Atomic structure

Name:

Class:

Date:

Time: **204 min.**

Marks: **182 marks**

Comments:

Q1.

This question is about atomic structure.

(a) Define the term mass number.

___

___

(1)

(b) Complete **Table 1** for two of the fundamental particles in an atom.

Table 1

	Relative mass	**Relative charge**
Neutron		
Electron		

A sample of calcium consists of ^{40}Ca, ^{42}Ca and one other isotope.

(2)

(c) Predict whether the atomic radius of ^{40}Ca is larger than, smaller than or the same as the atomic radius of ^{42}Ca

Explain your answer.

Atomic radius of ^{40}Ca compared to ^{42}Ca ___

Explanation ___

___

___

___

(2)

(d) The relative abundances of two of these calcium isotopes are shown in **Table 2**.

Table 2

Mass number of isotope	40	42
Relative abundance / %	96.80	0.19

Determine the relative abundance of the third calcium isotope.

The sample of calcium has a relative atomic mass of 40.12

Use your answer and the data in **Table 2** to determine the mass number of the third isotope.

Give the mass number to the nearest integer.

Relative abundance ____________________

Mass number ____________________

(4)

(e) Calculate the mass, in kg, of one atom of ^{42}Ca

The Avogadro constant L = 6.02×10^{23} mol^{-1}

Mass ____________________ kg

(1)

(f) In a time of flight (TOF) mass spectrometer, a $^{42}Ca^{+}$ ion with a kinetic energy (KE) of 1.164×10^{-13} J takes 9.130×10^{-7} s to reach the detector.

$$KE = \frac{1}{2}mv^2$$

$$v = \frac{d}{t}$$

m = mass / kg
v = velocity / ms^{-1}
d = length of flight tube / m
t = time of flight / s

Use the equations and your answer to question (e) to calculate the length, in m, of the flight tube.

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

(If you could not answer question (e) you should assume a mass of 3.08×10^{-25} kg
This is **not** the correct answer.)

Length ____________________ m

(3)

(Total 13 marks)

Q2.

This question is about the elements in Period 3 of the Periodic Table.

(a) Write an equation, including state symbols, for the first ionisation energy of magnesium.

____

(1)

(b) Explain why the first ionisation energy of aluminium is less than the first ionisation energy of magnesium.

____

____

____

____

(2)

(c) Identify the element in Period 3 with the largest atomic radius.

Explain your answer.

Element ____

Explanation ____

____

____

____

____

(3)

(d) Silicon has the highest melting point of the elements in Period 3.

Explain this statement in terms of structure and bonding.

____

____

____

____

____

____

____

____

(3)

(Total 9 marks)

Q3.

What is the formula of rubidium nitride?

A Rb_5N ⬭

B RbN ⬭

C Rb_3N ⬭

D RbN_3 ⬭

(Total 1 mark)

Q4.

Which atom contains the most neutrons?

A ^{59}Co ⬭

B ^{64}Ni ⬭

C ^{63}Cu ⬭

D ^{64}Zn ⬭

(Total 1 mark)

Q5.

The highest oxidation state of an element is +4

What is the electron configuration of this element?

A $1s^2\ 2s^2$ ⬭

B $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^4$ ⬭

C $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^2\ 4s^2$ ⬭

D $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^4\ 4s^2$ ⬭

(Total 1 mark)

Q6.

(a) Give the meaning of the term isotopes in terms of fundamental particles.

___

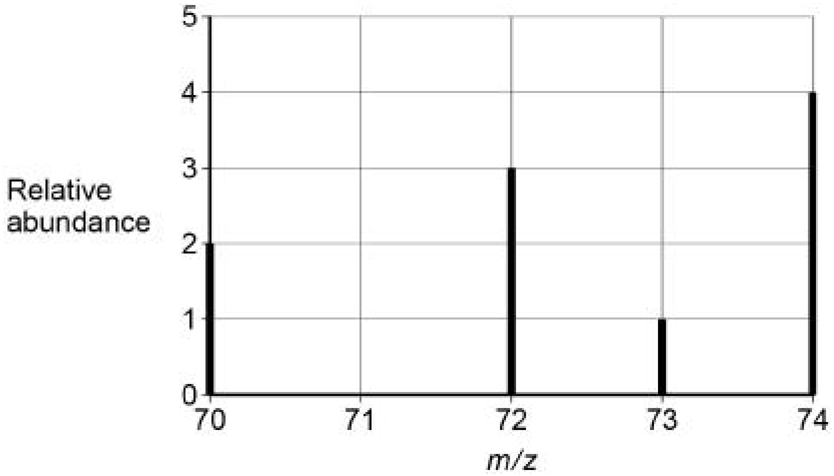
___

___

___

(2)

The mass spectrum of a sample of germanium is shown in the graph below.



(b) Calculate the relative atomic mass of this sample of germanium.

Relative atomic mass ______________________

(2)

(c) Complete the electron configuration of the Ge^{+} ion.

[Ar] ______________________

(1)

(d) Write an equation to represent the process that occurs when the first ionisation energy of germanium is measured.
Include state symbols in your equation.

____

(1)

(e) Calculate the mass, in kg, of a $^{72}Ge^{+}$ ion.
The Avogadro constant $L = 6.02 \times 10^{23}$ mol^{-1}

Mass ______________________ kg

(1)

(f) In a time of flight (TOF) mass spectrometer, the kinetic energy (KE) of a $^{72}Ge^{+}$ ion is 1.318×10^{-14} J.

Use your answer to part (e) to calculate the velocity of this $^{72}Ge^{+}$ ion.

$KE = \frac{1}{2} mv^2$

(m = mass / kg and v = velocity / ms^{-1})

(If you could not answer to part (e) you should assume a mass of 9.80×10^{-24} kg
This is **not** the correct answer.)

Velocity ________________________ $m\ s^{-1}$

(2)

(g) State why the chemical properties of ^{72}Ge and ^{74}Ge are the same.

____

____

(1)

(Total 10 marks)

Q7.

Which element is in the p block of the Periodic Table?

A Technetium ○

B Terbium ○

C Thallium ○

D Thorium ○

(Total 1 mark)

Q8.

(a) Give the meaning of the term **relative atomic mass**.

____

____

____

____

(2)

(b) A sample of nickel was ionised by electron impact in a time of flight (TOF) mass spectrometer to produce Ni^+ ions. The relative abundance of each isotope is shown in the table below.

m/z	58	60	62

Relative abundance	19	8	3

Calculate the relative atomic mass of nickel in the sample.

Give your answer to one decimal place.

Relative atomic mass ______________________________

(2)

(c) State why the inside of a TOF mass spectrometer is operated under vacuum.

____

____

____

(1)

(d) Complete the electron configuration of the $^{58}Ni^{+}$ ion.

$1s^2$ ____

(1)

(e) Calculate the mass, in kg, of a $^{58}Ni^{+}$ ion.

Give your answer to three significant figures.

The Avogadro constant, $L = 6.02 \times 10^{23}$ mol^{-1}

Mass ______________________________ kg

(1)

(f) ° A $^{58}Ni^{+}$ ion travels down the flight tube of a TOF mass spectrometer with constant kinetic energy.
The flight tube is 1.80 m long and the $^{58}Ni^{+}$ ion takes 5.82×10^{-7} s to reach the detector.

$$KE = \frac{1}{2}mv^2$$

$$v = \frac{d}{t}$$

where KE = kinetic energy (J)
m = mass (kg)
v = velocity (m s^{-1})
d = length of the flight tube (m)
t = time (s)

Use your answer to part (e) to calculate the kinetic energy, in J, of the $^{58}Ni^{+}$ ion as it travels down the flight tube.

(If you were unable to answer part (e), you should use the value 7.37×10^{-25} kg. This is **not** the correct answer.)

Give your answer to three significant figures.

Kinetic energy ______________________________ J

(3)

(Total 10 marks)

Q9.

(a) Complete the electron configuration for the aluminium ion, Al^{3+}

$1s^2$ ____

(1)

(b) Write an equation, including state symbols, to represent the process for which the energy change is the second ionisation energy of aluminium.

____

(1)

(c) Explain why the second ionisation energy of aluminium is greater than the first ionisation energy of aluminium.

____

____

(1)

(d) An element, **Z**, in Period 2 of the Periodic Table has the successive ionisation energies shown in the table.

	First	Second	Third	Fourth	Fifth
Ionisation energy / kJ mol^{-1}	1090	2350	4610	6220	37 800

Choose the correct identity of the Period 2 element **Z**.
Tick (✓) the correct box.

Boron ☐

Carbon ☐

Nitrogen ☐

Silicon ☐

(1)
(Total 4 marks)

Q10.

(a) The abundance of each isotope in a time of flight (TOF) mass spectrum of a sample of germanium is shown in the table.

m/z	70	72	74
Abundance (%)	24.4	32.4	43.2

Give the formula of the ion that will reach the detector first.

____

(1)

(b) Use the data in Table above to calculate the relative atomic mass of this sample of germanium.

Give your answer to one decimal place.

Relative atomic mass = ____________________

(2)

(c) Explain how the abundance of each isotope is determined in a TOF mass spectrometer.

____

____

____

____

____

(2)

(d) Calculate the mass, in kg, of one atom of ^{72}Ge
The Avogadro constant = 6.02×10^{23} mol^{-1}.

Give your answer to the appropriate number of significant figures.

Mass = ____________________ kg

(2)

(e) In a TOF mass spectrometer, the ions are accelerated to the same kinetic energy (KE).

KE = $\frac{1}{2}mv^2$ where m = mass (kg) and v = velocity (m s^{-1})

$v = \frac{d}{t}$ where d = distance (m) and t = time (s)

A $^{72}Ge^{+}$ ion is accelerated to a kinetic energy of 3.98×10^{-16} J as it travels down the flight tube that is 3.00 m long.

Calculate the time taken for the $^{72}Ge^{+}$ ion to reach the detector.
Use your answer to part (d) in your calculation.

Time = ____________________ s

(3)

(Total 10 marks)

Mark schemes

Q1.

(a) Number of protons and neutrons (in the nucleus of an atom) 1

(b)

	Relative mass	Relative charge
Neutron	1	0
Electron	1/1837 or negligible (not 0)	−1

Allow 5.444×10^{-4} or 1/2000

(c) Same

If not same CE = 0/2 1

Same number of protons and electrons

Allow equal force of attraction between protons and electrons in both isotopes 1

(d) Other isotope is 3.01% 1

$$40.12 = \frac{(40 \times 96.80) + (42 \times 0.19) + (\mathbf{3.01} \times Y)}{100}$$ 1

$3.01 \times Y = 4012 - (40 \times 96.80) - (42 \times 0.19)$ 1

OR $Y = 43.86$ 1

Mass number = 44 1

(e) $42/(6.02 \times 10^{23} \times 1000) = 6.98 \times 10^{-26}$ (kg) 1

(f) ∘ $d = \frac{t\sqrt{2KE}}{\sqrt{m}}$

Rearrangement 1

$$d = 9.130 \times 10^{-7} \times \frac{\sqrt{2 \times 1.164 \times 10^{-13}}}{\sqrt{6.98 \times 10^{-26}}}$$

= 1.67 m

Working

1

if 3.08×10^{-25} used d = 0.79 m

Allow ecf from question (e)
Ans to 3sf

1

[13]

Q2.

(a) $Mg(g) \longrightarrow Mg^{+}(g) + e^{-}$

1

(b) Electron removed from a (3)p orbital

1

Which is higher in energy (so more easily lost)

Allow greater shielding (from $3s^2$)

1

(c) Sodium

1

If not sodium then CE = 0/3

Smallest number of protons

1

All electrons in period 3 elements enter the same (3rd) principal energy level OR elements in period 3 have similar shielding

1

(d) Macromolecular/giant atomic/giant covalent molecule

1

<u>covalent</u> bonds

1

Many/strong (covalent) bonds need to be broken or take a lot of energy to break

1

[9]

Q3.

C

[1]

Q4.

B

[1]

Q5.

C

[1]

Q6.

(a) same number of protons 1

different number of neutrons

Either order 1

(b) $$\frac{(2\times70)+(3\times72)+(1\times73)+(4\times74)}{10}=\frac{725}{10}$$ 1

= 72.5 1

(c) [Ar] $4s^2\ 3d^{10}\ 4p^1$

Allow 3d and 4s in either order 1

(d) $Ge(g) \longrightarrow Ge^+(g) + e^{(-)}$

Allow other alternative equations 1

(e) 1.20×10^{-25} (kg)

3 significant figures or more 1

(f) $°V = \sqrt{(2KE/m)}$ 1

$= \sqrt{(2 \times 1.318 \times 10^{-14} / 1.20 \times 10^{-25})}$

$= 4.69 \times 10^5$ (m s^{-1}) 1

Using alternative data supplied in question:

$= \sqrt{(2 \times 1.318 \times 10^{-14} / 9.80 \times 10^{-24})}$

$= 5.19 \times 10^4$ (m s^{-1})

Allow 2 significant figures or more

(g) same electron configuration

Allow same number of (outer) electrons 1

[10]

Q7.

C

[1]

Q8.

(a) $\frac{\text{Average/mean mass of 1 atom (of an element)}}{\text{1/12 mass of one atom of 12C}}$

OR

$\frac{\text{Average/mean mass of atoms of an element}}{\text{1/12 mass of one atom of 12C}}$

OR

$\frac{\text{Average / mean mass of atoms of an element} \times 12}{\text{mass of one atom of 12C}}$

OR
<u>(Average) mass of one mole of atoms</u>
1/12 mass of one mole of 12C
OR
<u>(Weighted) average mass of all the isotopes</u>
1/12 mass of one atom of 12C
OR
Average mass of an atom / all isotopes (compared to C-12) on a scale in which an atom of C-12 has a mass of 12

If moles and atoms mixed, max = 1
Mark top and bottom line independently.
All key terms must be present for each mark.

2

(b) $$\frac{(58 \times 19) + (60 \times 8) + (62 \times 3)}{30}$$

1

58.9

1

(c) To stop the ions produced colliding with air or other particles / so that there are only the ions produced from the sample present

***Not** just to remove air*

1

(d) $(1s^2)2s^2 2p^6 3s^2 3p^6 3d^8 4s^1$

1

(e) 9.63×10^{-26} (kg)

1

(f) ° $$KE = \frac{1}{2}m\left(\frac{d}{t}\right)^2$$

1

$$= \frac{7.37 \times 10^{-25}}{2} \times \frac{1.80^2}{(5.82 \times 10^{-7})^2}$$

1

4.61×10^{-13} (J)

If 7.37×10^{-25} used

$$= \frac{7.37 \times 10^{-25}}{2} \times \frac{1.80^2}{(5.82 \times 10^{-7})^2}$$

3.52×10^{-12} (J)

1

[10]

Q9.

(a) $2s^2 2p^6$

1

(b) $Al^+(g) \longrightarrow Al^{2+}(g) + e^{(-)}$

1

(c) The electron is being removed from a positive ion

Nuclear charge is the same but ion smaller than atom so energy needed to remove electron is greater

1

(d) Carbon

1

[4]

Q10.

(a) $^{70}Ge^{+}$

1

(b) $$A_r = \frac{(70 \times 24.4) + (72 \times 32.4) + (74 \times 43.2)}{100}$$

1

= 72.4

1

(c) Ions hit the detector and accept electrons causing current to flow

1

Bigger current = higher abundance of that ion

1

(d) 1.20×10^{-25} (kg)

This answer scores 2 marks

1 mark for 1.20×10^{-22} or 1.196×10^{-25} or 1.196×10^{-22}

2

(e) $$KE = \frac{1}{2} m \frac{d^2}{t^2} \quad \text{OR} \quad 3.98 \times 10^{-16} = \frac{1}{2} \times 1.196 \times 10^{-25} \times \frac{3^2}{t^2}$$

Allow consequential marking based on answer to (d)

1

$$t^2 = \frac{0.5 \times 1.196 \times 10^{-25} \times 3^2}{3.98 \times 10^{-16}}$$

1

$t = 3.68 \times 10^{-5}$ (s)

1

[10]

Examiner reports

Q1.

Part (a) was generally answered well but some students confused mass number with relative molecular mass.

Answers to part (b) were generally good.

In part (c) many students could state that the isotopes had the same atomic radius but then gave incomplete explanations.

The calculation in part (d) was well answered with many students scoring all the marks.

In part (e) several students failed to give their answer in kg.

Most students gained some credit in part (f) but a few could not rearrange the equation correctly; a few students made transcription errors in the kinetic energy value but did use their values correctly.

Q2.

Equations in part (a) were well done but a few students omitted state symbols.

In part (b) many students stated that aluminium was in a p orbital that was higher in energy but failed to refer to an electron being removed.

Many students gave the correct element in part (c) but often the explanations were incomplete.

In part (d) many students could state the structure but then confused their answer by including references to intermolecular forces in silicon.

Q6.

Most students could give the meaning of isotopes in part (a), although some did not refer to all of the fundamental particles.

The calculation in part (b) was well answered.

Several students could not give the correct electron configuration in part (c).

In part (d) answers were generally correct although several students did not add state symbols.

Many students did not convert the mass into kg in part (e) but were generally able to use their answers in a correctly in part (f).

About half the students could correctly answer part (g).

Q8.

Many students did not gain both marks for the definition in part (a).

The calculation in part (b) was done well by many students although a few divided by the wrong number.

Some students gave good answers to part (c).

In part (d) many students could not give the correct electron configuration; the main error was losing the d electrons (rather than the s electrons).

In part (e) some students gave the mass of the ion in grams.

Answers to part (f) were variable and a few candidates did not use the two equations given correctly. (Correct use of students incorrect answers to part (e) were given credit).

Q9.

Some students were unable to complete the electron arrangement in part (a) but the majority could give the correct equation in part (b).

There was a reasonable attempt at the explanation needed in part (c) but many failed to get the correct answer in part (d) and selected silicon which is in period 3.

Q10.

Only a few gave the correct formula of the ion in part (a) with many missing the charge.

The calculation was well done in part (b) but the answers to part (c) were very variable and many students did not know that current generated at the detector was proportional to abundance of the isotope.

Parts (d) and (e) were attempted with variable success; many students did not give the mass in kg and many could not successfully rearrange the equations to calculate the time.