1(a) A helium-neon laser emits red light of wavelength 6.3×10^{-7} m.

(i) Show that the energy of a single photon is about 3×10^{-19} J.

[2]

(ii) The power of the laser beam is 1.0 mW. Show that about 3×10^{15} photons are emitted by the laser each second.

[1]

(iii) The photons of red light are emitted by the neon atoms in the gas inside the laser.

Explain what *energy levels* are and how they can be used to explain the emission of photons from atoms.

In your answer take care to make your explanation clear.

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.... **[4]**

(iv) Another laser emits blue light. The power in its beam is also 1.0 mW.

Explain why the laser emitting blue light emits fewer photons per second compared with a laser of the same power emitting red light.

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.... **[2]**

(b) A photodiode is a circuit component which can be used to convert a light signal into an electrical one. Fig. 7.1 shows an enlarged cross-section through a photodiode to illustrate how it is constructed. Light incident on the thin transparent conducting surface layer of the diode passes through it to be absorbed in the insulating layer. The energy of each photon is sufficient to release one electron in the insulating layer. The potential difference *V* applied across the insulating layer causes these electrons to move to one of the conducting layers.

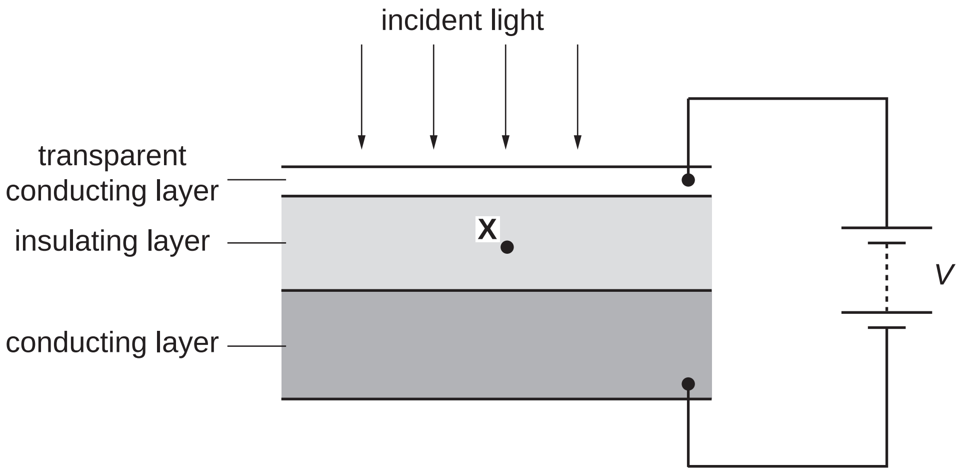

Fig. 7.1

(i) Draw an arrow on Fig. 7.1 to show the direction of motion of an electron released at point **X** in the centre of the insulating layer. **[1]**

(ii) The red light from the laser in **(a)** is incident on the photodiode. Experiments show that only 20% of the red light photons release electrons in the insulating layer and hence in the circuit of Fig. 7.1. Calculate the current through the photodiode.

current = ………………………….. A **[3]**

(iii) Suggest one reason why the efficiency of the photodiode is less than 100%.

....

.... **[1]**

[Total: 14]

2 Fig. 7.1 shows the three lowest energy levels of the hydrogen atom, labelled n = 1, 2 and 3.

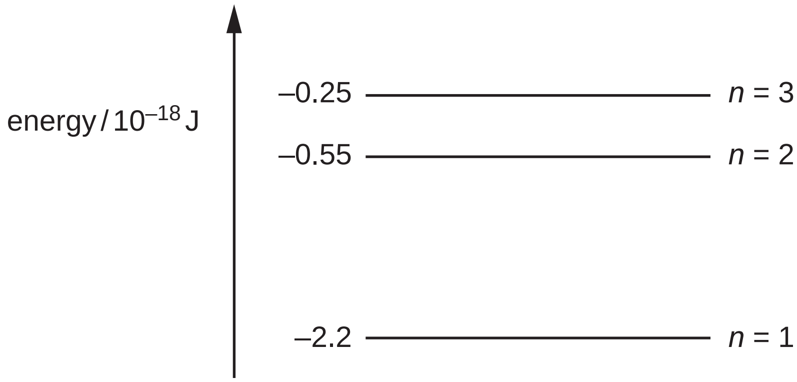

Fig. 7.1

(a) **(i)** Explain why electron transitions between the energy levels can produce three different wavelengths of radiation. You may draw lines on Fig. 7.1 to illustrate your explanation.

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.... **[3]**

(ii) The strong red line in the hydrogen spectrum has a wavelength of 6.56×10^{-7} m.

1 Calculate the energy of the photon at this wavelength.

energy = ... J **[2]**

2 Use Fig. 7.1 to identify the electron transition responsible for the spectral line of this wavelength.

....

.... **[1]**

(b) A parallel beam of light from a hydrogen lamp is incident on a diffraction grating. The first order red spectral line at 6.56×10^{-7} m is seen at an angle of 11.4° as shown in Fig. 7.2.

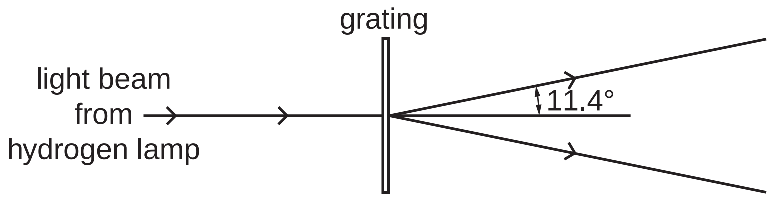

Fig. 7.2

(i) Calculate

1 the separation *d* of the lines on the grating

d = ... m **[3]**

2 the number of lines per millimetre on the grating.

number = ... lines mm^{-1} **[1]**

(ii) The hydrogen lamp also emits blue light at a wavelength of 4.86×10^{-7} m.

Draw rays on Fig. 7.2 to indicate roughly, that is without calculation, the direction of the **first** order blue spectral line as the rays leave the grating. **[1]**

[Total: 11]

3 Fig. 8.1 shows some energy levels of the hydrogen atom. The diagram is not to scale.

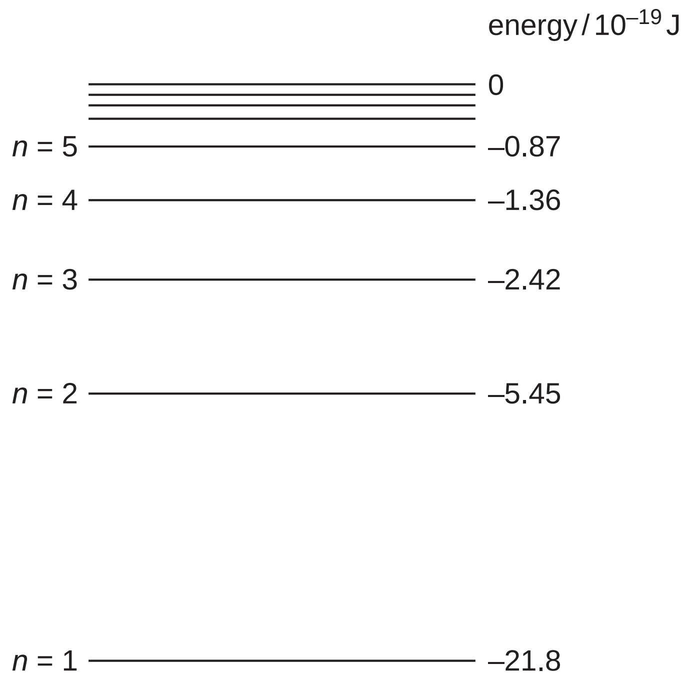

Fig. 8.1

The energy level corresponding to the lowest energy (ground) state of the atom is $n = 1$.

The hydrogen atom is ionised when it absorbs sufficient energy for the electron to escape from the proton; that is, for the energy labelled on Fig. 8.1 to become zero or positive.

(a) (i) Draw an arrowed line on Fig. 8.1 to indicate the process of ionisation of an atom initially in its ground state. **[1]**

(ii) Write down the value of the minimum energy required to ionise an atom in its ground state.

minimum energy = ... J **[1]**

(b) (i) Show that the energy change between levels required for the emission of a photon of wavelength 490 nm is about 4×10^{-19} J.

(ii) Draw an arrowed line on Fig. 8.1 to indicate the transition which results in the emission of a photon of wavelength 490 nm. **[1]**

(c) In space, a beam of photons of different energies passes through a cloud of atomic hydrogen gas. Explain, with a reason, what is likely to happen to photons of energy 19.38×10^{-19} J and to some of the hydrogen atoms.

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....

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.... **[3]**

[Total: 8]

4 In 1927 it was shown by experiment that electrons can produce a diffraction pattern.

(a) **(i)** Explain the meaning of the term *diffraction*.

....

....

.... **[1]**

(ii) State the condition necessary for electrons to produce observable diffraction when passing through matter, e.g. a thin sheet of graphite in an evacuated chamber.

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.... **[2]**

(b) Show that the speed of an electron with a de Broglie wavelength of 1.2×10^{-10} m is 6.0×10^{6} $m\,s^{-1}$.

[3]

(c) The electrons in **(b)** are accelerated to a speed of $6.0 \times 10^6\ \text{m s}^{-1}$ using an electron gun shown diagrammatically in Fig. 8.1.

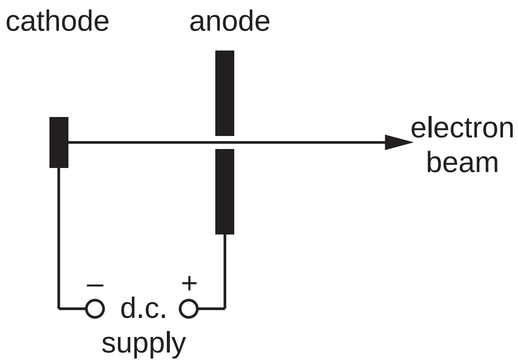

Fig. 8.1

(i) Calculate the potential difference V across the d.c. supply between the cathode and the anode.

V = ... V **[3]**

(ii) Suggest why, in an electron gun, the cathode is connected to the negative terminal of the supply rather than the positive terminal.

....

....

.... **[1]**

[Total: 10]