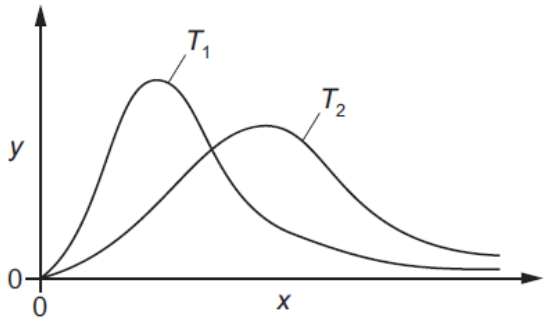
1 At higher pressures the molecules have more energy.

2 At higher pressures the volume of the molecules is a larger proportion of the total volume.

3 At higher pressures the molecules experience greater intermolecular forces.

7. June/2021/Paper_11/No.5

The diagram shows the Boltzmann distribution for the same gas at two different temperatures, T_1 and T_2.



What is plotted on the *y*-axis and which line represents the higher temperature?

	plotted on *y*-axis	higher temperature
A	number of molecules	T_1
B	number of molecules	T_2
C	molecular energy	T_1
D	molecular energy	T_2

8. June/2021/Paper_11/No.11

Which statement about catalysts is correct?

A They change the reaction pathway by increasing the activation energy.

B They increase the rate of reaction by lowering the enthalpy change of the reaction.

C They increase the number of particles that have sufficient energy to react.

D Heterogeneous catalysts are in the same state as the reactant.

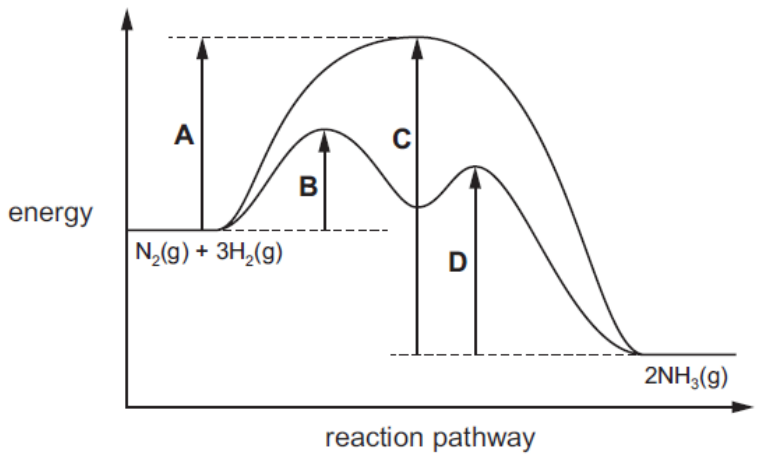
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9. June/2021/Paper_12/No.7

The reaction pathway diagram for the catalysed reaction and the uncatalysed reaction between N_2 and H_2 is shown.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

Which letter represents the activation energy for the first step in the decomposition of NH_3 in the presence of a catalyst?



10. June/2021/Paper_12/No.11

Two chemicals, X and Y, react together in solution to give product Z.

The rate of formation of product Z at the start of the reaction was measured in five experiments, 1–5, using various concentrations of X and Y. The results are shown.

experiment number	starting concentration of X / mol dm^{-3}	starting concentration of Y / mol dm^{-3}	rate of formation of Z at the start / mol dm^{-3} s^{-1}
1	0.10	0.10	0.0001
2	0.10	0.20	0.0004
3	0.10	0.40	0.0016
4	0.20	0.10	0.0001
5	0.40	0.10	0.0001

Which statement is correct?

A The rate of the reaction is directly proportional to the concentration of reagent X.

B The rate of the reaction is directly proportional to the concentration of reagent Y.

C The rate of the reaction is **not** affected by the concentration of reagent X.

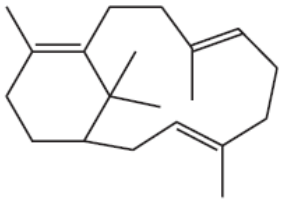
D The rate of the reaction is **not** affected by the concentration of reagent Y.

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11. June/2021/Paper_12/No.20

Compound P is treated with an excess of hydrogen gas in the presence of a nickel catalyst. The product Q is fully saturated.

compound P



What is the number of chiral carbon atoms in the product Q?

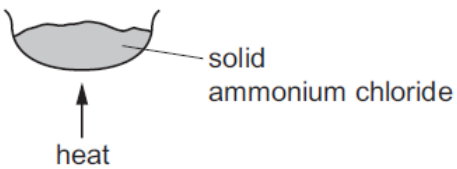
A 4 **B** 5 **C** 6 **D** 7

12. June/2021/Paper_12/No.33

When a sample of ammonium chloride is warmed it decomposes into ammonia and hydrogen chloride gas.

$NH_4Cl(s) \rightarrow NH_3(g) + HCl(g)$ reaction 1





When the mixture of hot ammonia and hydrogen chloride gases hit a cold surface, a white solid of ammonium chloride reforms.

Which statements are correct?

1 Reaction 1 is in dynamic equilibrium.

2 Reaction 1 is reversible.

3 Reaction 1 is an endothermic reaction.

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13. June/2021/Paper_12/No.34

Hydrogen chloride gas is formed by the reaction shown.

$$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$$

What will change the average kinetic energy of the reacting gas particles?

1 increasing the temperature and increasing the concentration of hydrogen

2 cooling the reaction mixture and adding a catalyst

3 adding a catalyst and increasing the concentration of chlorine

14. June/2021/Paper_13/No.12

The height of the peak of the curve in a Boltzmann distribution represents the number of molecules that have the most probable energy.

A sample of gas has its temperature decreased without changing the number of molecules present.

Which statement correctly describes a feature of the Boltzmann distribution for the gas when the temperature decreases?

A The value of the most probable energy would stay the same.

B The number of molecules with the most probable energy would increase.

C The area under the molecular energy distribution curve would decrease.

D The number of molecules at the very high energy end of the distribution would stay the same.

15. June/2021/Paper_13/No.33

Disaccharides are hydrolysed in slightly acidic solutions. This reaction is very slow.

A biological catalyst is added to a slightly acidic mixture of three disaccharides, sucrose, maltose and lactose. The hydrolysis reaction remains slow for sucrose and maltose but is now much faster for lactose.

Which statements about the catalyst are correct?

1 The catalyst increases the activation energy of all three hydrolysis reactions.

2 The catalyst shows specificity.

3 The hydrolysis of lactose using a catalyst has a different mechanism to the hydrolysis of lactose without a catalyst.

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16. June/2021/Paper_22/No.3

A large excess of 2-bromo-2-methylpropane is added to 0.0010 mol of NaOH(aq), which contains a few drops of phenolphthalein indicator. A stopwatch is started as soon as the substances are mixed. The time taken for the pink colour to disappear is recorded.

The experiment is repeated at different temperatures, keeping all concentrations and volumes of reagents constant.

temperature / °C	time taken for pink colour to disappear / s
20	300
25	65
35	20

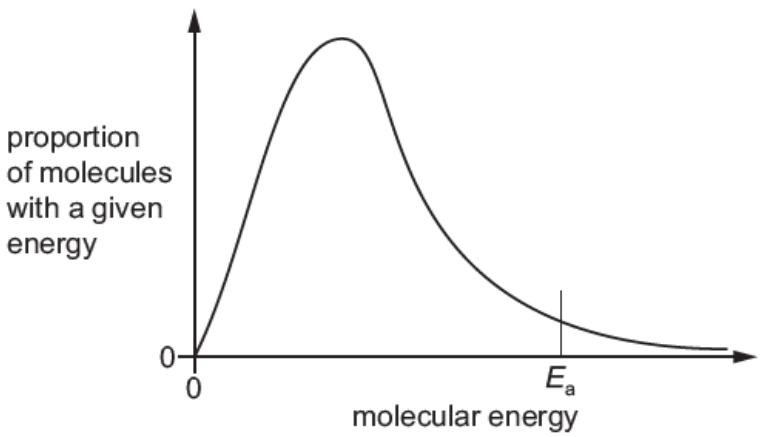
(a) Explain what is meant by the term *rate of reaction*.

.....

..... [1]

(b) The graph shows the energy distribution of molecules in a sample of 2-bromo-2-methylpropane at 25 °C.

E_a represents the activation energy for the reaction.



(i) Label the graph to show the proportion of 2-bromo-2-methylpropane molecules which have sufficient energy to react. [1]

(ii) Use the same axes to sketch the distribution of energies of molecules in a sample of 2-bromo-2-methylpropane at 50 °C. [2]

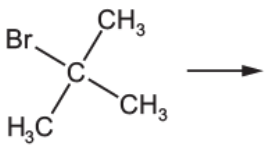
(iii) State the effect of an increase in temperature on E_a for this reaction.

..... [1]

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(c) (i) Draw the mechanism to show the reaction of 2-bromo-2-methylpropane with $OH^-(aq)$. Show the intermediate formed in this reaction.

Include all charges, partial charges, lone pairs and curly arrows as appropriate.



[3]

(ii) Name the mechanism for this reaction.

..... [1]

(d) The original experiment is repeated at 25 °C with 2-chloro-2-methylpropane instead of 2-bromo-2-methylpropane. All other variables remain constant.

Predict the effect of using 2-chloro-2-methylpropane compared to 2-bromo-2-methylpropane on the time taken for the pink colour to disappear. Explain your answer.

.....

.....

..... [2]

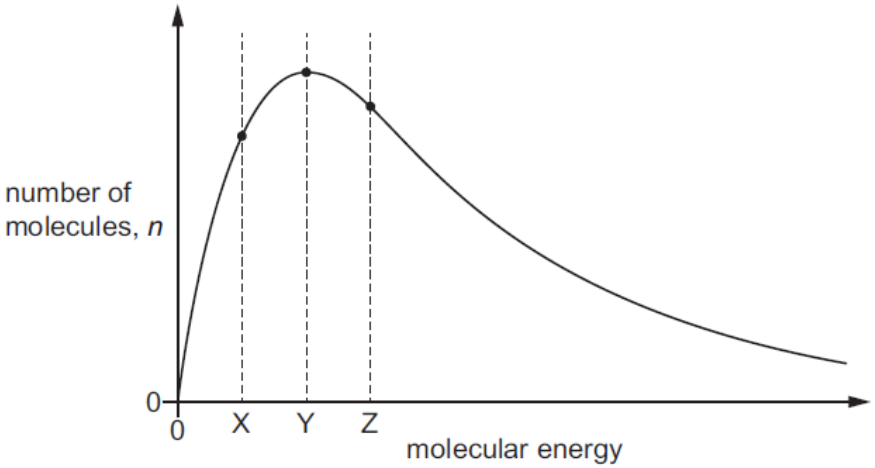
[Total: 11]

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Reaction Kinetics – 2022 June AS Chemistry 9701

1. June/2022/Paper_11/No.15

The Boltzmann distribution for a gas at a constant temperature of 50 °C is shown.



If the temperature of the gas is **reduced** by 10 °C, the graph changes shape.

What happens to the values of *n* for the molecular energies X, Y and Z?

	X	Y	Z
A	higher	lower	higher
B	higher	lower	lower
C	lower	higher	lower
D	lower	lower	lower

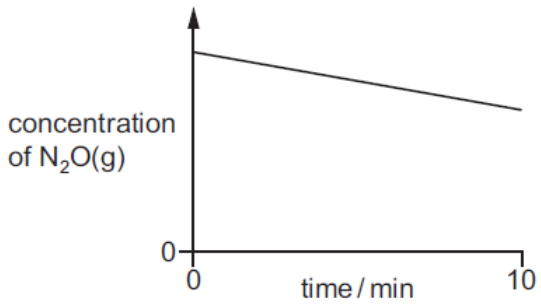
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2. June/2022/Paper_12/No.15

A large amount of $N_2O(g)$ decomposes into nitrogen gas and oxygen gas in the presence of a tiny amount of a gold foil catalyst.

The gold foil provides a solid surface on which the catalysed reaction takes place.

The graph shows the concentration of $N_2O(g)$ against time as it decomposes. The graph is a straight line.



Which row describes:

- the change in rate of reaction as $N_2O(g)$ decomposes from 0 to 10 minutes
- the effect of adding more gold foil catalyst on the rate of decomposition of the same amount and concentration of $N_2O(g)$?

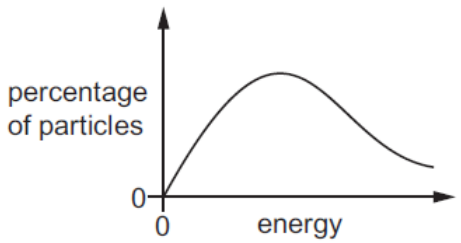
	change in rate of reaction as $N_2O(g)$ decomposes	effect of adding more gold foil on the rate of decomposition
A	none	increases
B	none	none
C	decreases	increases
D	decreases	none

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3. June/2022/Paper_13/No.15

The Boltzmann distribution of the particles in a mixture of gas X and gas Y is shown in diagram 1.

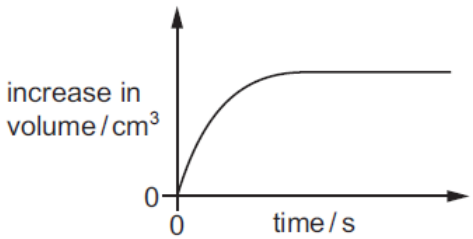
diagram 1



X and Y react and the reaction causes an increase in gas molecules present. The reaction goes to completion.

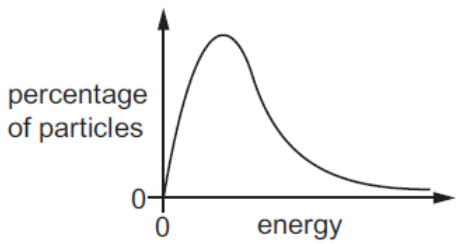
In experiment 1, the increase in volume is measured every 10 seconds. During the reaction, the temperature and pressure remain constant. The increase in volume is shown in the volume–time graph in diagram 2.

diagram 2

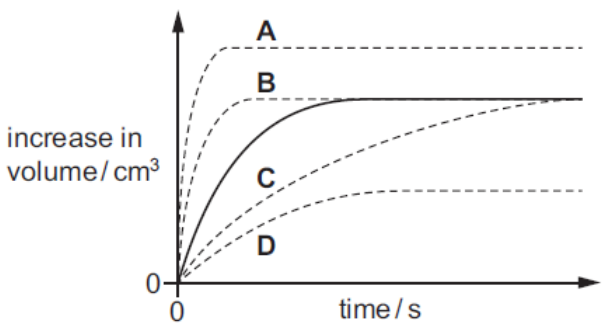


In experiment 2, the experiment is repeated using identical amounts of X and Y. A different temperature is used compared to experiment 1. The same pressure is used. The Boltzmann distribution of the second mixture of X and Y is shown in diagram 3. During the reaction the temperature and pressure remain constant.

diagram 3



Which curve on the volume–time graph would show the increase in volume against time for experiment 2? (The original line for experiment 1 is redrawn as a solid line.)



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4. June/2022/Paper_13/No.16

When the temperature of a particular reaction is increased by 10 °C (e.g. from 20 °C to 30 °C) the rate of the reaction approximately doubles.

What is the **most** significant reason for this increase?

A a different mechanism for the reaction

B an increased collision frequency of the reactant molecules

C more collisions have energy greater than the activation energy

D a reduced activation energy for the reaction

5. June/2022/Paper_21/No.2(c)

(c) Solid Ra and Ca show similar reactions with H_2O, but the reactions occur at different rates.

Separate samples, each containing a single piece of solid Ra or Ca, are added to equal volumes of cold water.

Each sample contains equal numbers of moles of solid and the H_2O is in excess.

(i) Construct an equation for the reaction of Ra with H_2O.

..... [1]

(ii) Identify which element, Ra or Ca, reacts with H_2O at a faster rate. Suggest how the observations of each reaction would differ.

.....

..... [1]

(iii) Suggest why these reactions occur at different rates.

.....

.....

..... [2]

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(iv) One of the solutions is cloudy when the reaction has finished.

At the end of each reaction, universal indicator is added to each reaction mixture.

Suggest pH values of the solutions made in both reactions. Explain your answer.

.....

.....

..... [2]

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6. June/2022/Paper_23/No.3a(v)

(v) Fig. 3.2 shows the Boltzmann distribution of energies for molecules of **G** at constant temperature, T°C.

Sketch, on Fig. 3.2, the Boltzmann distribution of energies for molecules of **G** at a higher temperature, (T+100)°C.

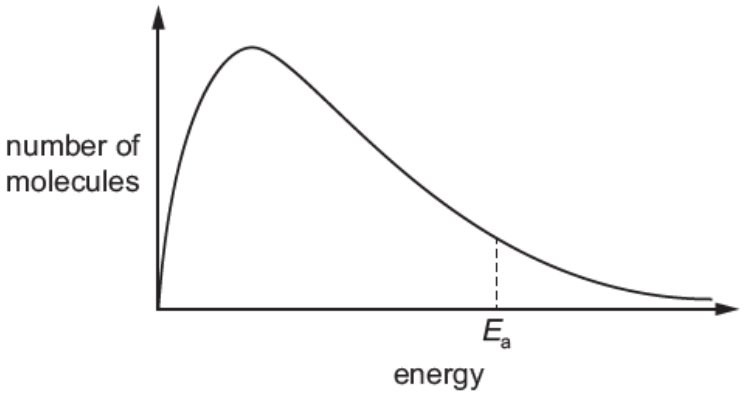


Fig. 3.2

[2]

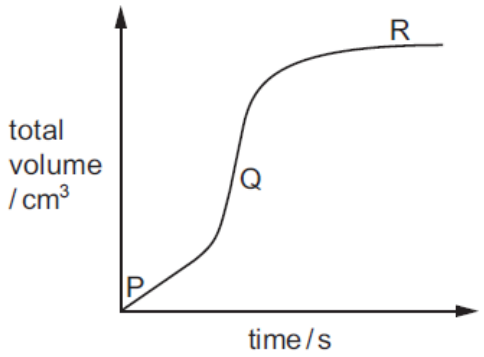
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Reaction Kinetics – 2022 Nov AS Chemistry 9701

1. Nov/2022/Paper_11/No.15

A large excess of magnesium ribbon is added to dilute hydrochloric acid and the volume of hydrogen gas produced is measured as the reaction proceeds. The reaction is exothermic.

The results are shown.



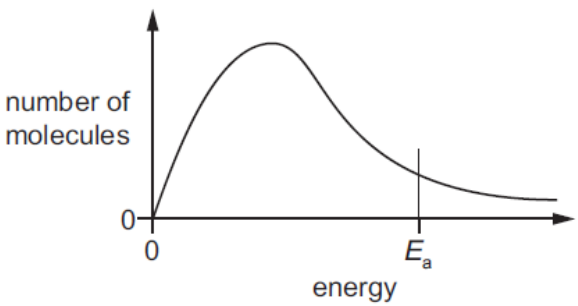
Which row explains the changes in the rate of reaction between points P and Q and between points Q and R?

	between points P and Q	between points Q and R
A	the reaction temperature is increasing	the acid concentration is falling
B	the reaction temperature is increasing	the magnesium has been used up
C	magnesium's surface area is decreasing	the acid concentration is falling
D	magnesium's surface area is decreasing	the magnesium has been used up

2. Nov/2022/Paper_11/No.16

Measurements are made to determine the activation energy, E_a, of a reaction.

The diagram shows E_a on the Boltzmann distribution at temperature T_1.

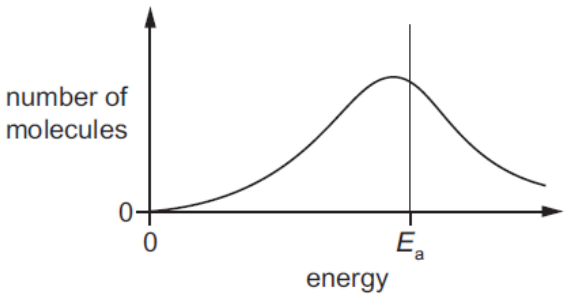


Measurements are then made at a higher temperature, T_2.

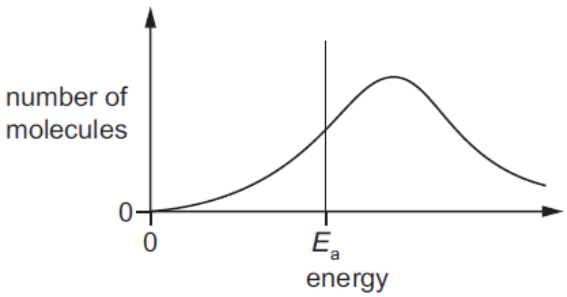
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Which diagram correctly shows the Boltzmann distribution and E_a at T_2?

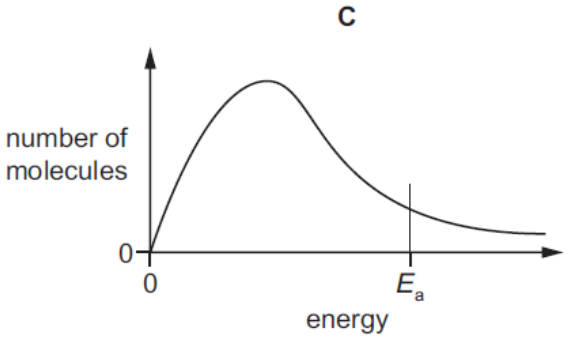
A



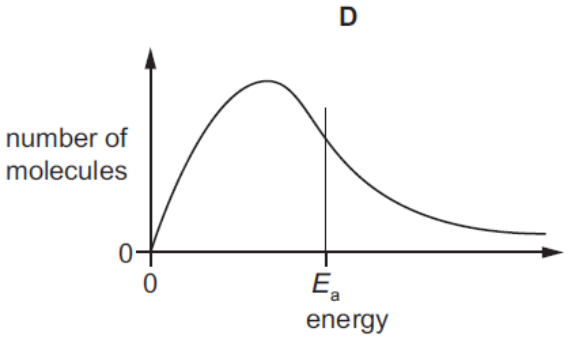
B



C



D



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Reaction Kinetics – 2023 AS Chemistry 9701

1. Nov/2023/Paper_ 9701/11/No.14

In reaction 1, a student measures the initial rate of production of $CO_2(g)$ when $CuCO_3(s)$ is added to 50 cm^3 of 0.1 mol dm^{-3} $HNO_3(aq)$.

In reaction 2, the student repeats the experiment using 50 cm^3 of 0.5 mol dm^{-3} $HNO_3(aq)$ and the same mass of $CuCO_3(s)$.

In reaction 1 and reaction 2, the acid is in excess and samples of the same $CuCO_3$ powder are used.

Which row is correct?

	$\frac{\text{rate of reaction 1}}{\text{rate of reaction 2}}$	$\frac{\text{initial number of effective collisions in reaction 1 per second}}{\text{initial number of effective collisions in reaction 2 per second}}$
A	greater than 1	greater than 1
B	greater than 1	less than 1
C	less than 1	greater than 1
D	less than 1	less than 1

2. Nov/2023/Paper_ 9701/11/No.15

The forward reaction of a reversible reaction is exothermic and has an activation energy of +30 kJ mol^{-1}.

The reverse reaction proceeds by a mechanism that is the exact reverse of the mechanism of the forward reaction.

Which statement about the activation energy of the reverse reaction is correct?

A The activation energy for the reverse reaction is equal to –30 kJ mol^{-1}.

B The activation energy for the reverse reaction is greater than 0 kJ mol^{-1} but less than +30 kJ mol^{-1}.

C The activation energy for the reverse reaction is equal to +30 kJ mol^{-1}.

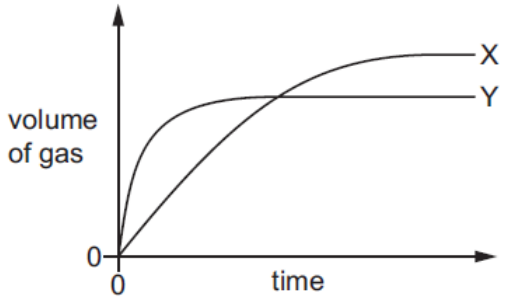
D The activation energy for the reverse reaction is greater than +30 kJ mol^{-1}.

3. Nov/2023/Paper_ 9701/12/No.16

The decomposition of hydrogen peroxide in the presence of MnO_2 produces water and oxygen gas.

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

The volume of gas collected when 0.2 g of MnO_2 is added to two different hydrogen peroxide solutions at 20 °C is shown on the graph as curves X and Y.



Which row shows the conditions that will result in curves X and Y?

	curve X			curve Y		
	volume of H_2O_2 / cm^3	concentration of H_2O_2 / mol dm^{-3}	form of MnO_2	volume of H_2O_2 / cm^3	concentration of H_2O_2 / mol dm^{-3}	form of MnO_2
A	50	0.1	lumps	50	0.2	powder
B	25	0.2	powder	25	0.1	lumps
C	50	0.1	lumps	20	0.2	powder
D	20	0.2	powder	40	0.1	lumps

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4. June/2023/Paper_9701/11/No.11

Iodine and propanone react according to the following equation.

$$I_2(aq) + CH_3COCH_3(aq) \rightarrow CH_3COCH_2I(aq) + HI(aq)$$

If the concentration of propanone is increased, keeping the total reaction volume constant, the initial rate of the reaction also increases.

What could be the reason for this?

A A greater proportion of collisions are successful at the higher concentration.

B The particles are further apart at the higher concentration.

C The particles have more energy at the higher concentration.

D There are more collisions per second between particles at the higher concentration.

5. June/2023/Paper_9701/11/No.15

The temperature of a sample of an inert gas is increased.

What effect does this have on the number of molecules with the most probable energy and on the number of molecules with higher energy?

	number of molecules with the most probable energy	number of molecules with higher energy
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

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6. June/2023/Paper_9701/12/No.15

The equations for two reactions are shown.

reaction X $2NOBr \rightarrow 2NO + Br_2$

reaction Y $2NOCl \rightarrow 2NO + Cl_2$

The two reactions have similar reaction mechanisms.

The initial rate of reaction X is greater than that of reaction Y when measured under identical conditions of temperature, pressure and reactant concentration.

Which statements explain this difference?

1 The activation energy for reaction X is less than that of reaction Y.

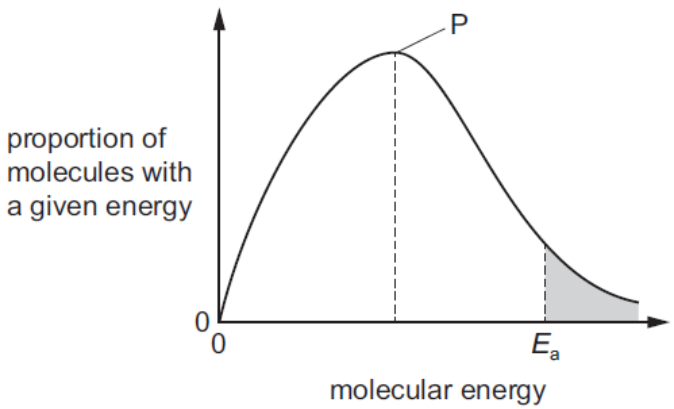
2 The Br–Br bond is weaker than the Cl–Cl bond.

3 A higher frequency of collisions between molecules of NOBr occur than between molecules of NOCl.

A 1 and 2 **B** 2 and 3 **C** 1 only **D** 3 only

7. June/2023/Paper_9701/12/No.16

The diagram shows the Boltzmann distribution of energies in a gas. The gas can take part in a reaction with an activation energy, E_a. The gas is maintained at a constant temperature.



Which statement is correct?

A If a catalyst is added, peak P will be lower and E_a will move to the left.

B If a catalyst is added, peak P will be lower and E_a will move to the right.

C If a catalyst is added, peak P will be the same and E_a will move to the left.

D If a catalyst is added, peak P will be the same and E_a will move to the right.

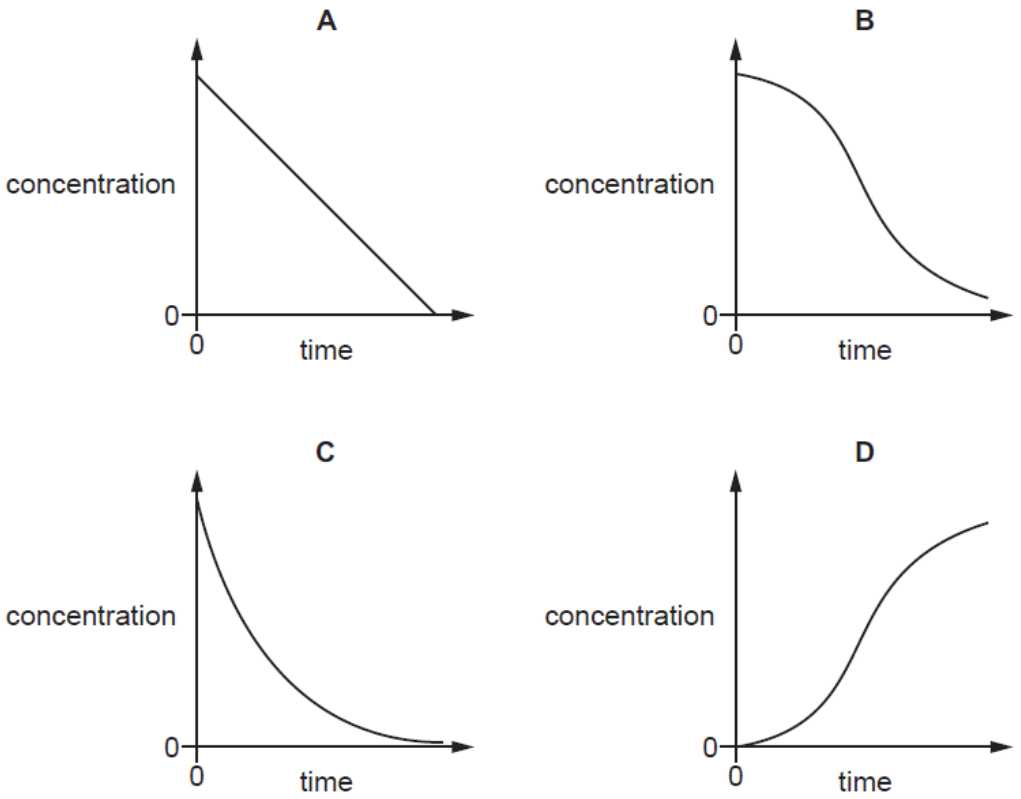
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8. June/2023/Paper_9701/13/No.18

The rate of an exothermic reaction is followed by measuring the concentration of a reactant at regular time intervals.

During the experiment the temperature of the reaction mixture is **not** controlled.

Which graph shows the change in concentration of reactant against time?



9. June/2023/Paper_9701/13/No.19

For a particular reversible reaction the backward reaction is endothermic.

The activation energy of the backward reaction is 160 kJ mol^{-1}.

It can be assumed that the backward reaction proceeds by a mechanism that is the exact reverse of the mechanism for the forward reaction.

Which statement about the activation energy of the forward reaction is correct?

A The activation energy of the forward reaction is equal to –160 kJ mol^{-1}.

B The activation energy of the forward reaction is greater than 0 kJ mol^{-1} but less than +160 kJ mol^{-1}.

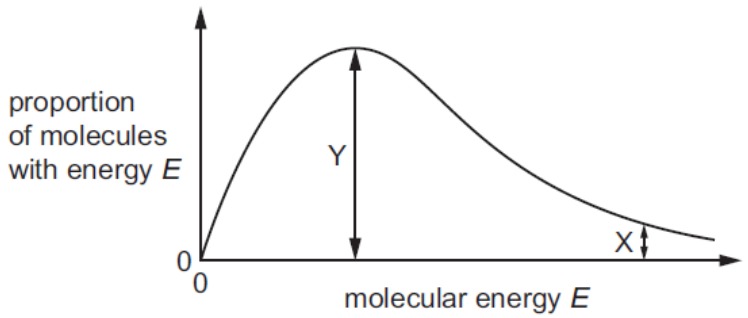
C The activation energy of the forward reaction is equal to +160 kJ mol^{-1}.

D The activation energy of the forward reaction is greater than +160 kJ mol^{-1}.

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10. June/2023/Paper_9701/13/No.21

The diagram shows the Boltzmann distribution of the energy of gaseous molecules at a particular temperature.



Which statement is correct?

A If the temperature of the gas is raised, the height of the maximum of the curve increases.

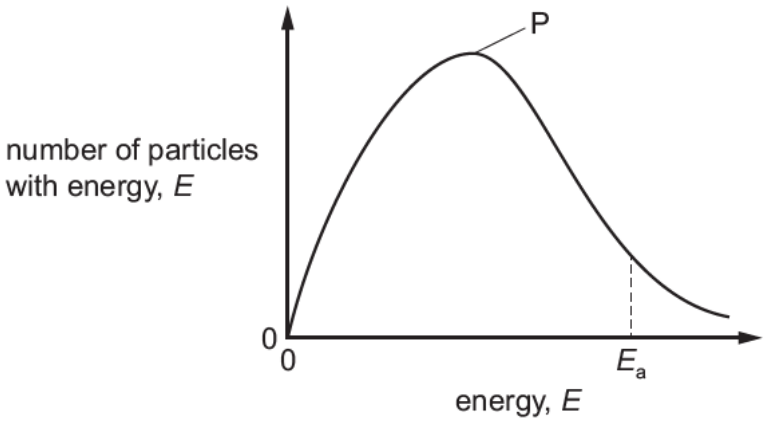
B If the temperature of the gas is raised, the maximum of the curve moves to the right.

C The length of the line labelled X shows the activation energy for the reaction.

D The length of the line labelled Y shows the enthalpy change of the reaction.

11. March/2023/Paper_9701/12/No.2

The diagram shows the Boltzmann distribution for one mole of a gas. The gas takes part in a reaction with an activation energy, E_a.



Which statement correctly describes the effect of an increase in temperature?

A Peak P will be higher and fewer molecules will have energy > E_a.

B Peak P will be higher and more molecules will have energy > E_a.

C Peak P will be lower and fewer molecules will have energy > E_a.

D Peak P will be lower and more molecules will have energy > E_a.

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12. March/2023/Paper_9701/12/No.3

A student carries out four experiments to investigate the rate of reaction between 3.0 g of calcium carbonate and hydrochloric acid.

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$$

experiment 1	$CaCO_3$ powder + 2.0 mol dm^{-3} HCl at 35 °C
experiment 2	$CaCO_3$ powder + 2.0 mol dm^{-3} HCl at 35 °C
experiment 3	large chips of $CaCO_3$ + 1.0 mol dm^{-3} HCl at room temperature
experiment 4	large chips of $CaCO_3$ + 1.0 mol dm^{-3} HCl at 35 °C

The student collects the $CO_2(g)$ and times how long it takes to produce the same volume of gas for each experiment.

What could be the correct times for the four experiments?

	experiment 1 / s	experiment 2 / s	experiment 3 / s	experiment 4 / s
A	5	10	30	95
B	5	10	95	30
C	5	30	95	10
D	95	30	10	5

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