Q1.

The diagram shows an energy-level diagram for a hydrogen atom.

\[ \text{ground state} \quad -13.6 \text{ eV} \]

Electrons, each having a kinetic energy of \( 2.0 \times 10^{-18} \text{ J} \), collide with atoms of hydrogen in their ground state. Photons are emitted when the atoms de-excite.

How many different wavelengths can be observed with incident electrons of this energy?

A 1
B 3
C 6
D 7

(Total 1 mark)

Q2.

The diagram below represents the decay of a particle \( X \) into a particle \( Y \) and two other particles.

The quark structure of particles \( X \) and \( Y \) are shown in the diagram.

(a) Deduce the name of particle \( X \).
Q3.

The diagram below shows the apparatus used to investigate Rutherford scattering, in which α particles are fired at a gold foil.

(a) Why is it essential for there to be a vacuum in the chamber?
(b) What observations made with this apparatus support each of the following conclusions? No explanation is required.

(i) The nuclear radius of gold is much smaller than its atomic radius.

(ii) Most of the mass of an atom of gold is contained in its nucleus.

(c) The drawing below shows $\alpha$ particles incident on a layer of atoms in a gold foil.

On this figure draw the complete path followed by each of the $\alpha$ particles shown.
Q4.

The diagram below shows the lowest three energy levels of a hydrogen atom.

\[
\begin{align*}
    n = 3 & \quad -1.51 \\
    n = 2 & \quad -3.41 \\
    n = 1 & \quad -13.6
\end{align*}
\]

(a) An electron is incident on a hydrogen atom. As a result an electron in the ground state of the hydrogen atom is excited to the \( n = 2 \) energy level. The atom then emits a photon of a characteristic frequency.

(i) Explain why the electron in the ground state becomes excited to the \( n = 2 \) energy level.

(ii) Calculate the frequency of the photon.

\[
\text{frequency} = \frac{1.70 \times 10^{-18}}{1.602 \times 10^{-19}} \quad \text{Hz}
\]

(iii) The initial kinetic energy of the incident electron is \( 1.70 \times 10^{-18} \) J.

    Calculate its kinetic energy after the collision.

\[
\text{kinetic energy} = \quad \text{J}
\]
(iv) Show that the incident electron cannot excite the electron in the ground state to the $n = 3$ energy level.

(b) When electrons in the ground state of hydrogen atoms are excited to the $n = 3$ energy level, photons of more than one frequency are subsequently released.

(i) Explain why different frequencies are possible.

(ii) State and explain how many possible frequencies could be produced.
Q5.

The diagram shows some of the energy levels for a hydrogen atom.

![Energy Level Diagram](image)

An excited hydrogen atom can emit photons of certain discrete frequencies. Three possible transitions are shown in the diagram.

(a) The transitions shown in the diagram result in photons being emitted in the ultraviolet, visible and infrared regions of the electromagnetic spectrum.

To which region of the spectrum do the emitted photons belong?

Tick (✔) the correct box for each transition, A, B and C.

<table>
<thead>
<tr>
<th>Transition</th>
<th>Ultraviolet</th>
<th>Visible</th>
<th>Infrared</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>✔</td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>B</td>
<td>✔</td>
<td>✔</td>
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</tr>
<tr>
<td>C</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

(1)

(b) Two ways to excite a hydrogen atom are by collision with a free electron or by the absorption of a photon.

Explain why, for a particular transition, the photon must have an exact amount of energy whereas the free electron only needs a minimum amount of kinetic energy.

___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________
___________________________________________________________________

(3)
Mark schemes

Q1.

B

[1]

Q2.

(a) Neutron

Condone misspelling eg neuton

1

(b) Weak (interaction)

Ignore nuclear or references to beta

1

(c) Bosons

Accept ‘exchange particles’

Do not allow ‘force mediator’

1

(d) charge number

\[
\frac{2}{3} - \frac{1}{3} - \frac{1}{3} \rightarrow \frac{2}{3} + \frac{1}{3} + \frac{2}{3} - 1 + 0 \checkmark
\]

Ignore equation if given, marking should be based on the numbers

baryon number

\[
\frac{1}{3} + \frac{1}{3} + \frac{1}{3} \rightarrow \frac{1}{3} + \frac{1}{3} + \frac{1}{3} + 0 + 0 \checkmark
\]

Allow 1 for both correct in terms of n & p instead of quarks:

\[
0 \rightarrow +1 + -1 + 0
\]

\[
1 \rightarrow 1 + 0 + 0
\]

2

(e) proton

Allow ‘free proton’

1

(f) Electron + an electron antineutrino + muon neutrino

All 3 needed

Condone anti-electron neutrino for electron anti-neutrino

No credit given for symbols

Allow antiparticle answer: positron, electron neutrino, muon antineutrino

1

[7]

Q3.

(a) to prevent the α particles being absorbed or scattered (1)
by air molecules (1)
(b)  (i) little or no deflection (1)
by a majority of $\alpha$ particles (1)

(ii) some $\alpha$ particles suffer large deflection
[or backscattering occurs] (1)

(c) first path continues undeflected (1)
third path shows backscattering (inside the dotted circle) (1)
second path undeflected or deflected downwards and
fourth path undeflected or deflected upwards (1)

Q4.

(a)  (i) absorbs enough energy (from the incident) electron (by collision) OR incident electron loses energy (to orbital electron) ✓
exact energy / $10.1\, (eV)$ needed to make the transition / move up to level 2 ✓

For second mark must imply exact energy

(ii) $(use\ of\ E_2 - E_1) = hf$
$-3.41 - -13.6 = 10.19 ✓$
energy of photon $= 10.19 \times 1.6 \times 10^{-19} = 1.63 \times 10^{-18} \, (J) \, ✓$
$6.63 \times 10^{-34} \times f = 1.63 \times 10^{-18}$
f $= 2.46 \times 10^{15} (Hz) ✓$
(accept 2.5 but not 2.4)

CE from energy difference but not from energy conversion

(iii) $E_k = 1.7 \times 10^{-18} - 1.63 \times 10^{-18} ✓ = 7.0 \times 10^{-20} \, J ✓$

(iv) energy required is $12.09 \, eV / 1.9 \times 10^{-18} ✓$
energy of incident electron is only $10.63 \, eV / energy\ of\ electron\ less\ than\ this$
$(1.7 \times 10^{-18} \, J) ✓$

State and explain must have consistent units i.e. eV or $J$

(b)  (i) Electrons return to lower levels by different routes / cascade / not straight to
ground state ✓

(ii) $3 ✓$
n=3 to n=1 or n=3 to n=2 and n=2 to n=1 ✓
no CE from first mark

Q5.

(a) | Transition | Ultraviolet | Visible | Infrared |
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>✓</td>
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<tr>
<td>B</td>
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<td>✓</td>
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<tr>
<td>C</td>
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</tbody>
</table>

*all correct 1 mark*

(b) EITHER
energy needed for electron to move to higher level/orbital ✓
OR
for a transition/excitation/change of levels an exact amount of energy is needed ✓
all the photon’s energy absorbed (in 1 to 1 interaction) ✓
electron can transfer part of its energy (to cause a transition/excitation)/ continues moving/ lower kinetic energy/ lower speed ✓

*Any implication of photoelectric effect max 1*
*Accept one energy level to another*