1. An argon-laser emits electromagnetic radiation of wavelength 5.1×10^{-7} m. The radiation is directed onto the surface of a caesium plate. The work function energy for caesium is 1.9 eV.

(i) Name the region of the electromagnetic radiation emitted by the laser.

....

[1]

(ii) Show that the work function energy of caesium is 3.0×10^{-19} J.

[1]

(iii) Calculate

1 the energy of a single photon

energy = ... J

[2]

2 the maximum kinetic energy of an electron emitted from the surface of caesium.

kinetic energy = ... J

[3]

(iv) State and explain what change, if any, occurs to the maximum kinetic energy of an emitted electron if the intensity of the laser light is reduced.

....

....

....

....

[2]

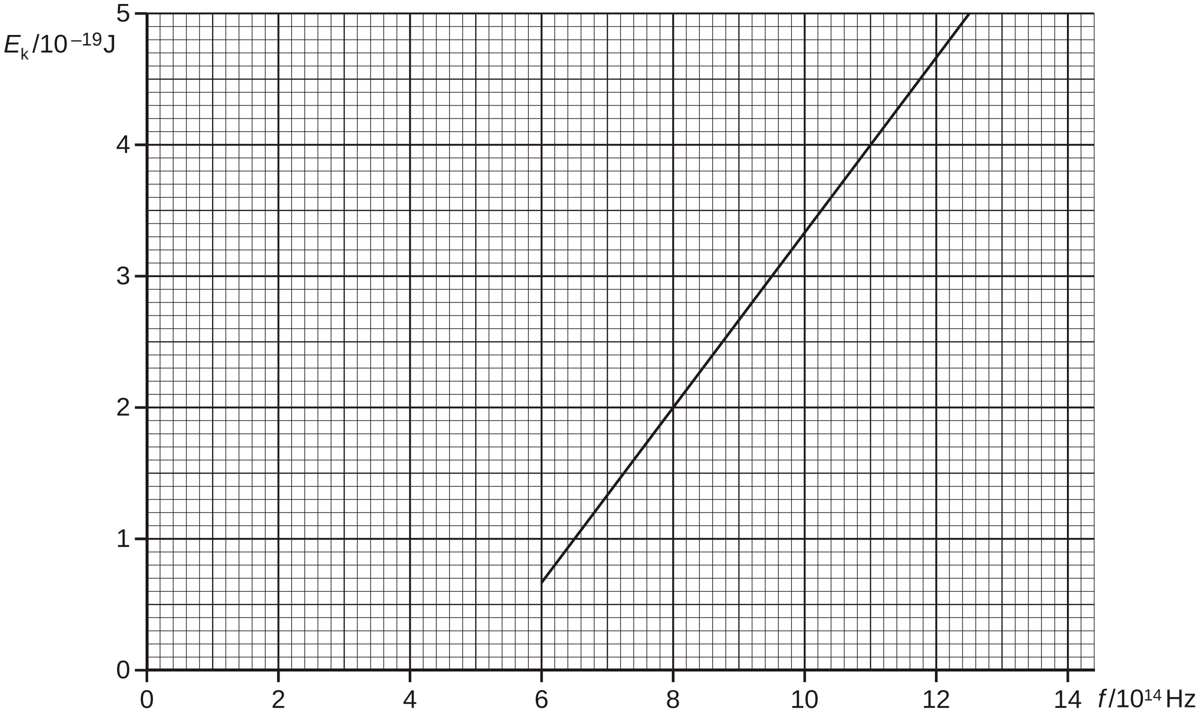
(v) The power of the laser beam is 80 mW. Calculate the number of electrons emitted per second from the caesium plate assuming that only 7.0% of the incident photons interact with the surface electrons.

number = ... s^{-1}

[2]

[Total 11 marks]

2. A negatively charged metal plate is exposed to electromagnetic radiation of frequency f. The figure below shows the variation with f of the maximum kinetic energy E_k of the photoelectrons emitted from the surface of the metal.



(i) Define the *threshold frequency* of a metal.

....

....

[1]

(ii) 1 Explain how the graph shows that the threshold frequency of this metal is 5.0×10^{14} Hz.

....

....

[1]

2 Calculate the work function energy of this metal in joules.

work function energy = ... J

[2]

(iii) Electromagnetic radiation falls on the surface of a metal having work function energy greater than your answer in **(ii).**

1 State and explain the change, if any, to the gradient of the line shown in the figure above.

....

....

....

[2]

2 State and explain the change, if any, to the position of the line shown in the figure.

....

....

....

[2]

[Total 8 marks]

3. In this question, one mark is available for the quality of written communication.

Describe and explain the photoelectric effect in terms of photons interacting with the surface of a metal.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

[6]

Quality of Written Communication [1]

[Total 7 marks]

4. (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.

....

....

....

....

....

....

....

....

[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.

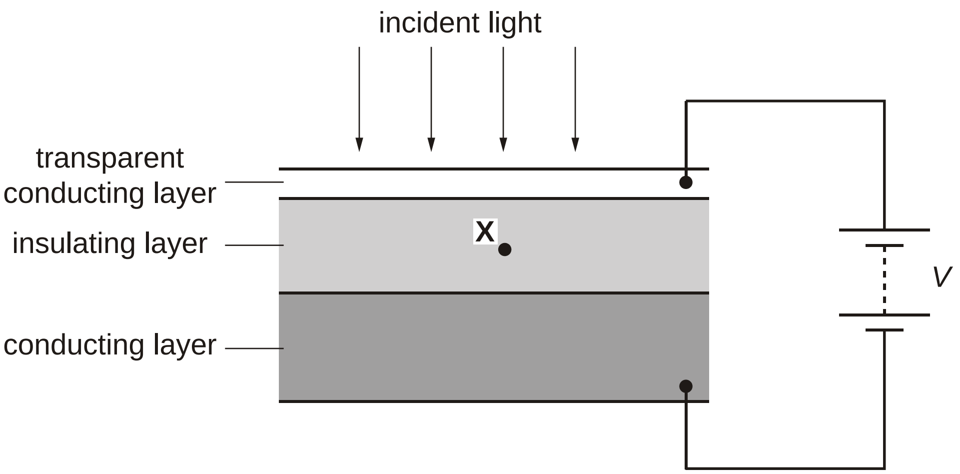
....

....

....

[2]

(b) A photodiode is a circuit component which can be used to convert a light signal into an electrical one. The figure below 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.



(i) Draw an arrow on the figure above to show the direction of motion of an electron released at point **X** in the centre of the insulating layer.

[1]

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

(ii) The red light from the laser 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 the figure above. 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 marks]

5. 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.

....

....

....

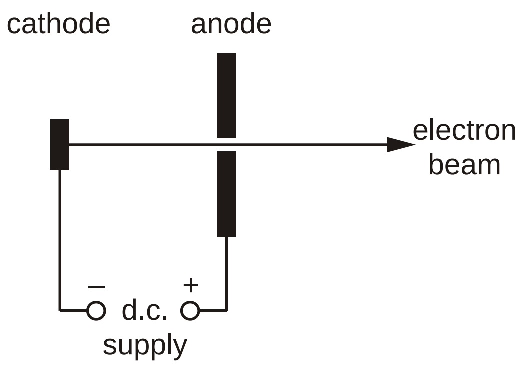
....

[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 6.0×10^{6} m s^{-1} using an electron gun shown diagrammatically in the figure below.



(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.

....

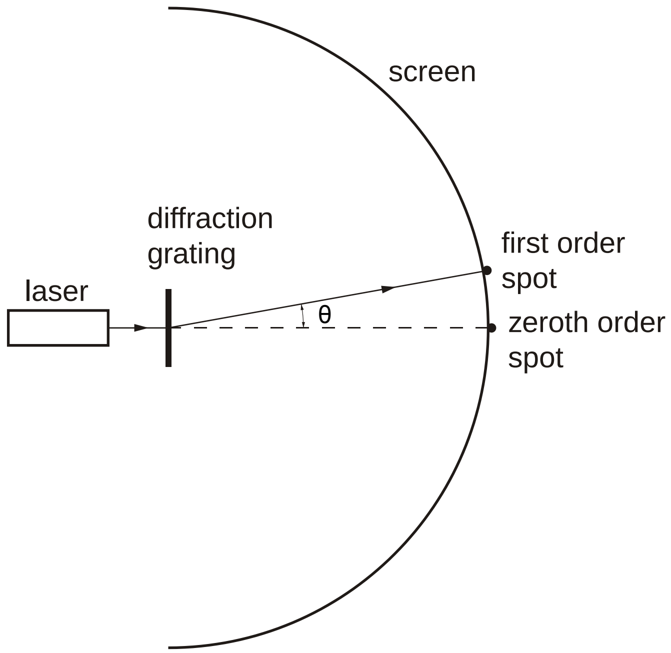
....

....

[1]

[Total 10 marks]

6. (a) A parallel beam of red light of wavelength 6.3×10^{-7} m from a laser is incident normally on a diffraction grating as shown in the figure below.



Bright red spots are observed on the curved screen placed beyond the grating.

(i) The diffraction grating has 300 lines per millimetre. Show that the separation *d* between adjacent lines of the grating is 3.3×10^{-6} m.

[1]

(ii) Calculate the angle θ at which the first order red spot is seen. This is the first spot away from the straight through position.

θ = ... degrees

[3]

(iii) The screen curves around the full 180° in front of the grating. Explain why there are eleven bright red spots on the screen.

....

....

....

....

....

[3]

(b) Calculate

(i) the energy of each photon of light emitted by the laser at a wavelength of 6.3×10^{-7} m

energy = ... J

[2]

(ii) the number of photons emitted each second to produce a power of 0.50 mW.

number = ...

[2]

[Total: 11 marks]

7. Electromagnetic radiation incident on a metal plate releases energetic electrons from its surface. The metal plate is placed in an evacuated chamber. The energy of each photon is 2.8 eV. The metal has a work function energy of 1.1 eV.

(i) Explain what is meant by the *work function energy* of the metal.

....

....

[1]

(ii) State the speed of the photons.

....

[1]

(iii) For an electron emitted from the surface of the metal, calculate

1. its maximum kinetic energy in joules

energy = ... J

[3]

2. its maximum speed.

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

[2]

(iv) State the change, if any, to your answer for the maximum speed of an electron emitted from the surface of the metal when the intensity of the incident electromagnetic radiation is doubled.

....

....

[1]

[Total 8 marks]

8. In this question, two marks are available for the quality of written communication.

The Planck constant *h* is a very important fundamental constant in the study of wave-particle duality.

- With the aid of equations, discuss how this constant is used to describe the behaviour of electromagnetic waves and moving electrons.
- Describe the experimental evidence for the wave behaviour of the electron.

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

[6]

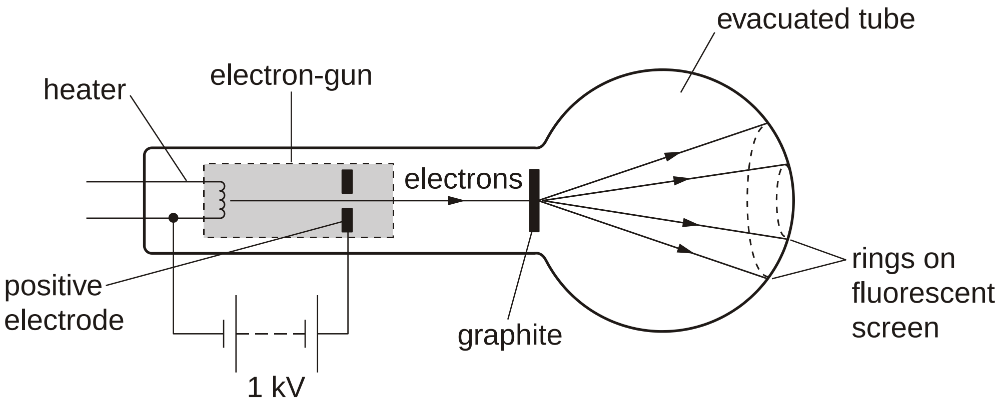
Quality of Written Communication [2]

[Total 8 marks]

9. Show that the wavelength of a photon of energy 3.9 eV is 320 nm.

[Total 2 marks]

10. Wave-particle duality suggests that an electron can exhibit both particle-like and wave-like properties. The figure below shows the key features of an experiment to demonstrate the wave-like behaviour of electrons.



The electrons are accelerated to high speeds by the electron-gun. These high speed electrons pass through a thin layer of graphite (carbon atoms) and emerge to produce rings on the fluorescent screen.

(a) In this question, two marks are available for the quality of written communication.

Use the ideas developed by de Broglie to explain how this experiment demonstrates the wave-like nature of electrons. Suggest what happens to the appearance of the rings when the speed of the electrons is increased.

....

....

....

....

....

....

....

....

....

....

....

....

[5]

Quality of Written Communication [2]

(b) Suggest how, within the electron-gun, this experiment provides evidence for the particle-like property of the electrons.

....

....

[1]

[Total 8 marks]