1. Two stable isotopes of helium are ${}^{4}_{2}\text{He}$ and ${}^{3}_{2}\text{He}$.

(a) An atom of ${}^{4}_{2}\text{He}$ is produced in a rock that contains uranium. It is produced following the radioactive decay of a ${}^{238}_{92}\text{U}$ atom. The decay also creates an atom of thorium (Th).

Write an equation for the decay of ${}^{238}_{92}\text{U}$.

${}^{238}_{92}\text{U} \longrightarrow$

(2)

(b) A ${}^{3}_{2}\text{He}$ nucleus can be produced by the decay of a tritium nucleus ${}^{3}_{1}\text{H}$.

State and explain which exchange particle is responsible for this decay.

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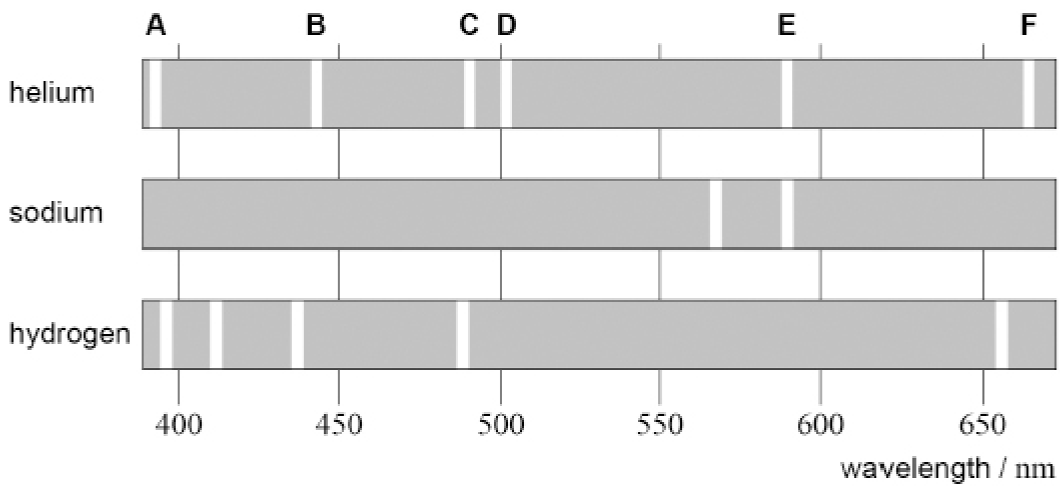
(2)

Helium was discovered by analysing the light in the **absorption** spectrum of the Sun.

The figure below shows the positions of the brightest lines, labelled **A** to **F**, in the **emission** spectrum of helium. The brightest lines in the emission spectra of sodium and hydrogen are also shown.



(c) Before helium was identified, some scientists suggested that the lines of the helium spectrum seen in the absorption spectrum of the Sun were due to the presence of sodium and hydrogen.

Discuss, with reference to the lines **A** to **F** in the figure above, the evidence for and against this suggestion.

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(2)

(d) Calculate, in eV, the change in energy level responsible for the spectral line labelled **E** in the diagram above.

change in energy level = _______________ eV

(3)

(e) Explain, with reference to the processes within an atom, the difference between an emission spectrum and an absorption spectrum.

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(3)
(Total 12 marks)

2. In a discharge tube a high potential difference is applied across hydrogen gas contained in the tube. This causes the hydrogen gas to emit light that can be used to produce the visible line spectrum shown in **Figure 1**.

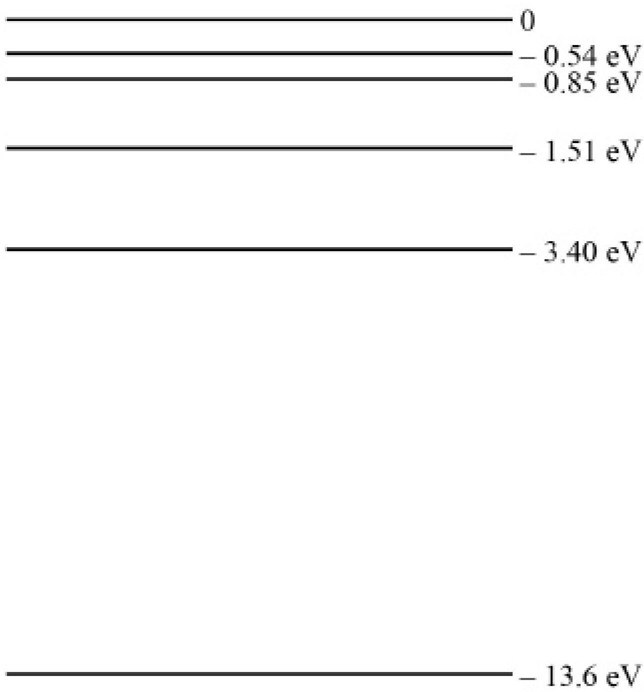
Figure 1

The visible line spectrum in **Figure 1** has been used to predict some of the electron energy levels in a hydrogen atom.

The energy levels predicted from the visible line spectrum are those between 0 and −3.40 eV in the energy level diagram.

Some of the predicted energy levels are shown in **Figure 2**.

Figure 2



not to scale

(a) Calculate the energy, in eV, of a photon of light that has the lowest frequency in the visible hydrogen spectrum shown in **Figure 1**.

energy of photon = ______________________________ eV

(3)

(b) Identify the state of an electron in the energy level labelled 0.

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(1)

(c) Identify the state of an electron that is in the energy level labelled –13.6 eV.

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(1)

(d) Explain why the energy levels are negative.

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(1)

(e) Discuss how the discharge tube is made to emit electromagnetic radiation of specific frequencies.

In your answer you should:

- explain why there must be a high potential difference across the tube
- discuss how the energy level diagram in **Figure 2** predicts the spectrum shown in **Figure 1**
- show how one of the wavelengths of light is related to two of the energy levels in the energy level diagram.

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(6)

(Total 12 marks)

3. The table shows results of an experiment to investigate how the de Broglie wavelength λ of an electron varies with its velocity v.

v / 10^7 m s^{-1}	λ / 10^{-11} m
1.5	4.9
2.5	2.9
3.5	2.1

(a) Show that the data in the table are consistent with the relationship $\lambda \propto \frac{1}{v}$

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(2)

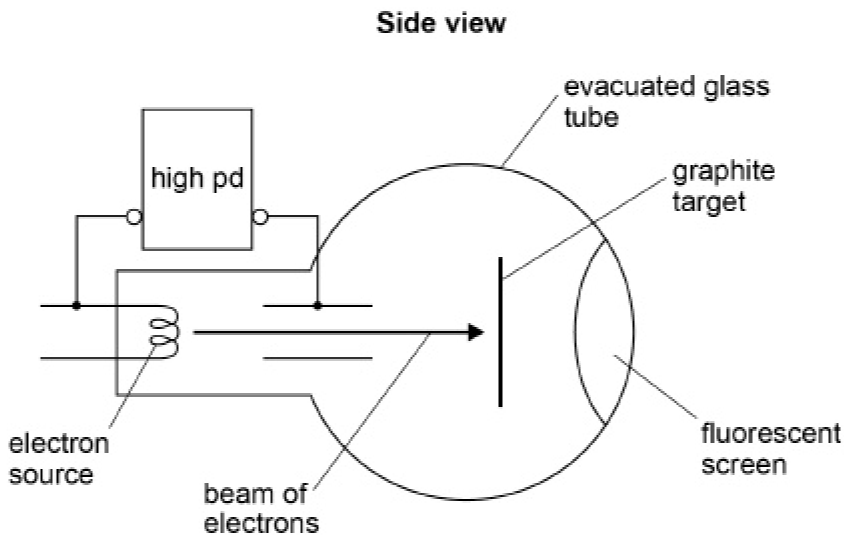
(b) Calculate a value for the Planck constant suggested by the data in the table.

Planck constant = ______________________ J s

(2)

(c) **Figure 1** shows the side view of an electron diffraction tube used to demonstrate the wave properties of an electron.

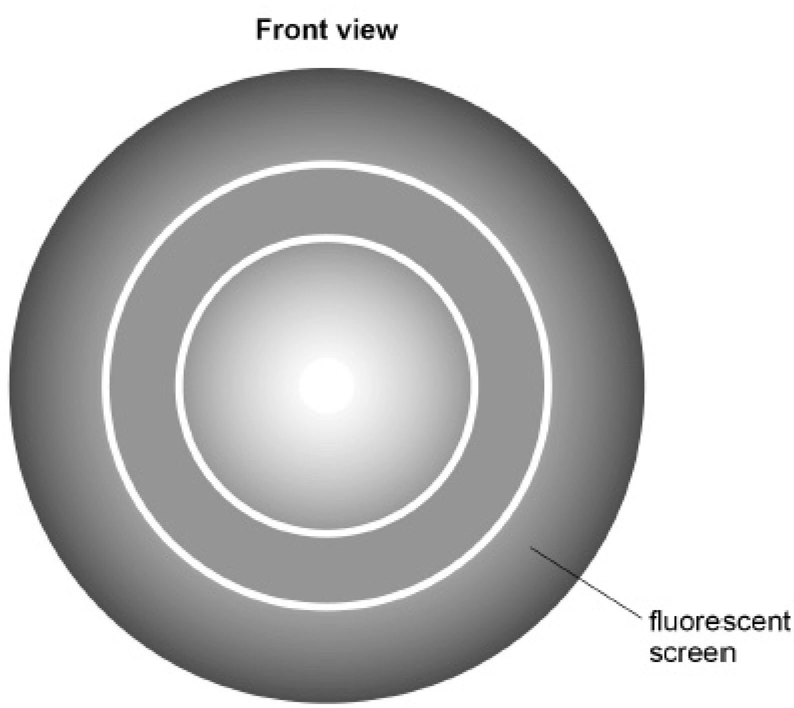
Figure 1



An electron beam is incident on a thin graphite target that behaves like the slits in a diffraction grating experiment. After passing through the graphite target the electrons strike a fluorescent screen.

Figure 2 shows the appearance of the fluorescent screen when the electrons are incident on it.

Figure 2



Explain how the pattern produced on the screen supports the idea that the electron beam is behaving as a wave rather than as a stream of particles.

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(3)

(d) Explain how the emission of light from the fluorescent screen shows that the electrons incident on it are behaving as particles.

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(3)

(Total 10 marks)

4. Cosmic rays are high-energy particles coming from Space. They collide with the air molecules in the Earth's atmosphere to produce pions and kaons.

(a) Pions and kaons are mesons. Identify the quark–antiquark composition for a meson.

Tick (✓) the correct answer in the right-hand column.

	✓ if correct
qqq	
$q\bar{q}\bar{q}$	
$q\bar{q}$	
qq	

(1)

(b) A positron with a kinetic energy of 2.0 keV collides with an electron at rest, creating two photons that have equal energy.

Show that the energy of each photon is 8.2×10^{-14} J.

(3)

(c) Calculate the wavelength of a photon of energy 8.2×10^{-14} J.

wavelength = ________________________ m

(2)

(d) Show that the speed of the positron before the collision was about 2.7×10^7 m s^{-1}.

(3)

(e) Calculate the de Broglie wavelength of the positron travelling at a speed of 2.7×10^7 m s^{-1}.

wavelength = ________________________ m

(2)

(f) The separation between the carbon atoms in graphite is about 0.15 nm.

Discuss whether electrons travelling at 2.7×10^7 m s^{-1} can be can be used to demonstrate diffraction as they pass through a sample of graphite.

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(4)

(Total 15 marks)