Please check the examination details below before entering your candidate information

Candidate surname	Other names
StemUp Model Solution	

Pearson Edexcel Level 3 GCE

Centre Number	Candidate Number

Thursday 21 May 2020

Morning (Time: 1 hour 30 minutes)	Paper Reference **8CH0/02**

Chemistry

Advanced Subsidiary

Paper 2: Core Organic and Physical Chemistry

Candidates must have: Scientific calculator
Data Booklet
Ruler

Total Marks

Instructions

- Use **black** ink or **black** ball-point pen.
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided
  – *there may be more space than you need.*

Information

- The total mark for this paper is 80.
- The marks for **each** question are shown in brackets
  – *use this as a guide as to how much time to spend on each question.*
- For the question marked with an **asterisk** (*), marks will be awarded for your ability to structure your answer logically showing the points that you make are related or follow on from each other where appropriate.
- A Periodic Table is printed on the back cover of this paper.

Advice

- Read each question carefully before you start to answer it.
- Show all your working in calculations and include units where appropriate.
- Check your answers if you have time at the end.

Turn over ▶

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Answer ALL questions.

Some questions must be answered with a cross in a box ☒.
If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 This question is about organic compounds containing fluorine and chlorine.

(a) The use of chlorofluorocarbons as refrigerants has ceased due to concerns about their effects on the ozone layer. One such compound is dichlorodifluoromethane.

Give the molecular formula of dichlorodifluoromethane.

(1)

CCl_2F_2

(b) (i) A different refrigerant contains 34.0% chlorine and 54.5% fluorine by mass, with the remainder carbon.

Calculate the empirical formula of this compound.

(3)

C = 100 − (34.0 + 54.5) = 11.5 %

Cl : 34.0 ÷ 35.5 = 0.958

F : 54.5 ÷ 19.0 = 2.868

C : 11.5 ÷ 12.0 = 0.958

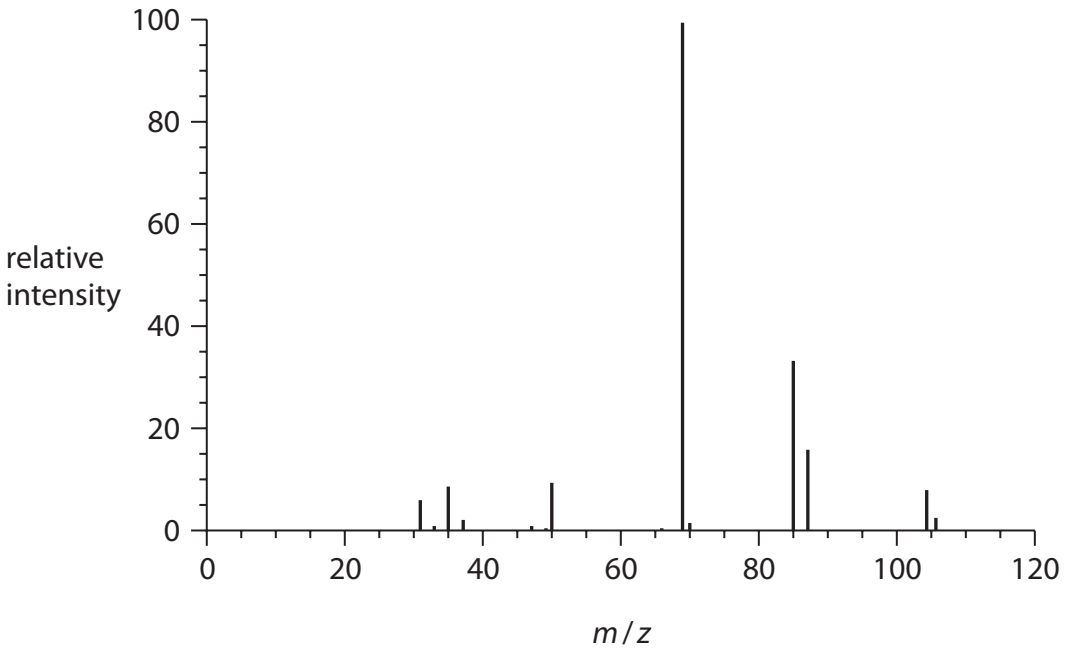
divide by smallest (0.958): Cl = 1, F = 2.99 ≈ 3, C = 1

empirical formula = $CClF_3$

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(ii) Use the mass spectrum to show that the empirical and the molecular formulae of this compound are the same.

(1)



The molecular ion peak is at m/z = 104 (and 106, due to the ^{37}Cl isotope). This matches the mass of the empirical formula $CClF_3$ (12.0 + 35.5 + 3 × 19.0 = 104.5), so the molecular formula is also $CClF_3$.

(iii) Suggest the species responsible for the peak at $m/z = 69$.

(1)

CF_3^+

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(c) Compounds containing carbon and fluorine but no chlorine can be used as refrigerants as they are not harmful to the ozone layer.
These can be made by the reaction of fluorine with alkanes or fluoroalkanes.
A refrigerant currently in use contains the compound trifluoromethane, CHF_3.

(i) Write the equation for the formation of trifluoromethane by the reaction of difluoromethane with fluorine. State symbols are not required.

(1)

$CH_2F_2 + F_2 \rightarrow CHF_3 + HF$

(ii) The mechanism for this reaction is similar to that of the reaction between chlorine and methane.

Give the equations for the following steps in the mechanism for the reaction between fluorine and difluoromethane. Curly arrows are not required.

(3)

Initiation step

$F_2 \rightarrow 2F\cdot$

First propagation step

$F\cdot + CH_2F_2 \rightarrow \cdot CHF_2 + HF$

Second propagation step

$\cdot CHF_2 + F_2 \rightarrow CHF_3 + F\cdot$

(Total for Question 1 = 10 marks)

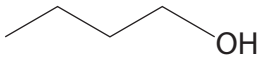
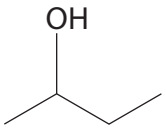
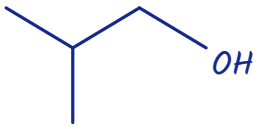
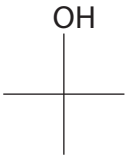
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2 This question is about alcohols and their reactions.

The table gives some of the names and skeletal formulae of isomers having the formula C_4H_9OH.

(a) Complete the table.

(2)

Name	Skeletal formula
butan-1-ol	
butan-2-ol	
2-methylpropan-1-ol	
2-methylpropan-2-ol	

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(b) (i) Some alcohols react with concentrated phosphoric acid to form alkenes.

What is the type of this reaction?

(1)

☒ **A** addition

☒ **B** elimination

☒ **C** oxidation

☒ **D** substitution

(ii) When butan-2-ol reacts with concentrated phosphoric acid, two stereoisomers are formed.

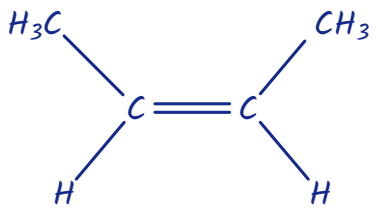
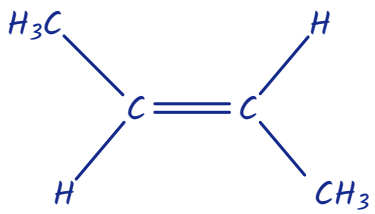
Explain what is meant by the term stereoisomers.

(2)

Stereoisomers are compounds with the same structural formula (same molecular formula and same order of bonded atoms) but with a different arrangement of the atoms (bonds) in space.

(iii) Draw the structures and give the names of the two stereoisomers.

(2)

Stereoisomer 1	Stereoisomer 2
	
Name: *Z-but-2-ene (cis)*	Name: *E-but-2-ene (trans)*

(iv) Name this type of stereoisomerism.

(1)

geometric (E/Z or cis-trans) isomerism

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(c) 2-methylpropan-2-ol may be formed by the reaction between 2-bromo-2-methylpropane and aqueous potassium hydroxide.

What is the role of the hydroxide ions in this reaction?

(1)

- ☒ **A** alkali
- ☒ **B** catalyst
- ☒ **C** electrophile
- ☒ **D** nucleophile

(d) (i) $CH_3CH_2CH_2CH_2OH$ reacts with the oxidising agent potassium dichromate(VI) in dilute sulfuric acid.

Two organic products can be formed, depending on the conditions.

Write a balanced equation for the formation of **one** of these products, giving its name and the condition required to achieve this product in high yield.

Use **[O]** in the equation to represent each oxygen atom from the oxidising agent.

(3)

Equation

$CH_3CH_2CH_2CH_2OH + 2[O] \rightarrow CH_3CH_2CH_2COOH + H_2O$

Name *butanoic acid*

Condition *heat under reflux (with excess oxidising agent)*

(ii) The colour of the solution at the end of the reaction in (d)(i) will be

(1)

- ☒ **A** brown
- ☒ **B** green
- ☒ **C** orange
- ☒ **D** yellow

(Total for Question 2 = 13 marks)

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3 This question is about reaction kinetics.

(a) The best way to describe the activation energy of a reaction is

(1)

☒ **A** the average energy of the particles when they react

☒ **B** the difference in energy between the reactants and the products

☒ **C** the minimum energy required to make the particles collide

☒ **D** the minimum energy required for a reaction to occur

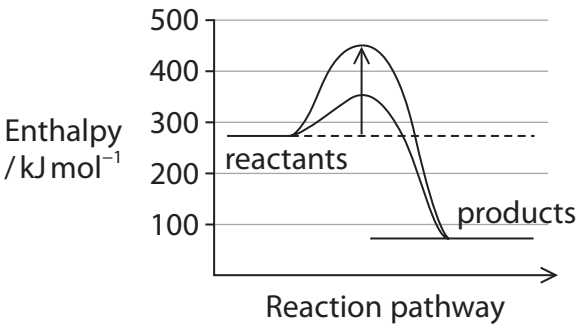
(b) The diagrams show two reaction profiles for the same reversible reaction involving gaseous reactants.

Shown on each diagram are the reaction profiles for the pathway without a catalyst and the pathway catalysed by a heterogeneous catalyst.

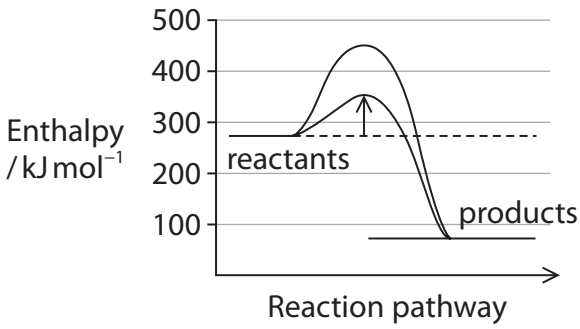
(i) In which diagram does the arrow represent the activation energy for the backward reaction when a catalyst is present?

(1)

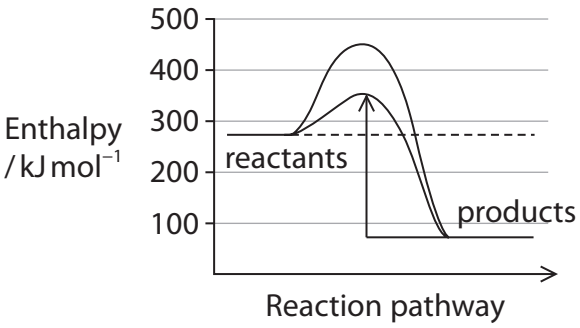
☒ **A**



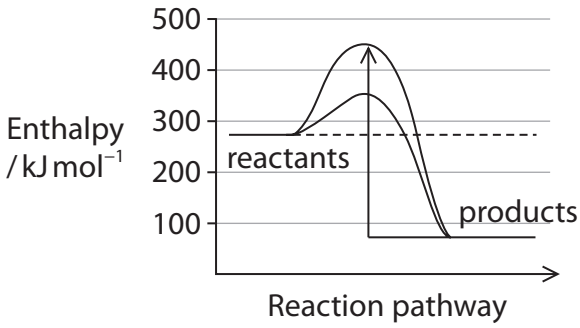
☒ **B**



☒ **C**



☒ **D**



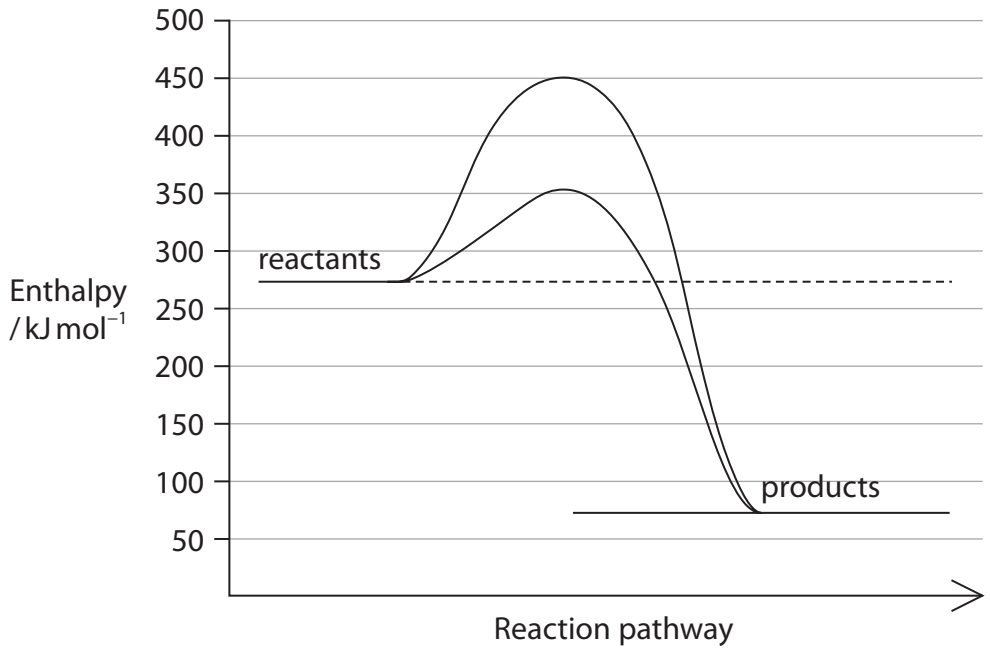
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(ii) Estimate, using the diagram, the **decrease** in the activation energy for the forward reaction when a catalyst is added.

(1)



- ☐ **A** 75 kJ mol^{-1}
- ☒ **B** 100 kJ mol^{-1}
- ☐ **C** 175 kJ mol^{-1}
- ☐ **D** 200 kJ mol^{-1}

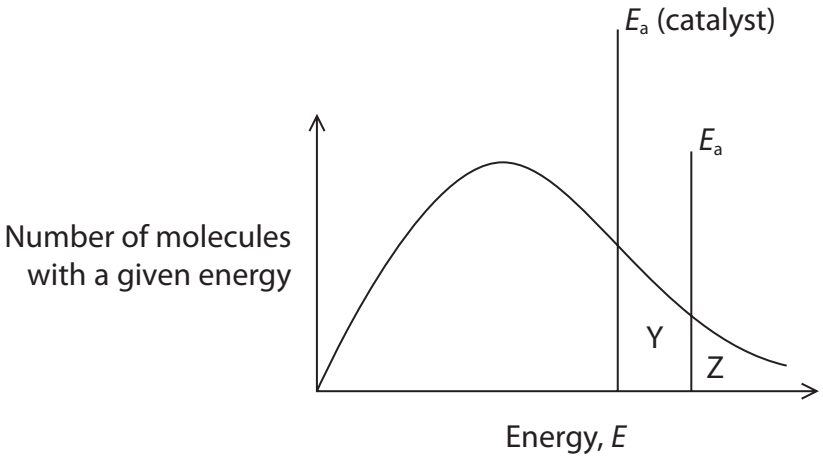
(c) State why a **solid** (heterogeneous) catalyst is suitable for a reaction in the **gas** phase.

(1)

It provides a surface for the reaction: the gas molecules are adsorbed onto the surface of the solid, where they react, and the solid is easily separated from the gaseous products.

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(d) The diagram shows a Maxwell-Boltzmann distribution of molecular energies for gaseous molecules.



(i) Which is the area of the graph corresponding to the number of molecules with sufficient energy to react when a catalyst is present?

(1)

☒ **A** Y

☒ **B** Y – Z

☒ **C** Y + Z

☒ **D** Z

(ii) Which would always result in a **decrease** in the number of molecules contained within area Y?

(1)

☒ **A** decreasing the temperature of the gas

☒ **B** increasing the pressure of the gas

☒ **C** putting the gas in a smaller container

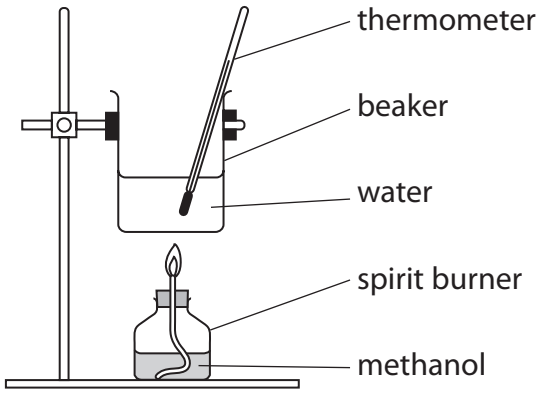
☒ **D** removing a quarter of the catalyst

(Total for Question 3 = 6 marks)

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4 Methanol, CH_3OH, is a liquid fuel.

An experiment was carried out to determine the enthalpy change of combustion of liquid methanol.



The energy obtained from burning 2.08 g of methanol was used to heat 75.0 g of water.

The temperature of the water rose from 25.0 °C to 91.0 °C.

[Specific heat capacity of water = 4.18 $J\,g^{-1}\,°C^{-1}$]

(a) Use the data to calculate a value for the enthalpy change of combustion of one mole of methanol.

Give your answer to an appropriate number of significant figures and include a sign and units.

(4)

energy absorbed by water, Q = mcΔT = 75.0 × 4.18 × (91.0 − 25.0)

Q = 75.0 × 4.18 × 66.0 = 20 691 J

moles of methanol = 2.08 ÷ 32.0 = 0.0650 mol

energy per mole = 20 691 ÷ 0.0650 = 318 323 J mol^{-1}

= 318 kJ mol^{-1}, released (exothermic) so negative

$\Delta_c H$ = −318 kJ mol^{-1} (3 s.f.)

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(b) Methanol can be synthesised from methane and steam by a process that occurs in two steps.

Step **1** $CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g)$ $\Delta H = +206\,kJ\,mol^{-1}$

Step **2** $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$ $\Delta H = -91\,kJ\,mol^{-1}$

(i) Explain the effects of increasing the pressure on the yield of the products and on the rate of the reaction in Step **1**.

(4)

Yield: increasing the pressure decreases the yield of the products, because the position of equilibrium shifts to the side with fewer moles of gas, and the left hand side has fewer moles of gas (2 moles of gaseous reactants form 4 moles of gaseous products). So the equilibrium shifts to the left.

Rate: increasing the pressure increases the rate of reaction, because there are more gas particles in a given volume, so collisions occur at an increased frequency (more collisions per second), so there are more successful collisions per unit time.

(ii) Step **2** is carried out at a compromise temperature of 500 K.

Explain why 500 K is considered to be a compromise for Step **2** by considering what would happen at higher and lower temperatures.

(3)

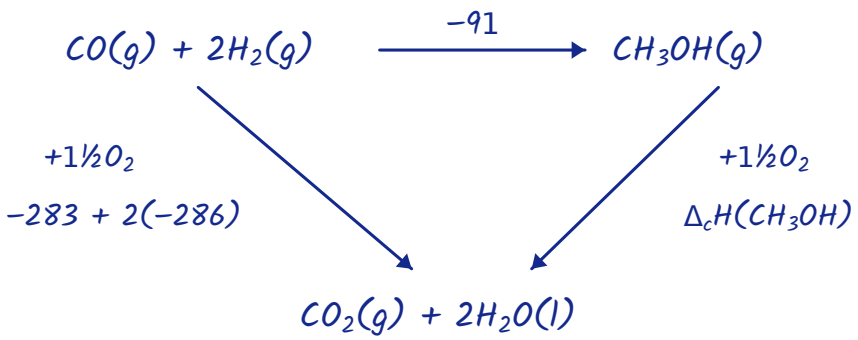
At higher temperatures the rate would be faster but the yield of methanol would be less, because the forward reaction is exothermic so the equilibrium shifts to the left. At lower temperatures the yield would be higher but the reaction would be too slow. So 500 K is a compromise between yield and rate: it gives a reasonable yield at a reasonable rate.

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(c) Calculate a value for the standard enthalpy change of combustion of gaseous methanol using the enthalpy change for Step **2** and the standard enthalpy change of combustion of gaseous carbon monoxide and of hydrogen.

Substance	Standard enthalpy change of combustion / kJ mol^{-1}
CO	−283
H_2	−286

(3)



$\Delta_cH(CH_3OH) = -\Delta H(\text{step 2}) + \Delta_cH(CO) + 2\Delta_cH(H_2)$

$= +91 + (-283) + 2 \times (-286)$

$\Delta_cH(CH_3OH, g) = -764 \text{ kJ mol}^{-1}$

(Total for Question 4 = 14 marks)

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5 This question concerns iodine monochloride, ICl, a red-brown solid which melts at 27 °C to form a red-brown liquid.

Iodine monochloride is used in measuring unsaturation in organic compounds.

(a) Iodine monochloride gas can be produced by the reaction between iodine vapour and chlorine gas. The reaction is exothermic.

$$I_2(g) + Cl_2(g) \rightarrow 2ICl(g) \quad \Delta_r H = -30\,kJ\,mol^{-1}$$

The table shows bond energy values for the bonds in iodine and chlorine.

Calculate the value of the bond energy of the I—Cl bond using these data and the equation.

Bond	Energy / kJ mol^{-1}
I—I	151
Cl—Cl	243

(2)

bonds broken: I–I + Cl–Cl = 151 + 243 = 394 kJ mol^{-1}

ΔH = bonds broken − bonds made

−30 = 394 − 2 × E(I–Cl)

2 × E(I–Cl) = 394 + 30 = 424

E(I–Cl) = 424 ÷ 2 = +212 kJ mol^{-1}

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(b) Iodine monochloride is a polar molecule which adds rapidly to double bonds in a similar way to hydrogen chloride. This reaction can be used to determine the degree of unsaturation in oils.

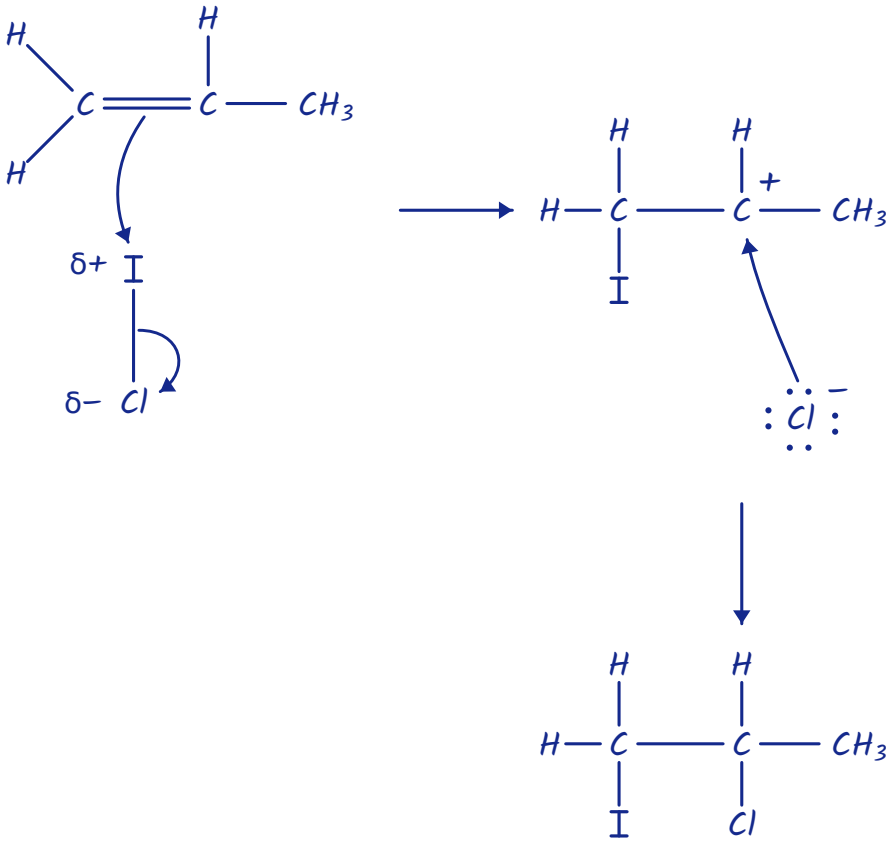
(i) Add the dipole to a molecule of iodine monochloride.

(1)

$$\overset{\delta+}{I}—\overset{\delta-}{Cl}$$

(ii) Draw the mechanism for the addition of iodine monochloride to propene. You should include all curly arrows and relevant lone pairs and dipoles.

(3)



2-chloro-1-iodopropane

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(c) (i) To determine the extent of unsaturation of an oil, 0.250 g of the oil was treated with 25.00 cm^3 of a 0.100 mol dm^{-3} ICl solution. Unreacted ICl reacted with excess potassium iodide solution, forming iodine according to the equation:

$$ICl + KI \rightarrow I_2 + KCl$$

The amount of iodine produced was measured by reacting the mixture with a solution of sodium thiosulfate, $Na_2S_2O_3$.

The iodine released reacted with 32.65 cm^3 of 0.100 mol dm^{-3} sodium thiosulfate solution in the mole ratio of 1 mol I_2 : 2 mol $Na_2S_2O_3$.

Calculate the number of moles of iodine monochloride which reacted with 0.250 g of the oil.

(3)

moles of ICl added = 25.00 × 0.100 ÷ 1000 = 2.50 × 10^{-3} mol

moles of $Na_2S_2O_3$ = 32.65 × 0.100 ÷ 1000 = 3.265 × 10^{-3} mol

moles of I_2 = 3.265 × 10^{-3} ÷ 2 = 1.6325 × 10^{-3} mol

= moles of unreacted ICl (1 ICl : 1 I_2)

moles of ICl reacted = 2.50 × 10^{-3} − 1.6325 × 10^{-3}

= 8.675 × 10^{-4} mol

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(ii) Unsaturation in oils is measured using a scale called 'Iodine number'.
This is the mass of iodine which will react with 100 g of the oil.
Because iodine adds very slowly to double bonds, the reaction of iodine monochloride is used instead.

Given that 1 mol of I_2 is equivalent to 1 mol of ICl, use your answer in (c)(i) to calculate the mass of iodine that would react with 100 g of oil and hence identify the unsaturated oil from the list of possible oils and their iodine numbers.

Oil	Iodine number
cocoa butter	35–40
coconut oil	7–10
cod liver oil	145–180
palm oil	44–51
peanut oil	84–106

(2)

mass of $I_2 = 8.675 \times 10^{-4} \times 253.8 = 0.220$ g (per 0.250 g oil)

mass for 100 g of oil = $0.220 \times (100 \div 0.250) = 0.220 \times 400$

= 88.1 g, so iodine number ≈ 88

The oil is peanut oil (84–106).

(iii) Give a reason why the reaction of iodine monochloride is significantly faster than the reaction of iodine.

(1)

ICl has a permanent dipole ($I\delta+$) so the iodine is a better electrophile, but I_2 is non-polar with no permanent dipole.

(Total for Question 5 = 12 marks)

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6 Aqueous hydrogen peroxide decomposes according to the following equation.

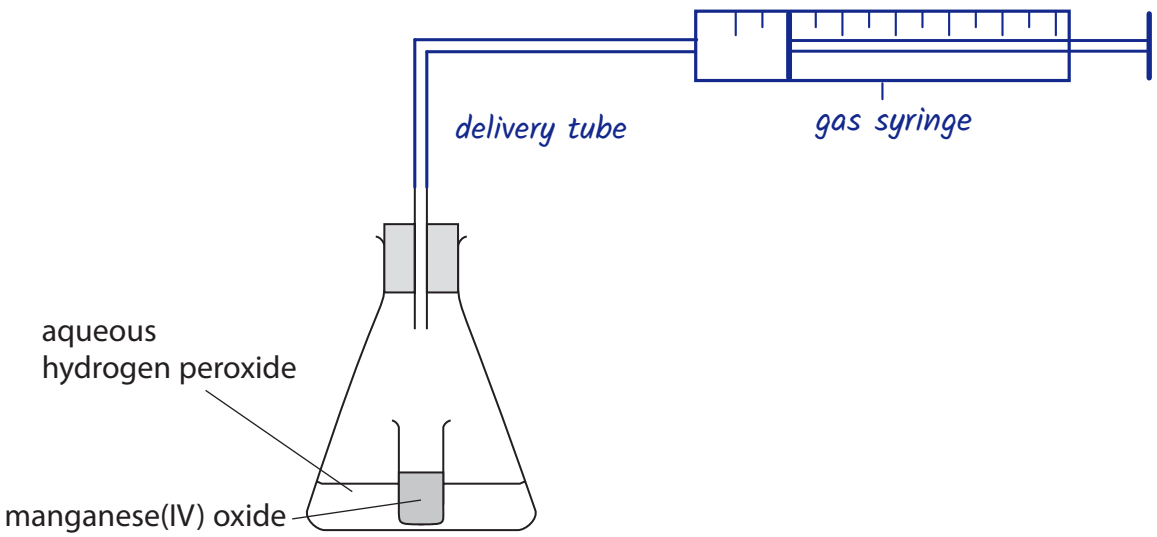
$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

The decomposition is catalysed by manganese(IV) oxide.

This can be investigated by measuring the volume of oxygen produced at various times as the reaction proceeds. Part of the apparatus used in the experiment is shown. The manganese(IV) oxide is placed in a small glass container, which is then tipped over to start the reaction. A stop clock is started at the same time.

(a) Complete the diagram to show how the gas can be collected **and** its volume measured, labelling the apparatus used.

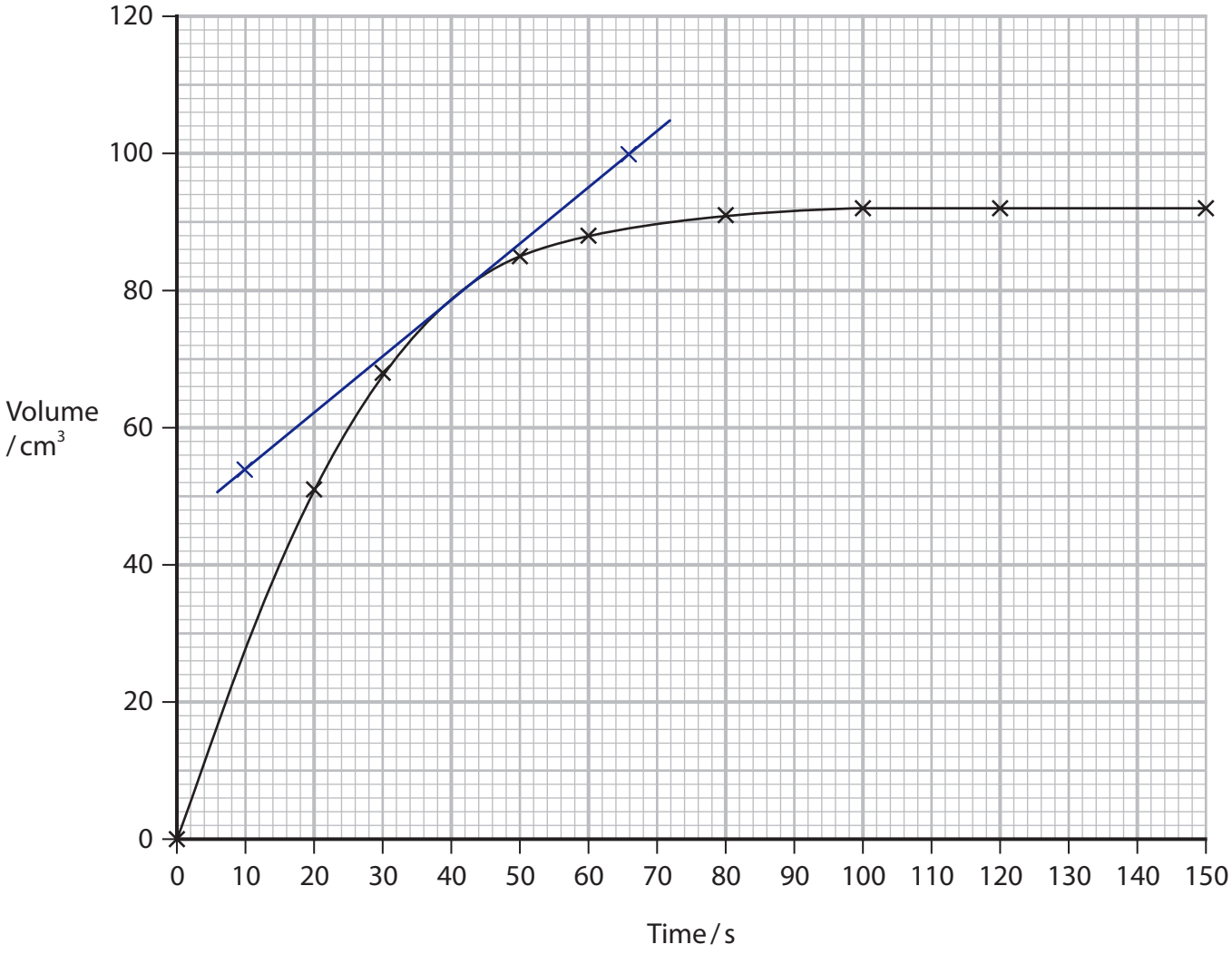
(2)



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(b) An experiment was carried out using 0.25 g of manganese(IV) oxide granules and 50 cm^3 of aqueous hydrogen peroxide of concentration 0.16 mol dm^{-3}. The results are shown in the table and plotted on a graph.

Time / s	0.0	20.0	30.0	50.0	60.0	80.0	100	120	150
Volume of O_2 / cm^3	0	51	68	85	88	91	92	92	92



(i) The rate of reaction may be assumed to be approximately constant up to the first volume measurement (20.0 s in this experiment).

Use this approximation to calculate the initial rate of this reaction, giving the **units** with your answer.

(1)

initial rate = 51 ÷ 20.0 = 2.55 cm^3 s^{-1}

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(ii) Draw a tangent at 40 s on the graph on Page 20 and use it to calculate the rate of reaction at this time.

(2)

tangent drawn at 40 s on the graph on page 20

gradient = (100 – 54) ÷ (66 – 10)

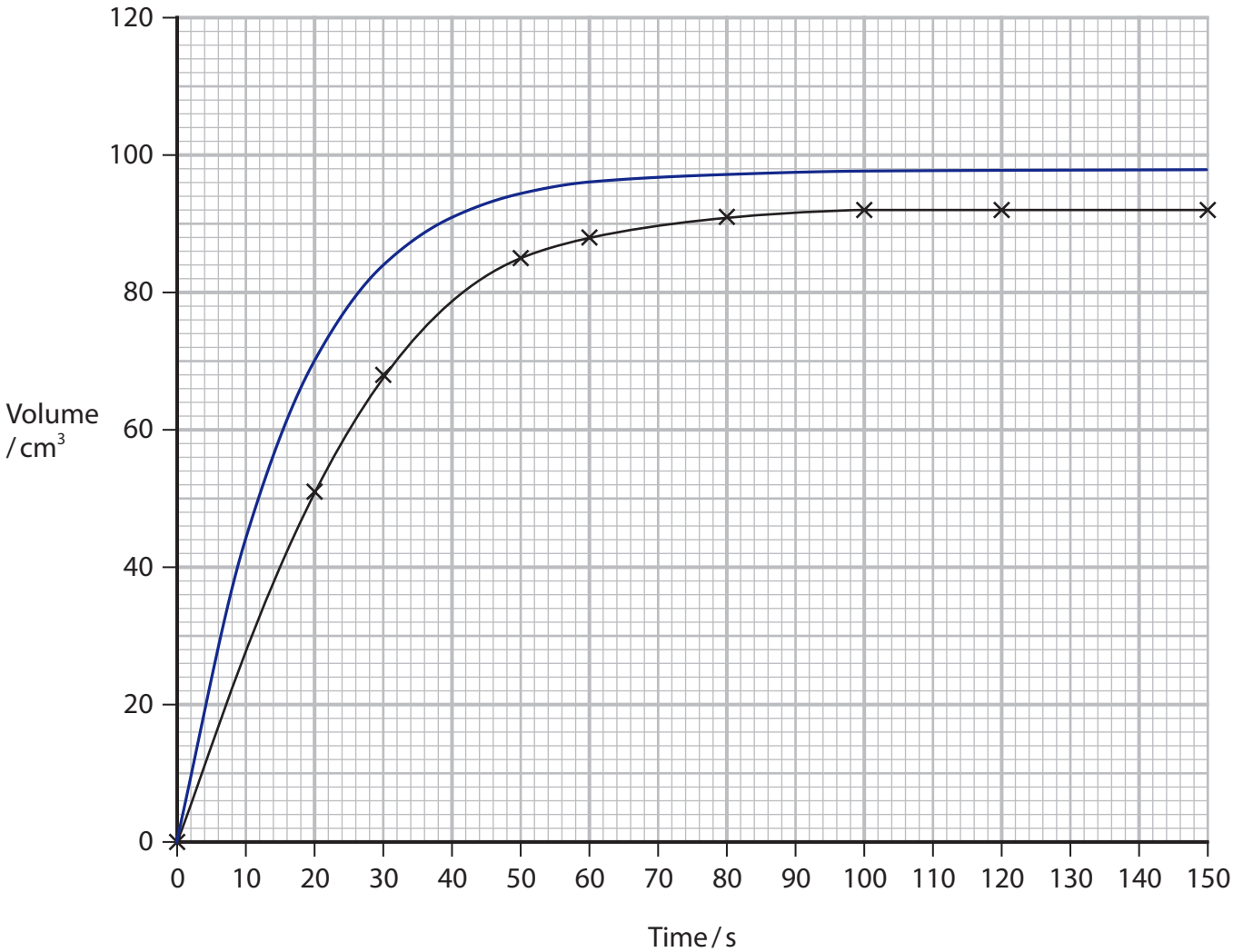
= 46 ÷ 56

rate at 40 s = 0.82 cm^3 s^{-1}

(iii) The experiment was repeated on a different day when the laboratory was 20 °C warmer. The volume of oxygen was recorded for the same total time of 150 s.

Draw the line that you would expect to obtain in this experiment. Assume the pressure in the laboratory is the same. No calculation is required.

(2)



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(iv) Explain, using collision theory, any differences between the line you have drawn and the original line of best fit.

(2)

The new line is steeper (the rate of reaction is faster) at the higher temperature, because the particles have more energy, so a greater proportion of collisions have energy greater than or equal to the activation energy.

The final volume is slightly higher because the volume of a gas increases with temperature.

(c) Catalysts are not used up during a reaction. Manganese(IV) oxide acts as a heterogeneous catalyst.

Describe in outline a method to show that the manganese(IV) oxide is not used up in the decomposition of hydrogen peroxide **and** that it still functions as a catalyst.

(4)

After the reaction has finished, filter the mixture to collect the solid manganese(IV) oxide.

Rinse the solid with water and dry it (e.g. in a warm oven or desiccator).

Reweigh the dry solid: it should still weigh 0.25 g, showing that the manganese(IV) oxide has not been used up.

Then repeat the experiment with the recovered manganese(IV) oxide and a fresh 50 cm^3 sample of the 0.16 mol dm^{-3} hydrogen peroxide, under the same conditions.

Identical results (the same volumes of O_2 at the same times) show that it still functions as a catalyst.

(Total for Question 6 = 13 marks)

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7 Halogenoalkanes react with water to produce alcohols and halide ions.

$$C_4H_9X + H_2O \rightarrow C_4H_9OH + X^- + H^+$$

(a) Test tube experiments can be carried out to investigate the relative rates of these substitution reactions.

The halogenoalkanes 1-chlorobutane, 1-bromobutane and 1-iodobutane can be used.

Some of the steps in these experiments are

- each halogenoalkane is added to a different tube containing 1 cm^3 of ethanol
- the test tubes are placed in the same beaker of hot water
- aqueous silver nitrate is added to each tube and the tubes are shaken
- a precipitate forms in each tube.

(i) State the purpose of adding ethanol to each of the test tubes.

(1)

Ethanol acts as a co-solvent: it dissolves both the halogenoalkane and the water, so they mix to form a homogeneous mixture.

(ii) Give **one** reason why the test tubes were put in the same beaker of hot water.

(1)

So that all the tubes are at the same temperature, so only the type of halogen affects the rate of reaction.

(iii) Give **one** reason why the test tubes were shaken after the addition of aqueous silver nitrate.

(1)

To ensure the reactants are mixed thoroughly (so the mixture is homogeneous).

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(b) (i) State how the halogen atom present in each halogenoalkane can be identified using observations from this experiment in (a).

(1)

From the colour of the precipitate: a white precipitate shows chloride (1-chlorobutane), a cream precipitate shows bromide (1-bromobutane) and a yellow precipitate shows iodide (1-iodobutane).

(ii) Identify further reagents that can be added, including relevant observations, to confirm the identity of the halogen atom present in each halogenoalkane.

(2)

Add dilute ammonia solution, then concentrated ammonia solution, to each precipitate. AgCl (from 1-chlorobutane) dissolves in dilute ammonia; AgBr (from 1-bromobutane) dissolves only in concentrated ammonia; AgI (from 1-iodobutane) is insoluble in both dilute and concentrated ammonia.

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*(c) Outline the method for a test tube experiment, **which expands on the steps in (a)**, to investigate how the rate of the substitution reaction depends on whether the halogenoalkane is primary, secondary or tertiary.

Your experiment should test a series of isomeric bromoalkanes reacting with water.

Your plan should include

- the chemicals you will use
- an outline of how the experiment will be carried out
- the observations or measurements you will make and how you will interpret them.

(6)

Chemicals: use a series of isomeric bromoalkanes, C_4H_9Br: 1-bromobutane (primary), 2-bromobutane (secondary) and 2-bromo-2-methylpropane (tertiary), with ethanol, water and aqueous silver nitrate.

Method: add the same volume (or the same number of moles, e.g. 5 drops) of each bromoalkane to separate test tubes, each containing 1 cm^3 of ethanol. In other test tubes put equal volumes (e.g. 1 cm^3) of the same aqueous silver nitrate solution. Place all the tubes in the same beaker of hot water (e.g. 50 °C) so they reach the same temperature.

Add the silver nitrate solution to each bromoalkane at the same moment, shake to mix and start a stop clock.

Measurements: time how long it takes for a cream precipitate of silver bromide to first appear in each tube (or observe the order in which the precipitates form). The precipitate forms as the Br^- ions are released by the substitution (hydrolysis) reaction.

Interpretation: the shorter the time taken for the precipitate to appear, the faster the rate of reaction, since rate is proportional to 1 ÷ time.

Expected result: the precipitate forms first with the tertiary bromoalkane (2-bromo-2-methylpropane), then the secondary (2-bromobutane) and last with the primary (1-bromobutane). So the order of rate is tertiary > secondary > primary.

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(Total for Question 7 = 12 marks)

TOTAL FOR PAPER = 80 MARKS

The Periodic Table of Elements

1	2											3	4	5	6	7	0 (8) (18)
							1.0 H hydrogen 1										4.0 He helium 2
(1)	(2)		Key									(13)	(14)	(15)	(16)	(17)	
6.9 Li lithium 3	9.0 Be beryllium 4		relative atomic mass atomic symbol name atomic (proton) number									10.8 B boron 5	12.0 C carbon 6	14.0 N nitrogen 7	16.0 O oxygen 8	19.0 F fluorine 9	20.2 Ne neon 10
23.0 Na sodium 11	24.3 Mg magnesium 12	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	27.0 Al aluminium 13	28.1 Si silicon 14	31.0 P phosphorus 15	32.1 S sulfur 16	35.5 Cl chlorine 17	39.9 Ar argon 18
39.1 K potassium 19	40.1 Ca calcium 20	45.0 Sc scandium 21	47.9 Ti titanium 22	50.9 V vanadium 23	52.0 Cr chromium 24	54.9 Mn manganese 25	55.8 Fe iron 26	58.9 Co cobalt 27	58.7 Ni nickel 28	63.5 Cu copper 29	65.4 Zn zinc 30	69.7 Ga gallium 31	72.6 Ge germanium 32	74.9 As arsenic 33	79.0 Se selenium 34	79.9 Br bromine 35	83.8 Kr krypton 36
85.5 Rb rubidium 37	87.6 Sr strontium 38	88.9 Y yttrium 39	91.2 Zr zirconium 40	92.9 Nb niobium 41	95.9 Mo molybdenum 42	[98] Tc technetium 43	101.1 Ru ruthenium 44	102.9 Rh rhodium 45	106.4 Pd palladium 46	107.9 Ag silver 47	112.4 Cd cadmium 48	114.8 In indium 49	118.7 Sn tin 50	121.8 Sb antimony 51	127.6 Te tellurium 52	126.9 I iodine 53	131.3 Xe xenon 54
132.9 Cs caesium 55	137.3 Ba barium 56	138.9 La* lanthanum 57	178.5 Hf hafnium 72	180.9 Ta tantalum 73	183.8 W tungsten 74	186.2 Re rhenium 75	190.2 Os osmium 76	192.2 Ir iridium 77	195.1 Pt platinum 78	197.0 Au gold 79	200.6 Hg mercury 80	204.4 Tl thallium 81	207.2 Pb lead 82	209.0 Bi bismuth 83	[209] Po polonium 84	[210] At astatine 85	[222] Rn radon 86
[223] Fr francium 87	[226] Ra radium 88	[227] Ac* actinium 89	[261] Rf rutherfordium 104	[262] Db dubnium 105	[266] Sg seaborgium 106	[264] Bh bohrium 107	[277] Hs hassium 108	[268] Mt meitnerium 109	[271] Ds darmstadtium 110	[272] Rg roentgenium 111							

Elements with atomic numbers 112-116 have been reported but not fully authenticated

* Lanthanide series	140 Ce cerium 58	141 Pr praseodymium 59	144 Nd neodymium 60	[147] Pm promethium 61	150 Sm samarium 62	152 Eu europium 63	157 Gd gadolinium 64	159 Tb terbium 65	163 Dy dysprosium 66	165 Ho holmium 67	167 Er erbium 68	169 Tm thulium 69	173 Yb ytterbium 70	175 Lu lutetium 71
* Actinide series	232 Th thorium 90	[231] Pa protactinium 91	238 U uranium 92	[237] Np neptunium 93	[242] Pu plutonium 94	[243] Am americium 95	[247] Cm curium 96	[245] Bk berkelium 97	[251] Cf californium 98	[254] Es einsteinium 99	[253] Fm fermium 100	[256] Md mendelevium 101	[254] No nobelium 102	[257] Lr lawrencium 103

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