**1** An electron initially at rest is accelerated through a potential difference. It is then brought to rest in a collision, and all of its kinetic energy is converted into a single photon of electromagnetic radiation. Which one of the following quantities is **not** required to find a value for the wavelength of the photon?

**A** The mass of the electron

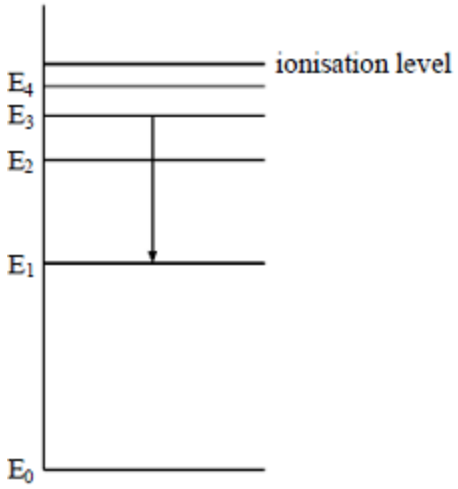
**B** The charge on the electron

**C** The velocity of electromagnetic waves

**D** The value of the potential difference

**(Total 1 mark)**

**2** The diagram shows some energy levels of an atom.




The transition $E_3$ to $E_1$ corresponds to the emission of visible light.

A transition corresponding to the emission of infrared radiation could be

**A** $E_1$ to $E_0$

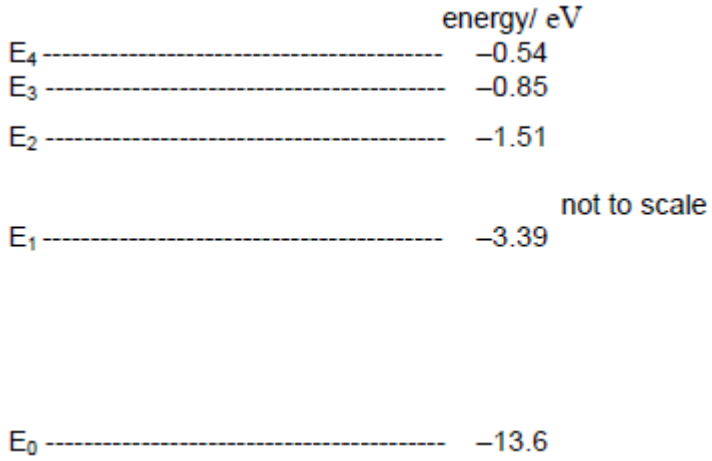
**B** $E_4$ to $E_1$

**C** $E_1$ to $E_2$

**D** $E_3$ to $E_2$

**(Total 1 mark)**

**3** The diagram gives some of the energy levels of a hydrogen atom.




The transition of an excited hydrogen atom from $E_3$ to $E_1$ causes a photon of visible light to be emitted.

Which transition causes a photon of ultraviolet light to be emitted?

**A** $E_4$ to $E_3$ ⬭

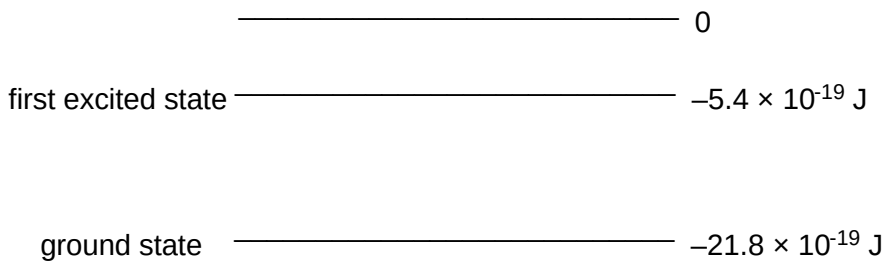
**B** $E_3$ to $E_2$ ⬭

**C** $E_2$ to $E_1$ ⬭

**D** $E_1$ to $E_0$ ⬭

**(Total 1 mark)**

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




A free electron of kinetic energy $20.0 \times 10^{-19}$ J collides with a hydrogen atom in its ground state. The hydrogen atom is excited from its ground state to the first excited state. The kinetic energy of the free electron after the collision is

**A** $1.8 \times 10^{-19}$ J

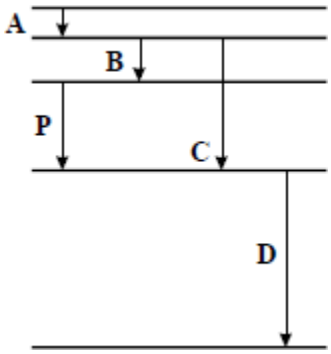
**B** $3.6 \times 10^{-19}$ J

**C** $5.4 \times 10^{-19}$ J

**D** $16.4 \times 10^{-19}$ J

**(Total 1 mark)**

**5** The diagram **drawn to scale** shows some of the energy levels of an atom. Transition **P** results in the emission of a photon of wavelength $4 \times 10^{-7}$ m.




Which one of the transitions **A**, **B**, **C**, or **D** could result in the emission of a photon of wavelength $8 \times 10^{-7}$ m?

**(Total 1 mark)**

**6** (a) State what happens in an atom when line spectra are produced.

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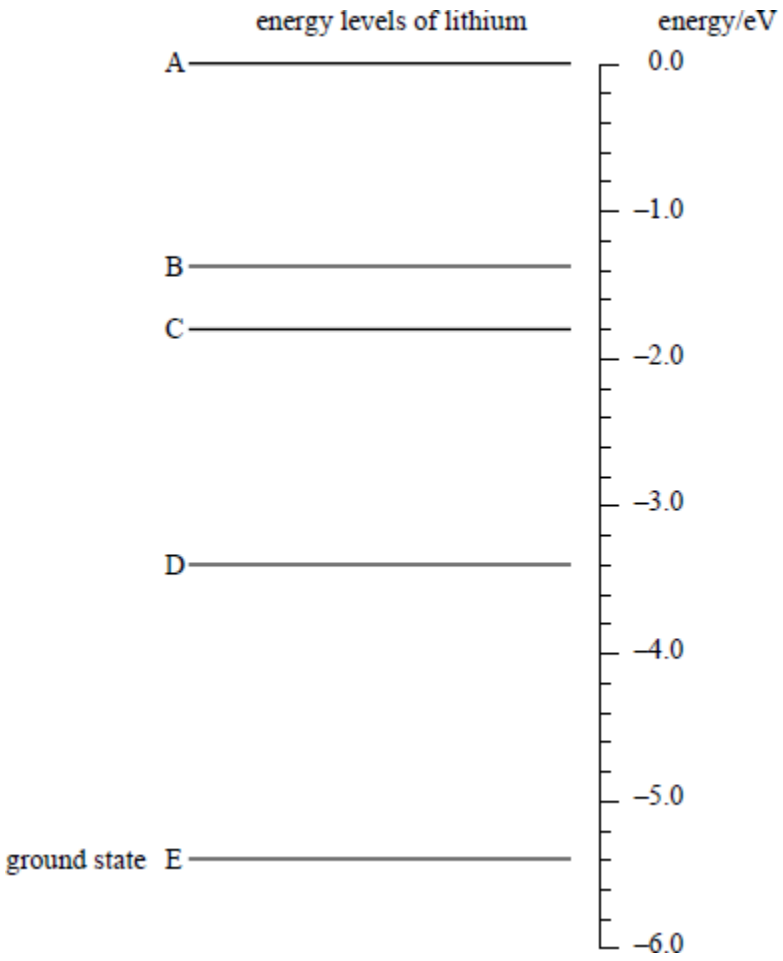
**(2)**

(b) The diagram below represents some energy levels of the lithium atom.




(i) Calculate the ionisation energy, in J, of the lithium atom.

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(ii) An excited lithium atom may emit radiation of wavelength $6.1 \times 10^{-7}$ m.
Show that the frequency of this radiation is approximately $5.0 \times 10^{14}$ Hz.

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(iii) Calculate the energy, in J, of each photon of this radiation.

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(iv) Draw, on the diagram, an arrow between two energy levels which shows the transition responsible for the emission of a photon of energy 2.0 eV.

(v) Two transitions emit radiation of similar frequencies. One of them is the transition between A and C. What is the other?

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(vi) A transition between which two levels would give radiation of the longest possible wavelength?

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**(9)**
**(Total 11 marks)**

**7** (a) When free electrons collide with atoms in their *ground state*, the atoms can be excited or ionised.

(i) State what is meant by ground state.

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**(1)**

(ii) Explain the difference between excitation and ionisation.

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**(3)**

(b) An atom can also become excited by the absorption of photons. Explain why only photons of certain frequencies cause excitation in a particular atom.

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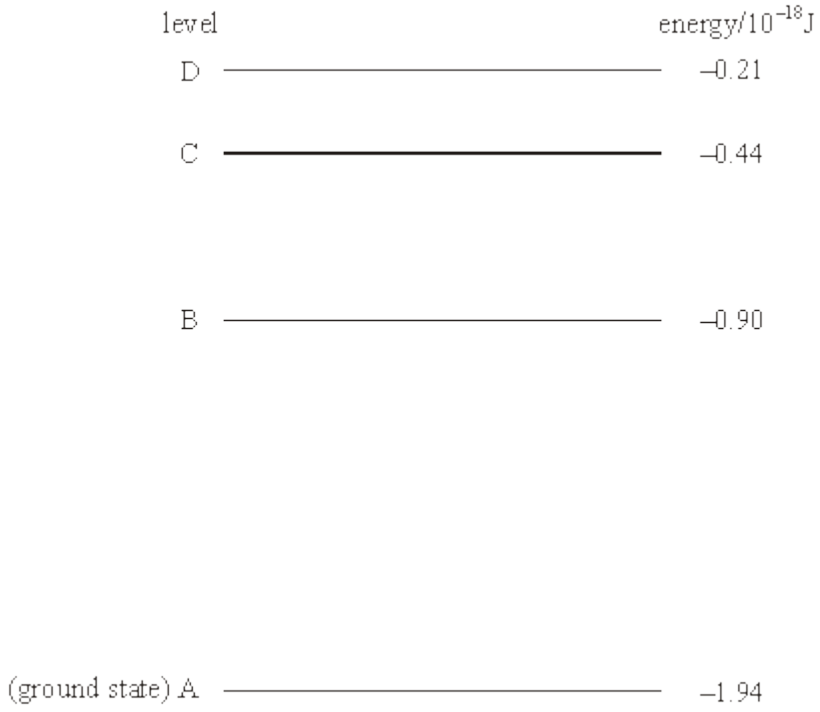
**(4)**

(c) The ionisation energy of hydrogen is 13.6 eV. Calculate the minimum frequency necessary for a photon to cause the ionisation of a hydrogen atom. Give your answer to an appropriate number of significant figures.

answer .....Hz

**(4)**
**(Total 12 marks)**

**8** The diagram shows some of the electron energy levels of an atom.




An incident electron of kinetic energy $4.1 \times 10^{-18}$ J and speed $3.0 \times 10^{6}$ m $s^{-1}$ collides with the atom represented in the diagram and excites an electron in the atom from level B to level D.

(a) For the incident electron, calculate

(i) the kinetic energy in eV,

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(ii) the de Broglie wavelength.

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**(4)**

(b) When the excited electron returns directly from level D to level B it emits a photon. Calculate the wavelength of this photon.

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**(3)**
**(Total 7 marks)**

**9** A diffraction grating was used to measure the wavelength of a certain line of a line emission spectrum.

(a) The grating had 600 lines per millimetre. The angle of diffraction of the second order line was 35.8°.

(i) Calculate the wavelength of this line.

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(ii) Calculate the energy, in eV, of a photon of this wavelength.

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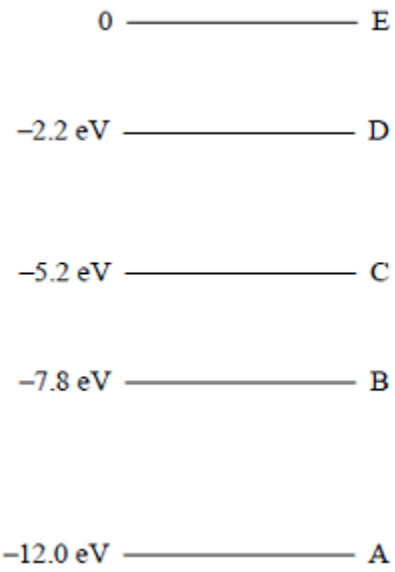
**(5)**

(b) The line emission spectrum observed in part (a) was produced by a hot gas.

(i) The energy level diagram for the atoms that produced the line spectrum is shown in the diagram below. Mark on the diagram a vertical arrow to show the electron transition between the two levels that produced photons of energy 6.8 eV.




(ii) The temperature of the gas was 5000K. Show that the mean kinetic energy of a gas atom at this temperature is 0.65 eV.

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(iii) Describe how the atoms of a gas produce a line emission spectrum and explain why the gas at a temperature of 5000K can produce a line of the wavelength calculated in part (a)(i).

You may be awarded marks for the quality of written communication in your answer.

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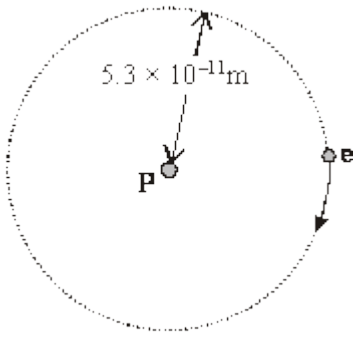
**(6)**
**(Total 11 marks)**

**10** The Bohr model of a hydrogen atom assumes that an electron **e** is in a circular orbit around a proton **P**. The model is shown schematically in **Figure 1**.

**Figure 1**




In the ground state the orbit has a radius of $5.3 \times 10^{-11}$ m. At this separation the electron is attracted to the proton by a force of $8.1 \times 10^{-8}$ N.

(a) State what is meant by <u>the ground state</u>.

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**(1)**

(b) (i) Show that the speed of the electron in this orbit is about $2.2 \times 10^{6}$ m $s^{-1}$.

mass of an electron = $9.1 \times 10^{-31}$ k g

(ii) Calculate the de Broglie wavelength of an electron travelling at this speed.

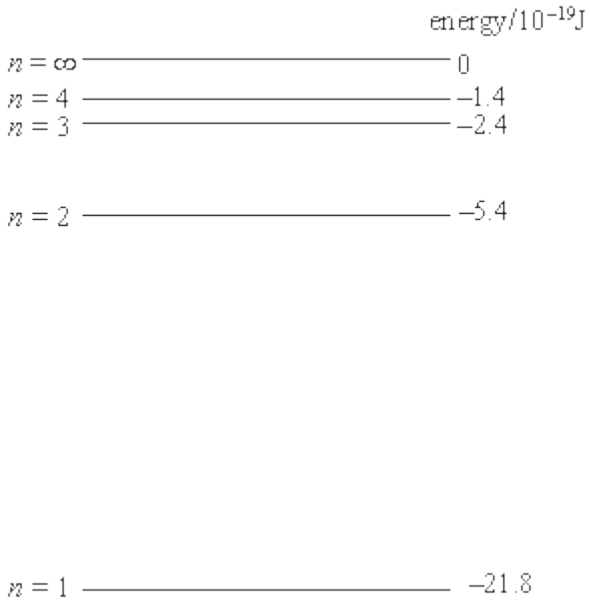
Planck constant = $6.6 \times 10^{-34}$ J s

(iii) How many waves of this wavelength fit the circumference of the electron orbit? Show your reasoning.

**(7)**

(c) The quantum theory suggests that the electron in a hydrogen atom can only exist in certain well-defined energy states. Some of these are shown in **Figure 2**.

**Figure 2**




An electron **E** of energy $2.5 \times 10^{-18}$ J collides with a hydrogen atom that is in its ground state and excites the electron in the hydrogen atom to the $n = 3$ level.

Calculate

(i) the energy that is needed to excite an electron in the hydrogen atom from the ground state to the $n = 3$ level,

(ii) the kinetic energy of the incident electron **E** after the collision,

(iii) the wavelength of the lowest energy photon that could be emitted as the excited electron returns to the ground state.

speed of electromagnetic radiation = $3.0 \times 10^8$ m $s^{-1}$

**(5)**

**(Total 13 marks)**

**11** Observations of the H-α line in the spectrum of a star indicate the presence of hydrogen. The H-α line has a wavelength of 656 nm and is produced by a transition of electrons into the −3.4 eV energy level.

Calculate the energy level that the electron moves from when emitting a photon corresponding to a wavelength of 656 nm. Give your answer in **J**.

energy level ..... J

**(Total 4 marks)**

**12** Some energy levels of an atom of a gas are shown in **Figure 1**.

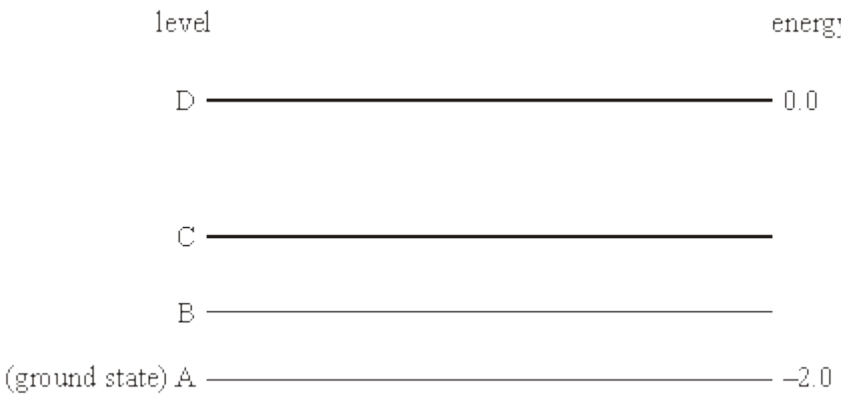



**Figure 1**

When a current is passed through the gas at low pressure, a line spectrum is produced. Two of these lines, which correspond to transitions from levels B and C respectively to the ground state, are shown in **Figure 2**.

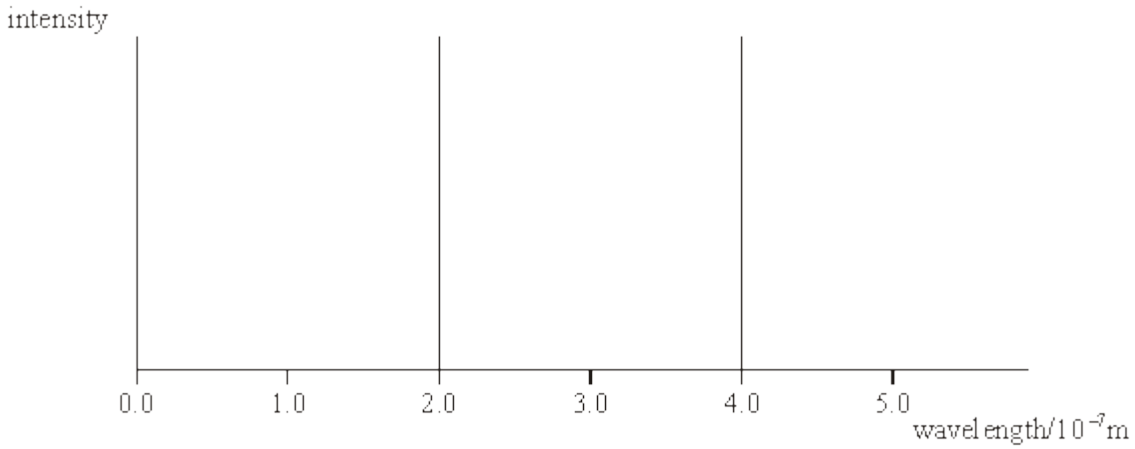



**Figure 2**

(a) Describe what happens to an electron in an atom in the ground state in order for the atom to emit light of wavelength $4.0 \times 10^{-7}$ m.

You may be awarded marks for the quality of written communication in your answer.

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**(3)**

(b) Determine the energy, in J, of

(i) the photons responsible for each of the two lines shown in **Figure 2**,

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(ii) levels B and C in **Figure 1.**

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energy of level B = .....

energy of level C = .....

**(5)**
**(Total 8 marks)**

**13** The diagram below shows part of an energy level diagram for a hydrogen atom.

n = 4 ——————— –0.85 eV
n = 3 ——————— –1.50 eV
n = 2 ——————— –3.40 eV

n = 1 ——————— –13.60 eV

(a) The level, n = 1, is the ground state of the atom.
State the ionisation energy of the atom in eV.

answer = ..... eV

**(1)**

(b) When an electron of energy 12.1 eV collides with the atom, photons of three different energies are emitted.

(i) On the diagram above show with arrows the transitions responsible for these photons.

**(3)**

(ii) Calculate the wavelength of the photon with the smallest energy. Give your answer to an appropriate number of significant figures.

answer =..... m

**(5)**
**(Total 9 marks)**

**14** (a) A fluorescent tube is filled with mercury vapour at low pressure. In order to emit electromagnetic radiation the mercury atoms must first be *excited*.

(i) What is meant by an excited atom?

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**(1)**

(ii) Describe the process by which mercury atoms become excited in a fluorescent tube.

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**(3)**

(iii) What is the purpose of the coating on the inside surface of the glass in a fluorescent tube?

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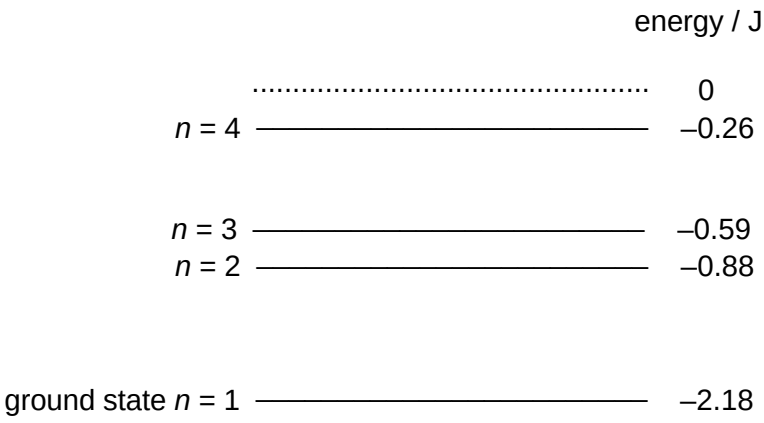
**(3)**

(b) The lowest energy levels of a mercury atom are shown in the diagram below. The diagram is **not** to scale.




(i) Calculate the frequency of an emitted photon due to the transition level $n = 4$ to level $n = 3$.

answer = ..... Hz

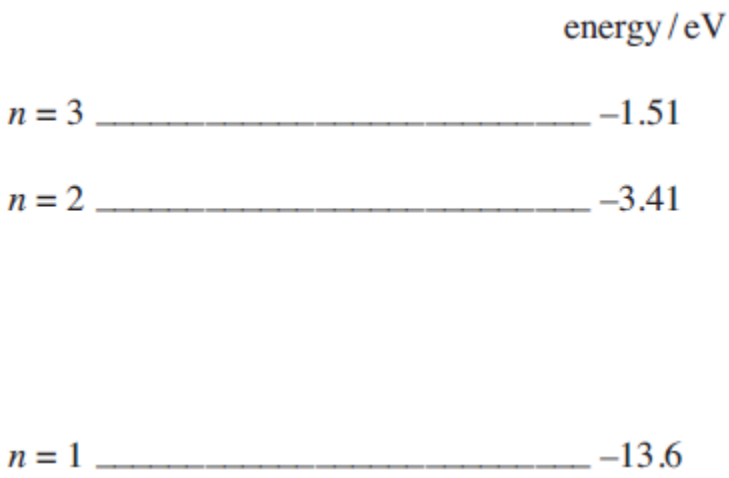
**(3)**

(ii) Draw an arrow on the diagram above to show a transition which emits a photon of a longer wavelength than that emitted in the transition from level $n = 4$ to level $n = 3$.

**(2)**

**(Total 12 marks)**

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




(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.

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**(2)**

(ii) Calculate the frequency of the photon.

frequency = ..... Hz

**(3)**

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

Calculate its kinetic energy after the collision.

kinetic energy = ..... J

**(2)**

(iv) Show that the incident electron cannot excite the electron in the ground state to the $n = 3$ energy level.

**(2)**

(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.

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**(1)**

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

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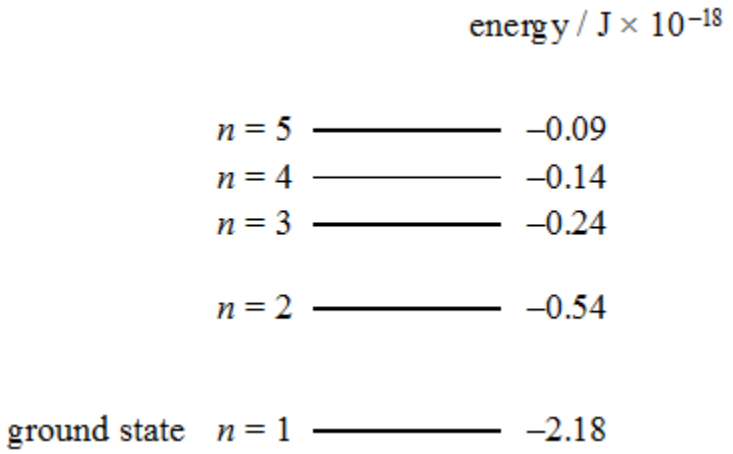
**(2)**

**(Total 12 marks)**

**16** The lowest energy levels of a hydrogen atom are represented in the diagram below, which is **not** to scale.




(a) Describe what happens when a hydrogen atom is ionised.

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(b) State the minimum amount of energy, in J, required to ionise a hydrogen atom from its ground state.

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(c) A hydrogen atom excited to the $n = 3$ energy level may emit either a single photon or two photons in returning to the ground state.

Describe what happens to the electron in each case.

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(d) Use the diagram above to identify the transition which produces a photon of energy $2.09 \times 10^{-18}$ J.

(e) Calculate the frequency of an emitted photon due to a transition from level $n = 2$ to the ground state.

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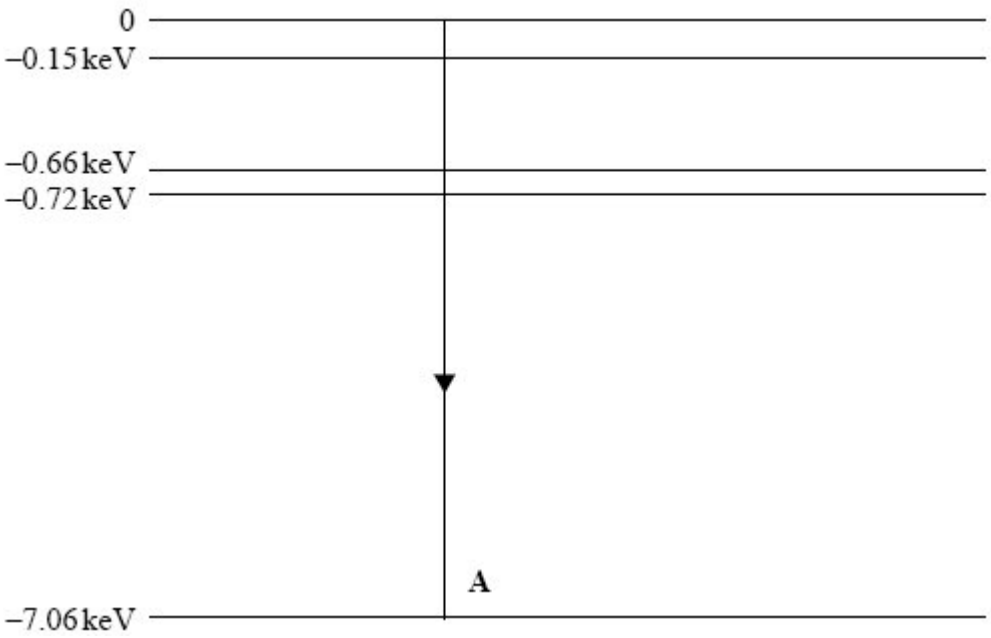
**(Total 8 marks)**

**17** (a) The diagram below shows some of the energy levels for an iron atom.




(i) Draw another arrow on the diagram above to represent the smallest energy change possible for an electron moving between two of the energy levels shown.
The electron energy change selected must result in energy being emitted from the atom.
Label this arrow **B**.

**(1)**

(ii) In the diagram above, when the energy change labelled **A** occurs an X-ray photon is emitted.

Show that the frequency of the photon is approximately $2 \times 10^{18}$ Hz.

**(3)**

(b) (i) Radiation of frequency $2 \times 10^{18}$ Hz has a wavelength of $1.5 \times 10^{-10}$ m. Calculate the speed of an electron that has a de Broglie wavelength of $1.5 \times 10^{-10}$ m.

speed .....m $s^{-1}$

**(2)**

(ii) Explain why electrons of this wavelength would be suitable to investigate the structure of a metallic crystal.

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**(2)**

**(Total 8 marks)**

**18** (a) A fluorescent tube is filled with mercury vapour at low pressure. After mercury atoms have been excited they emit photons.

(i) In which part of the electromagnetic spectrum are these photons?

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**(1)**

(ii) What is meant by an excited mercury atom?

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**(1)**

(iii) How do the mercury atoms in the fluorescent tube become excited?

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**(2)**

(iv) Why do the excited mercury atoms emit photons of characteristic frequencies?

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**(3)**

(b) The wavelength of some of the photons emitted by excited mercury atoms is 254 nm.

(i) Calculate the frequency of the photons.

frequency ..... Hz

**(2)**

(ii) Calculate the energy of the photons in electron volts (eV).

energy ..... eV

**(2)**

(c) Explain how the coating on the inside of a fluorescent tube emits visible light.

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**(2)**

**(Total 13 marks)**

**19** (a) The mercury atoms in a fluorescent tube are excited and then emit photons in the ultraviolet region of the electromagnetic spectrum.

(i) Explain how the mercury atoms become excited.

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**(3)**

(ii) Explain how the excited mercury atoms emit photons.

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**(2)**

(b) Explain how the ultraviolet photons in the tube are converted into photons in the visible part of the electromagnetic spectrum.

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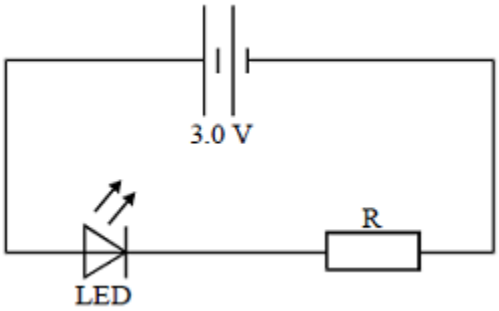
**(2)**
**(Total 7 marks)**

**20** The circuit diagram shows a light emitting diode (LED) connected in series with a resistor, R, and a 3.0 V battery of negligible internal resistance.




(a) The LED lights normally when the forward voltage across it is 2.2 V and the current in it is 35 mA.

Calculate

(i) the resistance of R,

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(ii) the number of electrons that pass through the LED each second.

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**(4)**

(b) The LED emits light at a peak wavelength of 635 nm.

(i) Calculate the energy of a photon of light of this wavelength.

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(ii) Estimate the number of photons emitted by the LED each second when the current through it is 35 mA. Assume all the photons emitted by the LED are of wavelength 635 nm and that all the electrical energy produces light.

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**(4)**
**(Total 8 marks)**