Please check the examination details below before entering your candidate information

Candidate surname	Other names
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Pearson Edexcel Level 3 GCE

Centre Number	Candidate Number

Wednesday 17 June 2020

Morning (Time: 2 hours 30 minutes)	Paper Reference **9CH0/03**

Chemistry

Advanced

Paper 3: General and Practical Principles in Chemistry

Candidates must have: **Data Booklet**
Scientific calculator
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 120.
- 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.

1 Aqueous sodium carbonate and aqueous sodium sulfate are both colourless solutions.

(a) Give the reagent and the observation to show the presence of carbonate ions.

(2)

Add dilute hydrochloric acid, $HCl(aq)$.

Effervescence (fizzing) is seen; the gas given off (CO_2) turns limewater cloudy (milky).

(b) Give the reagent and the observation to show the presence of sulfate ions.

(2)

Add dilute hydrochloric acid followed by barium chloride solution, $BaCl_2(aq)$.

A white precipitate forms (barium sulfate, $BaSO_4$).

(Total for Question 1 = 4 marks)

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2 This question is about flame tests for Group 1 and 2 metal ions.

(a) (i) State the colour of the flame produced by separate samples of potassium and strontium ions.

(1)

Potassium ions *lilac*

Strontium ions *crimson (red)*

(ii) Give a reason why carrying out a flame test on a mixture of potassium chloride and strontium chloride does not clearly show that two different metal ions are present.

(1)

The crimson (red) colour of the strontium ions masks (hides) the paler lilac colour of the potassium ions, so only one colour is seen.

(b) In the first stage of the flame test, the nichrome wire is dipped into concentrated hydrochloric acid and then heated in a Bunsen flame.

In the second stage, this nichrome wire is dipped into fresh hydrochloric acid and then into the metal salt to be tested before being reheated in the Bunsen flame.

(i) Give **two** reasons why the wire is made of nichrome and not iron.

(2)

Nichrome does not produce a colour in the flame (does not change the flame colour), whereas iron produces a colour and sparks.

Nichrome is inert (unreactive and stable when heated), whereas iron reacts with oxygen in the air and with hydrochloric acid.

(ii) Give a reason why the wire is dipped into acid and then heated in the first stage.

(1)

To clean the wire, by removing the residue of any previous sample that has been tested, so it cannot contaminate the flame colour.

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(iii) State why **fresh** concentrated hydrochloric acid is used in the second stage of the flame test.

(1)

The acid used before can become contaminated with residue from previous tests, which would give incorrect results.

(iv) State why **hydrochloric acid** is used in the second stage of the flame test.

(1)

It forms volatile metal chlorides, and moistens the wire so that some of the solid metal salt sticks to the wire.

(c) Explain, with reference to electron transitions, the formation of the colour in a flame test.

(3)

In the flame, heat energy excites the electrons in the metal ions: electrons are promoted from the ground state to higher energy levels (orbitals).

The excited electrons then fall back from the higher energy levels to lower energy levels (the ground state).

As the electrons fall they release energy as photons of light of a particular frequency in the visible region, which gives the characteristic flame colour.

(Total for Question 2 = 10 marks)

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3 This question is about a titration experiment carried out by a group of students to determine the concentration of a solution of ethanoic acid using sodium hydroxide.

(a) A student weighed about 4.00 g of sodium hydroxide pellets and added them to a beaker containing 50 cm^3 of deionised water.

The mixture was stirred with a glass rod to dissolve the pellets and to give a homogenous solution.

The solution was poured through a funnel into a 250.0 cm^3 volumetric flask and deionised water was added up to the mark and then the flask was shaken.

(i) Describe how you would ensure that all the sodium hydroxide was transferred to the volumetric flask.

(2)

Rinse the glass rod and the beaker several times with deionised water, and also rinse the funnel.

Transfer all of these washings into the volumetric flask before making the solution up to the mark.

(ii) A student adds deionised water above the mark and shakes the flask.

State why the procedure has to be restarted rather than using a teat pipette to remove the excess water.

(1)

Removing the excess solution with a teat pipette would also remove some of the dissolved sodium hydroxide, so the exact concentration would not be known (the total volume is already more than 250 cm^3).

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(b) Two students each cleaned a burette, then poured sodium hydroxide solution into their burettes.

(i) Student 1 used a funnel to pour sodium hydroxide solution into the burette.

Give **two** steps needed before the student takes the initial burette reading.

(2)

Remove the funnel from the top of the burette.

Open the tap to fill the tip (jet space) and remove any air bubbles.

Read with the eye level with the bottom of the meniscus.

(ii) Student 2 cleaned the burette by rinsing it with deionised water immediately before filling it with the sodium hydroxide solution.

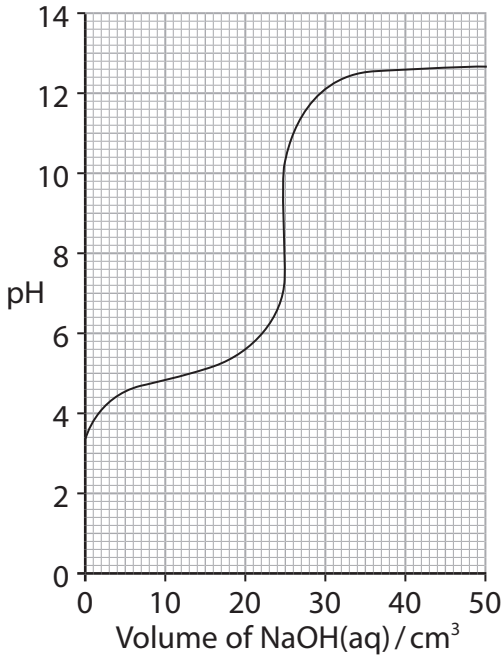
Give the effect, if any, on the value of the first titre. Justify your answer.

(1)

The titre will be larger, because the water left in the burette dilutes the sodium hydroxide solution (lowers its concentration), so a larger volume is needed to neutralise the acid.

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(c) The sketch shows the pH changes during a titration of 25.0 cm^3 of ethanoic acid with sodium hydroxide of the same concentration.



The ideal indicator for this titration will change colour on the addition of a very small volume of sodium hydroxide solution at a titre value very close to the equivalence point of the reaction.

(i) Assess the suitability of methyl red as an indicator for this titration. Make use of the Data Booklet in answering this question.

(4)

The vertical (steep) part of the pH curve is from about pH 7 to pH 10, with the equivalence point (mid-point of the vertical section) at about pH 8.5 to 8.8.

From the Data Booklet, methyl red changes colour over the pH range 4.2 to 6.3 (the mid-point of its colour change is pH 5.1).

The pH range of methyl red does not lie within the vertical part of the pH curve, so methyl red is not a suitable indicator.

Its colour change would be complete before the equivalence point is reached (it changes gradually, well below a titre of 25 cm^3), so the end-point would be inaccurate.

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(ii) Complete the table, with a tick (✓) or a cross (✗), to show whether or not the indicator would be suitable for use in this titration.

(1)

Indicator	pH range	Tick or Cross
Bromocresol purple	5.2 – 6.8	✗
Thymol blue	8.0 – 9.6	✓
Thymolphthalein	8.3 – 10.6	✓
Alizarin yellow R	10.1 – 13.0	✗

(d) Each student used a pipette to measure 25.0 cm^3 of the ethanoic acid solution into four separate conical flasks and added an indicator.

The results of one student's titrations are shown in the table.

Titration number	1	2	3	4
Final burette reading / cm^3	13.00	25.50	37.90	50.00
Initial burette reading / cm^3	0.25	13.00	25.50	37.90
Titre / cm^3	12.75	12.50	12.40	12.10
Concordant titres (✓)		✓	✓	

(i) Complete the table.

(1)

(ii) The low titre for titration **4** was queried by the teacher. The student had wanted to refill the burette and continue the titration but had been told the measurement uncertainty would increase if this was done.

Calculate the total percentage measurement uncertainty if the burette had been refilled to 0.00, and then a further 0.30 cm^3 had been added from the burette, to the conical flask.

The measurement uncertainty for each burette reading is ±0.05 cm^3.

(1)

four burette readings, so total uncertainty = 4 × 0.05 = 0.20 cm^3

titre = 12.10 + 0.30 = 12.40 cm^3

% uncertainty = (0.20 ÷ 12.40) × 100 = 1.6 %

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(e) The teacher carried out the experiment and obtained the following results.

Mass of sodium hydroxide used to make 250.0 cm^3 solution = 3.80 g

Volume of ethanoic acid solution = 25.00 cm^3

Mean titre of sodium hydroxide = 11.90 cm^3

$$CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(l)$$

Calculate the concentration of the ethanoic acid solution in **g dm^{-3}**.
Give your answer to an appropriate number of significant figures.

(5)

n(NaOH) weighed out = 3.80 ÷ 40.0 = 0.0950 mol

[NaOH] = 0.0950 ÷ 0.2500 = 0.380 mol dm^{-3}

n(NaOH) in titre = 0.380 × (11.90 ÷ 1000) = 4.522 × 10^{-3} mol

n(CH_3COOH) = 4.522 × 10^{-3} mol (1 : 1 ratio)

[CH_3COOH] = 4.522 × 10^{-3} ÷ (25.00 ÷ 1000) = 0.18088 mol dm^{-3}

M_r(CH_3COOH) = 60.0

concentration = 0.18088 × 60.0 = 10.853 g dm^{-3}

concentration of ethanoic acid = 10.9 g dm^{-3} (3 s.f.)

(Total for Question 3 = 18 marks)

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4 Hess's law can be used to determine enthalpy changes for reactions which cannot be obtained directly.
An example is the reaction of anhydrous copper(II) sulfate with water to form hydrated copper(II) sulfate, $CuSO_4.5H_2O$.

The following outline procedure was carried out.

Step **1** 42.75 g of deionised water was weighed out in a polystyrene cup and the temperature measured.

Step **2** 0.0250 mol of hydrated copper(II) sulfate was added to the water in the polystyrene cup with stirring, making a total of 45.00 g of water.

Step **3** The temperature change was recorded.

Step **4** Steps **1** to **3** were repeated using 45.00 g of deionised water and 0.0250 mol of anhydrous copper(II) sulfate.

(a) Calculate the mass of 0.0250 mol of hydrated copper(II) sulfate, $CuSO_4.5H_2O$.

(2)

$M_r(CuSO_4.5H_2O) = 63.5 + 32.1 + (4 \times 16.0) + (5 \times 18.0) = 249.6$

$mass = 0.0250 \times 249.6 = 6.24\ g$

(b) The reaction of hydrated copper(II) sulfate with water is shown.

$$CuSO_4.5H_2O(s) + aq \rightarrow CuSO_4(aq) \qquad \Delta H_1 = +18.2\ kJ\ mol^{-1}$$

Calculate the temperature change that would have given this enthalpy change for the stated experimental procedure.
Give your answer to a measurable number of significant figures and state whether the temperature increases or decreases.

[Specific heat capacity of the solution = 4.18 J g^{-1} $^oC^{-1}$]

(3)

$Q = \Delta H \times n = 18.2 \times 0.0250 = 0.455\ kJ = 455\ J$

$\Delta T = Q \div (m \times c) = 455 \div (45.00 \times 4.18)$

$\Delta T = 2.4189\ ^oC$

temperature change = 2.4 °C, and the temperature decreases

(the reaction is endothermic)

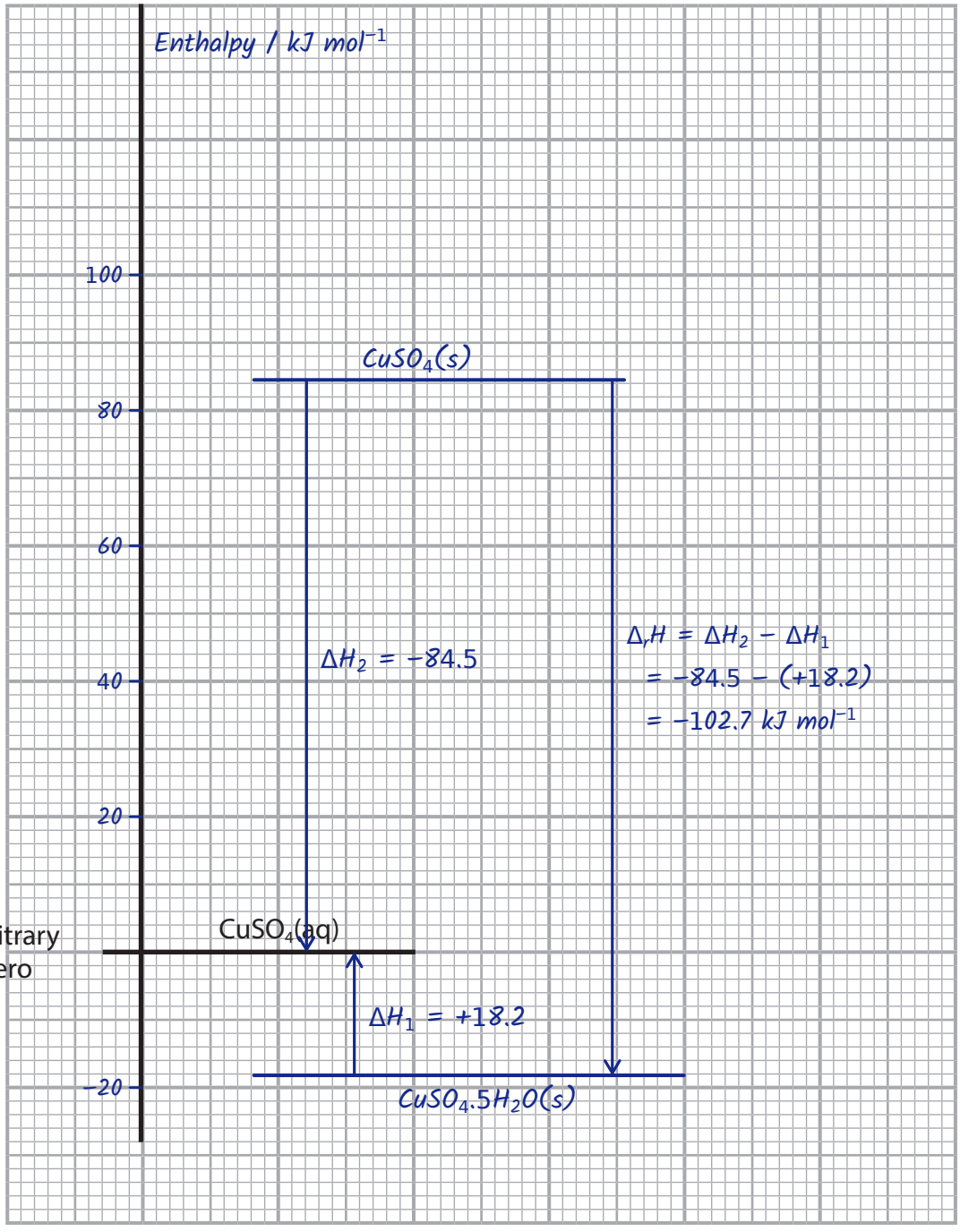
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(c) The reaction of anhydrous copper(II) sulfate with water is shown.

$$CuSO_4(s) + aq \rightarrow CuSO_4(aq) \quad \Delta H_2 = -84.5\ kJ\ mol^{-1}$$

(i) Draw to scale, on the graph paper, a labelled enthalpy level diagram which shows the enthalpy changes for the reactions of water with hydrated copper(II) sulfate (ΔH_1) and anhydrous copper(II) sulfate (ΔH_2).

(3)



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(ii) Use your enthalpy level diagram in (c)(i) to determine the enthalpy change, $\Delta_r H$, for the reaction

$$CuSO_4(s) + 5H_2O(l) \rightarrow CuSO_4.5H_2O(s)$$

You **must** show your working on the diagram.

(1)

$\Delta_r H$ = −102.7 kJ mol^{-1}

(d) State why the enthalpy change for the reaction of one mole of anhydrous copper(II) sulfate with five moles of water to form hydrated copper(II) sulfate, $CuSO_4.5H_2O$, cannot be measured directly.

(1)

Exactly 5 mol of water cannot be made to react with 1 mol of the solid anhydrous copper(II) sulfate: more than five water molecules would attach to some $CuSO_4$ and fewer to others, so the temperature change for this reaction alone cannot be measured.

(Total for Question 4 = 10 marks)

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5 This question is about extracting benzoic acid from a mixture of benzoic acid, C_6H_5COOH, and phenol, C_6H_5OH.

The following steps were carried out.

Step **1** A suitable mass of the mixture was placed in a separating funnel and some ether added. The funnel was shaken to dissolve the mixture.

Step **2** Aqueous sodium hydrogencarbonate was added to the separating funnel, and the contents shaken.

Step **3** Once the reaction was complete, the two layers were allowed to separate.

Step **4** The lower aqueous layer was removed and placed in a beaker.

Step **5** The ether layer in the separating funnel was washed with deionised water and the washings added to the beaker.

Step **6** Hydrochloric acid was added to the aqueous solution in the beaker to precipitate the benzoic acid.

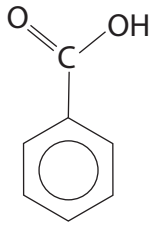
Step **7** The impure benzoic acid was filtered under reduced pressure.

Step **8** The impure benzoic acid was purified by recrystallisation.

Step **9** The melting temperature of the purified benzoic acid was measured and compared with the literature value of 122 °C.

(a) Complete the equation for the reaction between benzoic acid and sodium hydrogencarbonate.

(2)



+ $NaHCO_3$ → C_6H_5COONa + H_2O + CO_2

(b) In Step **2** there is a pressure build-up in the separating funnel.

Describe how you would lower the pressure.

(1)

Invert the stoppered funnel and slowly open the tap to release the gas (CO_2), then close the tap.

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(c) State why, in Step **4**, the aqueous layer was the lower of the two layers.

(1)

Water (the aqueous layer) is more dense than ether.

(d) Give a reason why, in Step **5**, the ether layer was washed with deionised water.

(1)

Some sodium benzoate has dissolved in the ether layer, so washing transfers it into the aqueous washings.

(e) Explain why the addition of hydrochloric acid in Step **6** results in the precipitation of benzoic acid.

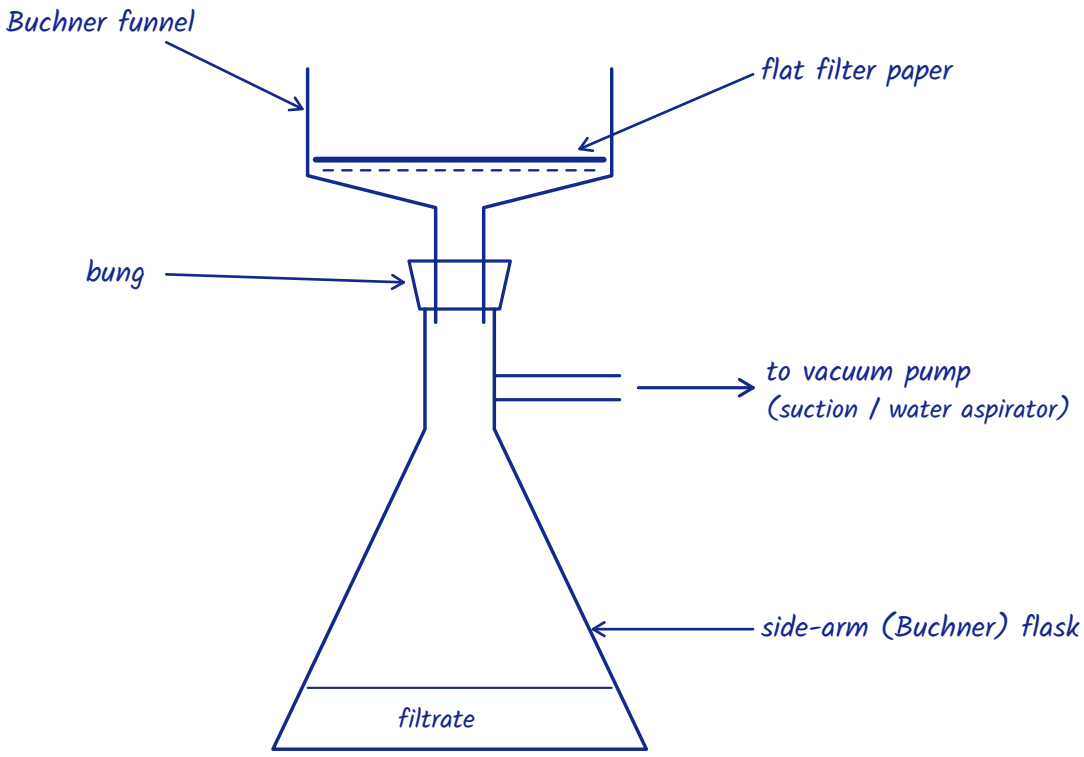
(2)

The benzoate ions are protonated by the H^+ ions in the hydrochloric acid, forming benzoic acid: $C_6H_5COO^- + H^+ \rightarrow C_6H_5COOH$.

Benzoic acid is much less soluble in water than its ionic sodium salt, so it precipitates.

(f) Draw a diagram of the apparatus used in Step **7** to filter under reduced pressure.

(2)



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(g) Benzoic acid can be purified in Step **8** because of its high solubility in hot water and low solubility in cold water.

Calculate the maximum number of benzoic acid molecules that can dissolve in 50.0 cm^3 of cold water if the solubility is 1.70 g per 1000 cm^3.

(3)

mass of benzoic acid in 50.0 cm^3 = 1.70 × (50.0 ÷ 1000) = 0.0850 g

$M_r(C_6H_5COOH)$ = 122.0

moles = 0.0850 ÷ 122.0 = 6.967 × 10^{-4} mol

number of molecules = 6.967 × 10^{-4} × 6.02 × 10^{23}

= 4.19 × 10^{20} molecules

(h) The melting temperature range of the purified benzoic acid in Step **9** was 116–121 °C.

Compare this result with the literature value, giving a reason for any differences.

(2)

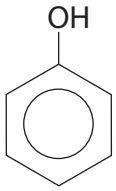
The purified benzoic acid melts over a wide range (5 °C, it is not sharp) and below the literature value of 122 °C.

This is because the sample is still impure: it still contains impurities such as phenol or water.

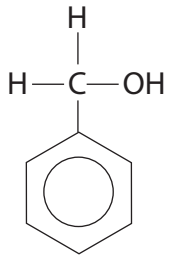
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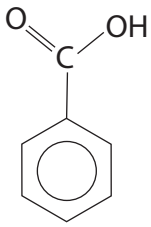
6 This is a question about the analysis of three aromatic substances with —OH groups.



phenol



phenylmethanol



benzoic acid

(a) Write the equation for the **complete** combustion of phenol.
State symbols are not required.

(2)

$C_6H_5OH + 7O_2 \rightarrow 6CO_2 + 3H_2O$

(b) When burned in air, these aromatic compounds undergo **incomplete** combustion.

(i) Calculate the percentage composition by mass of carbon in both phenylmethanol and benzoic acid.

(3)

phenylmethanol, C_7H_8O: $M_r = (7 \times 12.0) + (8 \times 1.0) + 16.0 = 108.0$

mass of carbon = $7 \times 12.0 = 84.0$

% C = $(84.0 \div 108.0) \times 100 = 77.8$ %

benzoic acid, $C_7H_6O_2$: $M_r = 84.0 + (6 \times 1.0) + (2 \times 16.0) = 122.0$

mass of carbon = $7 \times 12.0 = 84.0$

% C = $(84.0 \div 122.0) \times 100 = 68.9$ %

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(ii) Give the expected observation when these aromatic compounds undergo incomplete combustion.

(1)

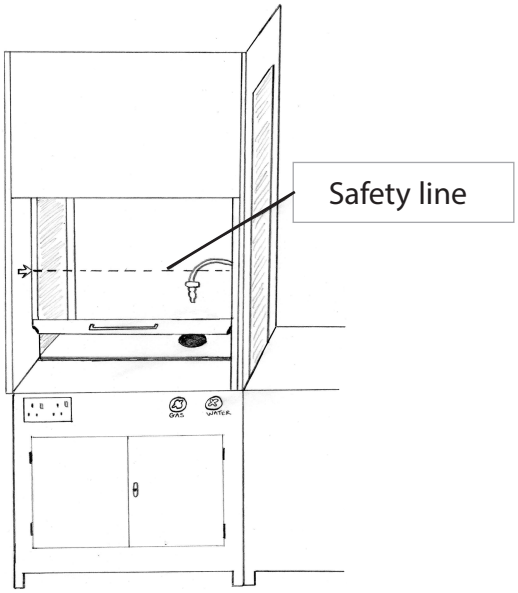
A smoky flame with black smoke (soot) is seen.

(iii) Identify another **type** of organic compound which will also produce the same observation as in (b)(ii).

(1)

Alkenes (compounds with C=C double bonds)

(iv) These combustion experiments must be carried out in a fume cupboard.



Explain why the front window of the fume cupboard must be below the safety line even with the exhaust fan switched on.

(2)

If the window is above the safety line, the opening is too large and the exhaust fan is not strong enough to draw all of the fumes in.

So toxic fumes, such as carbon monoxide and soot, would escape from the fume cupboard into the laboratory and could be breathed in.

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(c) Spectroscopy is an effective means of distinguishing between molecules.

(i) Compare and contrast the infrared spectra of phenol, phenylmethanol and benzoic acid.
Include relevant bonds and their wavenumber ranges using the Data Booklet.

(5)

Similarity: all three spectra have absorptions for the arene C–H bonds, at about 3030 cm^{-1} (and at 750 and 700 cm^{-1}).

Only phenol and phenylmethanol have an O–H (alcohol / phenol) absorption, broad, at 3750 to 3200 cm^{-1}.

Only benzoic acid has the very broad O–H absorption of a carboxylic acid at 3300 to 2500 cm^{-1}.

Only benzoic acid has a strong C=O absorption (aryl carboxylic acid) at 1700 to 1680 cm^{-1}.

Only phenylmethanol has alkane C–H absorptions (from its CH_2 group) at 2962 to 2853 cm^{-1} and 1485 to 1365 cm^{-1}.

So phenol shows neither a C=O nor an alkane C–H absorption.

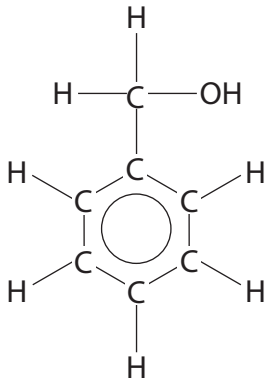
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(ii) Predict the number of peaks present, and their chemical shifts, in the ^{13}C nuclear magnetic resonance (NMR) spectrum of phenylmethanol. Use the information in the Data Booklet to help you.

(3)



phenylmethanol

There are five peaks in the ^{13}C NMR spectrum (five different carbon environments).

Four peaks are from the aromatic (benzene ring) carbons, with chemical shifts in the range 165 to 105 ppm.

One peak is from the CH_2 carbon bonded to the OH group (C–O), with a chemical shift in the range 75 to 55 ppm.

(iii) Give the formula of a fragment ion, with its *m/z* value, that you would expect to be present in the mass spectrum of benzoic acid but **not** in the mass spectrum of phenol or the mass spectrum of phenylmethanol.

(2)

fragment ion: $C_6H_5CO^+$

m/z = 105

(Total for Question 6 = 19 marks)

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***7** "Cobalt(II) ions combine with substances in solution to form complex ions with different coordination numbers."

Discuss this statement by referring to **two** complex ions containing cobalt(II).

Include

- reference to any difference in colour
- a definition of any terms used
- an explanation of the different shapes

(6)

Cobalt(II) ions form complex ions in which ligands are bonded to a central Co^{2+} ion.

A ligand is an atom, ion or molecule with a lone pair of electrons that forms a dative covalent (coordinate) bond to the central metal ion.

The coordination number is the number of dative covalent bonds from the ligands to the central metal ion.

In aqueous solution, Co^{2+} forms the hexaaquacobalt(II) ion, $[Co(H_2O)_6]^{2+}$, which is pink.

Each of the six water ligands forms one dative covalent bond using a lone pair on its oxygen atom, so the coordination number is 6.

When concentrated hydrochloric acid is added, the six water ligands are replaced by four chloride ligands in a ligand exchange reaction, forming the tetrachlorocobaltate(II) ion, $[CoCl_4]^{2-}$, which is blue. Its coordination number is 4.

$[Co(H_2O)_6]^{2+} + 4Cl^- \rightleftharpoons [CoCl_4]^{2-} + 6H_2O$

The colours are different because the different ligands, and the different number of ligands, split the d orbitals of Co^{2+} by a different amount, so a different frequency of visible light is absorbed and a different colour is transmitted.

Shapes: in $[Co(H_2O)_6]^{2+}$ the six bonding pairs of electrons repel each other equally and get as far apart as possible, so the ion is octahedral, with bond angles of 90°.

The chloride ion is much larger than the oxygen atom of a water ligand, so only four chloride ions can fit around the Co^{2+} ion. The four bonding pairs repel as far apart as possible, so $[CoCl_4]^{2-}$ is tetrahedral, with bond angles of 109.5°.

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So the statement is correct: cobalt(II) forms complex ions with coordination numbers of 6 and 4, which have different shapes and different colours.

(Total for Question 7 = 6 marks)

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8 This is a question about chromium(III) and chromium(VI) compounds.

(a) Describe the observations when aqueous sodium hydroxide is added drop by drop until in excess to a solution of chromium(III) ions.

(2)

A green precipitate forms ($Cr(OH)_3$), which dissolves in excess sodium hydroxide to give a dark green solution.

(b) The chromium(III) complex, $[Cr(OH)_6]^{3-}$, can be oxidised to chromate(VI) ions, CrO_4^{2-}, by hydrogen peroxide solution.

(i) Deduce the oxidation half-equation for this reaction, which takes place in alkaline conditions. State symbols are not required.

(2)

$[Cr(OH)_6]^{3-} + 2OH^- \rightarrow CrO_4^{2-} + 4H_2O + 3e^-$

(ii) If the solution of chromate(VI) ions is then acidified, the colour of the solution changes to orange as dichromate(VI) ions form.

Write the equation for this change. State symbols are not required.

(1)

$2CrO_4^{2-} + 2H^+ \rightarrow Cr_2O_7^{2-} + H_2O$

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(iii) In acidic conditions, dichromate(VI) ions can also be reduced to chromium(III) ions using hydrogen peroxide.

The value of $E^{\ominus}_{cell}$ = + 0.65 V for which the cell diagram is

Pt(s) | H_2O_2(aq), [$2H^+$(aq)+O_2(g)] ¦¦ [$Cr_2O_7^{2-}$(aq)+$14H^+$(aq)], [$2Cr^{3+}$(aq)+$7H_2O$(l)] | Pt(s)

Deduce from the cell diagram the oxidation and the reduction half-equations, and thus the overall equation for this reaction.
State symbols are not required.

(3)

Oxidation: $H_2O_2 \rightarrow O_2 + 2H^+ + 2e^-$

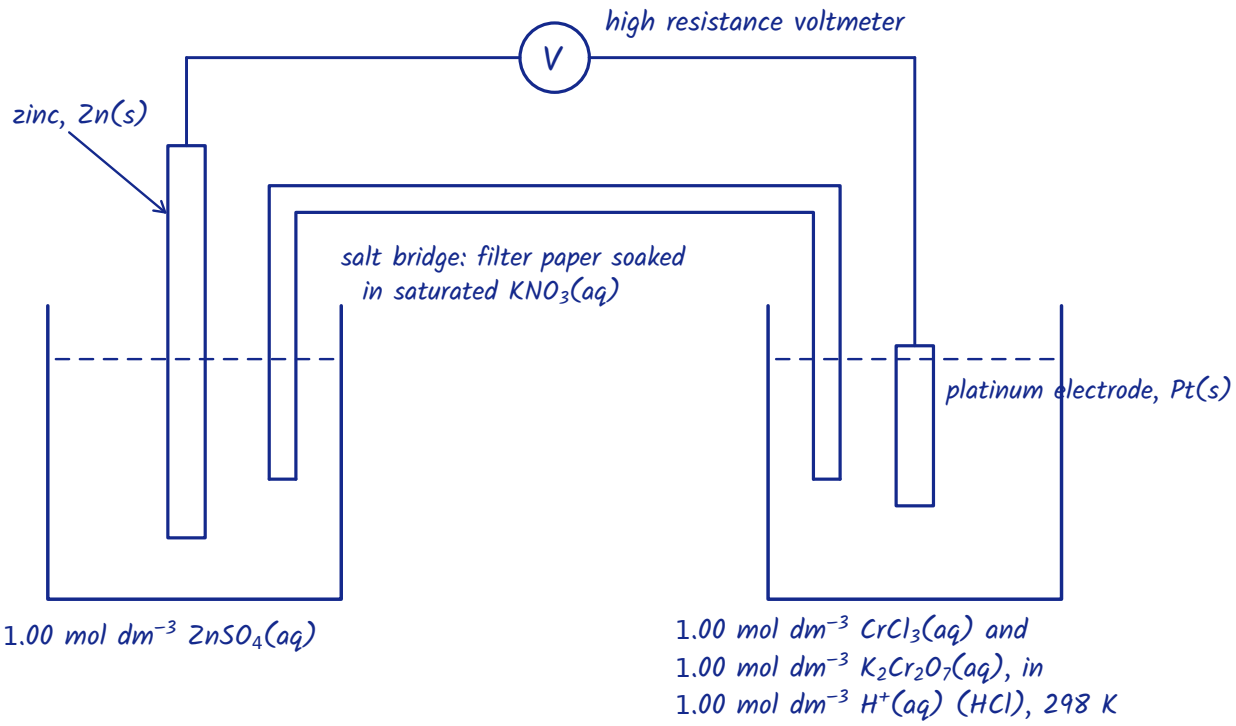
Reduction: $Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$

Overall: $Cr_2O_7^{2-} + 8H^+ + 3H_2O_2 \rightarrow 2Cr^{3+} + 7H_2O + 3O_2$

(c) Draw a labelled diagram of the apparatus that you would use to measure the standard emf of a cell with a zinc-zinc(II) electrode system and a chromium(III)-dichromate(VI) electrode system.

Include the **formulae** of all the compounds required and the concentrations of the solutions.

(7)



(Total for Question 8 = 15 marks)

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9 This question is about amines.

(a) Phenylamine is an aromatic amine and butylamine is an aliphatic amine.

Phenylamine can be prepared from nitrobenzene.



Butylamine can be prepared from butanenitrile.

$$C_3H_7CN \rightarrow C_4H_9NH_2$$

Compare and contrast these two preparations of amines.

(3)

Similarity: both preparations are reduction reactions.

Difference: phenylamine is made by reducing nitrobenzene with tin and concentrated hydrochloric acid (heated under reflux), then adding NaOH(aq).

Difference: butylamine is made by reducing butanenitrile with lithium tetrahydridoaluminate(III), $LiAlH_4$, in dry ether (or with hydrogen gas and a nickel catalyst).

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(b) Compare and contrast the basicity of phenylamine and butylamine.

(3)

Similarity: both are bases because the nitrogen atom has a lone pair of electrons which can accept a proton (H^+).

Phenylamine is a weaker base than butylamine: in phenylamine the lone pair of electrons on the nitrogen atom becomes incorporated into the delocalised π electron ring of the benzene ring, so the lone pair is less available and less able to accept a proton.

Butylamine is a stronger base: the alkyl group (C_4H_9) is electron-releasing (positive inductive effect), which increases the electron density on the nitrogen, so its lone pair is more able to accept a proton.

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(c) Write the equation for the reaction between propanoyl chloride and pentylamine. Include the name of the amide formed.

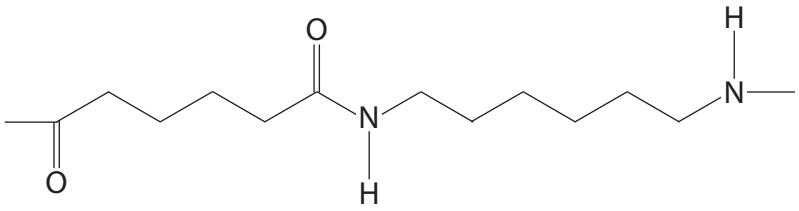
State symbols are not required.

(2)

$C_2H_5COCl + C_5H_{11}NH_2 \rightarrow C_2H_5CONHC_5H_{11} + HCl$

Name of amide *N-pentylpropanamide*

(d) A section of a polyamide is shown.



Identify, by name or formula, the amine monomer that reacts to form this polyamide.

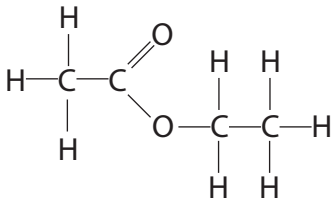
(1)

1,6-diaminohexane, $H_2N(CH_2)_6NH_2$

(Total for Question 9 = 9 marks)

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10 Ethyl ethanoate is an ester.



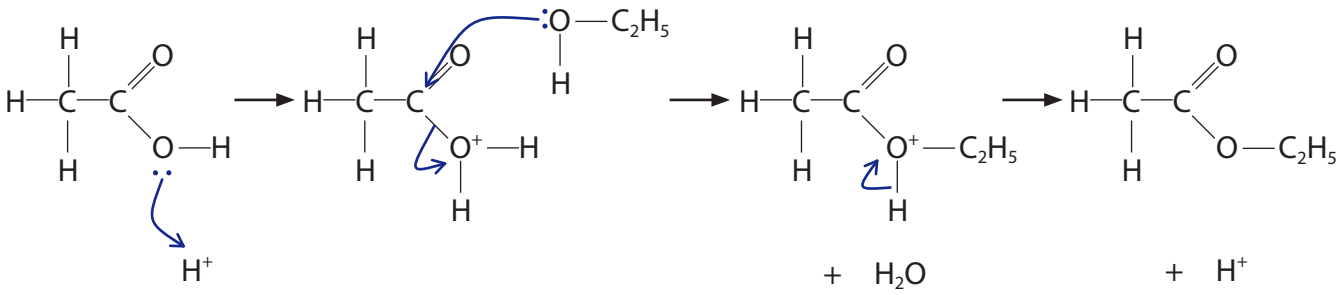
(a) One method for the formation of ethyl ethanoate is the reaction between ethanol and ethanoic acid, which is catalysed by hydrogen ions.

$$CH_3COOH + C_2H_5OH \rightleftharpoons CH_3COOC_2H_5 + H_2O$$

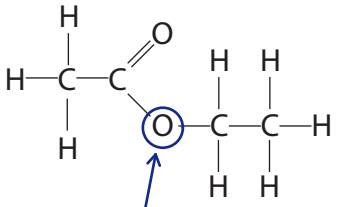
An incomplete simplified mechanism for this reaction is shown.

(i) Add curly arrows and relevant lone pairs of electrons to complete the mechanism.

(4)



(ii) In an experiment, the oxygen atom in ethanol is replaced by the oxygen-18 isotope, ^{18}O.
The products of the esterification are



and H—O—H

Label the ^{18}O oxygen atom in one of the products.
Justify your answer.

(2)

The ^{18}O atom is in the ester: it is the oxygen bonded to the ethyl group.

The oxygen of ethanol acts as the nucleophile, attacking the carbon of the carboxylic acid group, so it ends up in the ester; the C–O single bond in the carboxylic acid breaks (the acid loses OH), so the water contains no ^{18}O.

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(iii) Calculate the standard molar entropy of ethyl ethanoate using your knowledge of Gibbs free energy, ΔG, and the data in the table.

Include sign and units in your answer.

Use $\Delta G = -RT \ln K$ and other appropriate equations.

Quantity	Value
Gas constant, R	8.31 J mol^{-1} K^{-1}
Temperature, T	298 K
Equilibrium constant of esterification reaction, K	4.0
Enthalpy change of esterification reaction, ΔH	−6.0 kJ mol^{-1}
Standard molar entropy of ethanoic acid, S^{O}	159.8 J K^{-1} mol^{-1}
Standard molar entropy of ethanol, S^{O}	160.7 J K^{-1} mol^{-1}
Standard molar entropy of water, S^{O}	69.9 J $K^{-1}mol^{-1}$

(6)

$\Delta G = -RT \ln K = -8.31 \times 298 \times \ln 4.0$

$\Delta G = -3433 \text{ J mol}^{-1}$

$\Delta G = \Delta H - T\Delta S_{system}$

$\Delta S_{system} = (\Delta H - \Delta G) \div T$

$\Delta S_{system} = (-6000 - (-3433)) \div 298 = -8.614 \text{ J K}^{-1} \text{ mol}^{-1}$

$\Delta S_{system} = \Sigma S(\text{products}) - \Sigma S(\text{reactants})$

$-8.614 = [S(\text{ethyl ethanoate}) + 69.9] - (159.8 + 160.7)$

$S(\text{ethyl ethanoate}) = -8.614 + 159.8 + 160.7 - 69.9$

$S(\text{ethyl ethanoate}) = +242 \text{ J K}^{-1} \text{ mol}^{-1}$

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(b) Ethyl ethanoate can also be formed by reacting ethanol with ethanoyl chloride, CH_3COCl.

Identify **three** differences in the esterification reaction when ethanoyl chloride is used instead of ethanoic acid.

(3)

With ethanoyl chloride the reaction is irreversible (goes to completion), whereas with ethanoic acid it is reversible (an equilibrium).

The by-product is hydrogen chloride (steamy fumes of HCl) instead of water.

The reaction is very fast and occurs at room temperature, so no acid catalyst (H^+) and no heating are needed.

(Total for Question 10 = 15 marks)

TOTAL FOR PAPER = 120 MARKS

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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

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
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

* Lanthanide series

* Actinide series

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