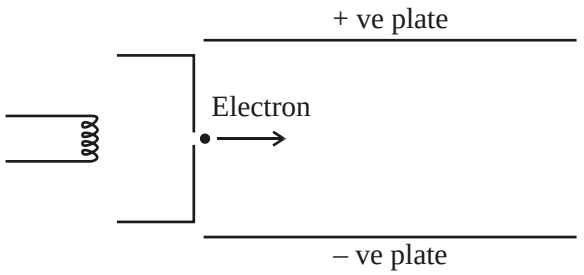
Quantum physics practice questions

1. The diagram below illustrates an experiment with electrons. A beam of electrons is created using an electron gun, and deflected using an electric field.



Explain how the electron gun creates a beam of electrons. Add to the diagram if that will help your explanation.

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(4)

The electrons are accelerated from rest through a potential difference of 340 V. Calculate their speed as they leave the gun.

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Speed = ...

(3)

Explain what is meant by the term **electric field.**

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(1)

The electric field which deflects the beam is created by applying a potential difference of 2500 V across plates 9.0 cm apart. Show that the vertical acceleration of the electrons due to this field is about 5×10^{15} m s^{-2}.

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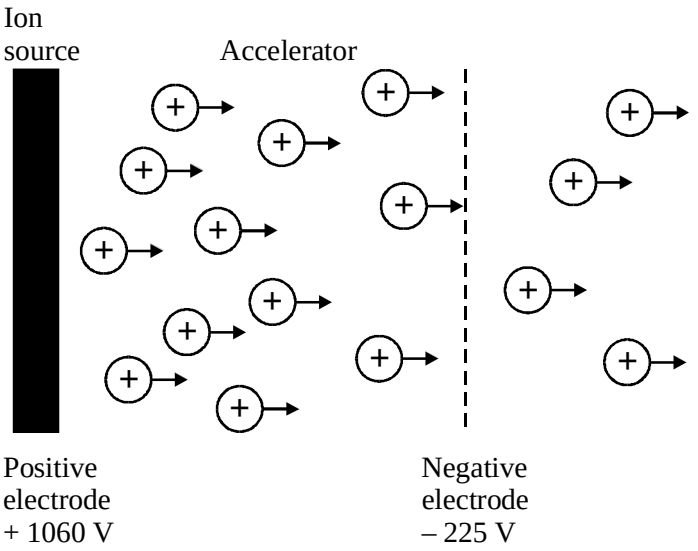
(4)
(Total 12 marks)

2. In 1998 NASA launched the probe called Deep Space 1. Once in orbit, this probe was the first to use a solar powered ion drive to propel it on its mission.

The diagram shows the main features of the ion drive.



Atoms of xenon are ionised and then accelerated until they are ejected out of the rear of the probe, providing the means of propulsion.

Explain how the ions are accelerated.

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(2)

A xenon atom is ionised by the loss of a single electron. Show that its speed after being accelerated is about 4×10^4 m s^{-1}.

Mass of xenon ion = 2.20×10^{-25} kg.

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(4)

The mass of xenon ejected in one second is 2.10×10^{-6} kg. Calculate the thrust on the space probe.

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Thrust = ...

(3)

Simply firing xenon ions into space would leave the probe negatively charged. Suggest a reason why this would lead to reduced thrust.

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(1)

Chemical rockets eject their propellant at about a tenth of the velocity achieved by ion drives, but produce much greater thrust by ejecting more than a thousand kilograms per second.

Suggest why ion drives may be preferable for missions extending over long distances and periods of time.

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(2)

(Total 12 marks)

3. X-rays are used in hospitals to aid diagnosis. The X-ray image is formed because more X-ray photons are absorbed by denser materials such as bones, thus changing the intensity of parts of

the image.

The principal method of absorption of X-rays is the photoelectric effect.

The photoelectric effect is also observed when light falls on a clean metal surface. It is only observed when the frequency of the light is above a threshold frequency. Explain why this is so.

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(2)

X-rays of a frequency of 1.70×10^{18} Hz can be used to form an image of a bone. The energy required to free a tightly bound-electron from a calcium atom in bone is 9.61×10^{-16}J.

Calculate the maximum kinetic energy with which one of these electrons is emitted from the calcium atom.

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Kinetic energy = ..……..……..……..……..……..……..

(3)

(Total 5 marks)

4. Astronomers can identify different gases present in the outer parts of stars by analysing the line spectra of the starlight.

Explain the meaning of *line spectra.*

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(2)

Explain how line spectra provide evidence for the existence of energy levels in atoms.

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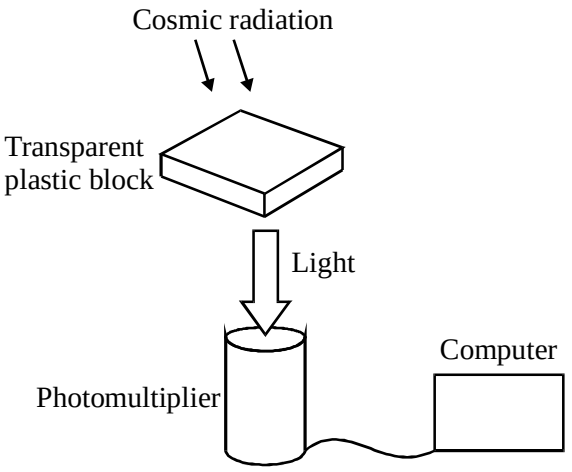
(3)
(Total 5 marks)

5. Scientists from Leeds University are involved in an experiment at the South Pole to look for cosmic radiation from a supernova observed in 1987. Cosmic radiation consists of high energy particles from space.

Their equipment involves the following:



Cosmic radiation causes this plastic block to emit light. If this light enters the photomultiplier, photoelectrons are released and the signal is sent to a computer which records the event.

A photomultiplier which has a photocathode made from antimony–caesium has a threshold

wavelength of 700 nm. Explain why a photocathode has a threshold wavelength.

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(4)

Show that the work function of antimony-caesium is about 3×10^{-19} J.

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(3)

The scientists' generator at the South Pole produces a voltage of 600 V and the photomultiplier needs potential differences of 200 V, 400 V and 600 V. Draw a circuit to show how a series of resistors could provide all of these potential differences from one 600 V supply.

(2)

Suggest why cosmic radiation from the supernova was not detected at the same time as the supernova was observed.

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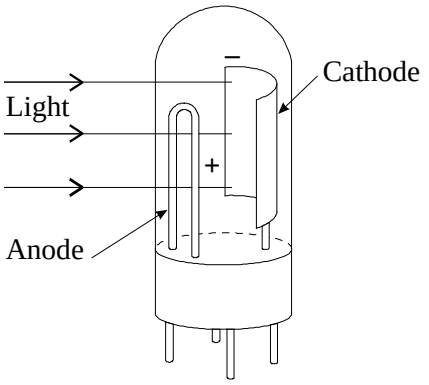
(1)

(Total 10 marks)

6. The intensity of the light falling on the photocell shown in the diagram below controls the electric current flowing in a circuit.



An electron is sometimes released when a photon hits a metal surface. This is known as the photoelectric effect and can be expressed mathematically by the Einstein equation.

$$hf = \phi + \frac{1}{2}mv_{max}^2$$

Show that the energy of a photon of light of frequency 6.0×10^{14} Hz is about 4×10^{-19}J.

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(1)

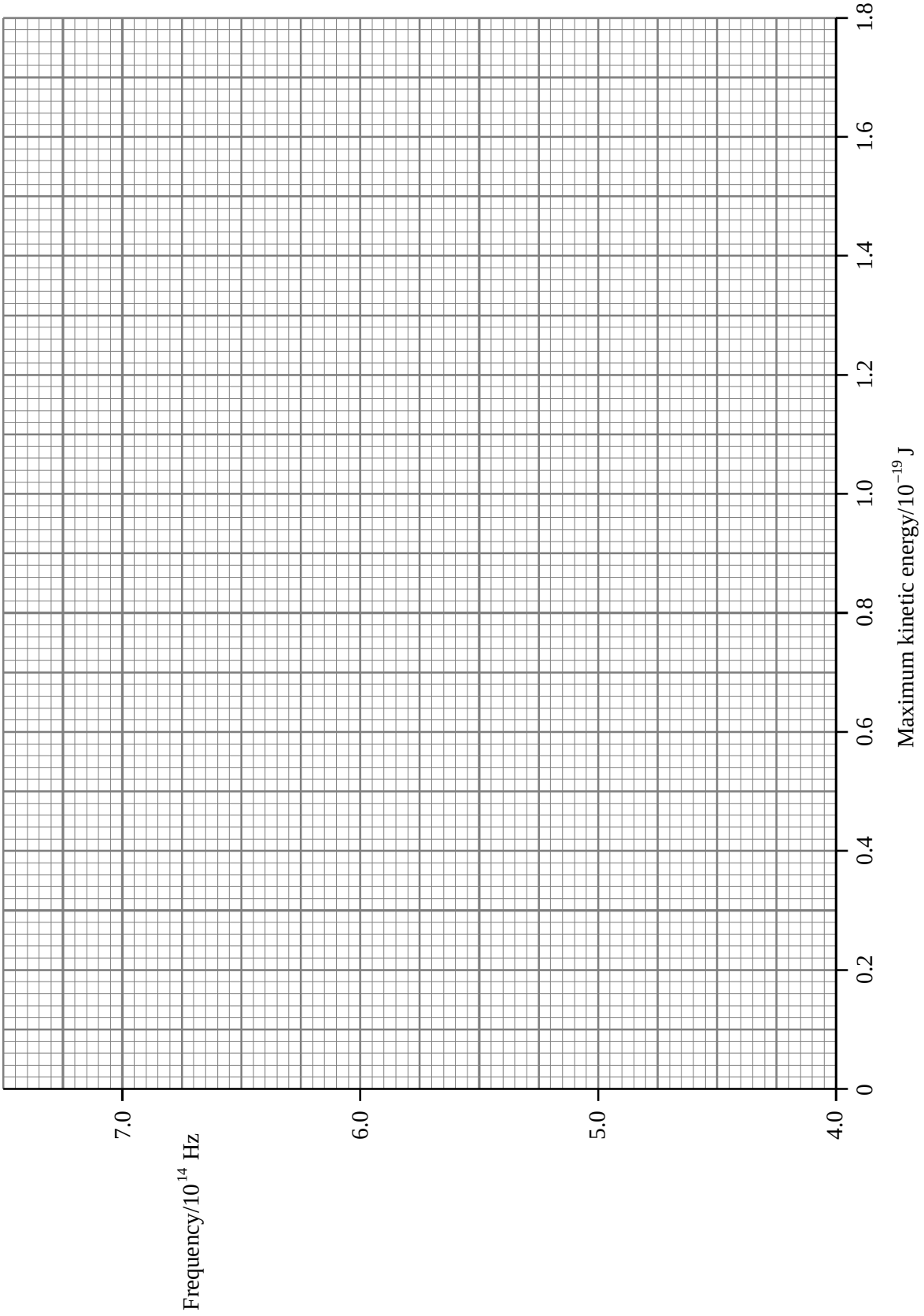
A student is investigating the photoelectric effect and selects light of various frequencies to shine on to a metal surface. Using his experimental data, he calculates the maximum kinetic energy of the electrons emitted from the surface. The results are given below.

Frequency/10^{14} Hz	**Maximum kinetic energy/10^{-19} J**
7.0	1.65
6.5	1.29
6.0	0.96
5.5	0.65
5.0	0.30

Plot the points on the grid below. Add the line of best fit.

The Einstein equation can be rearranged to give

$$f = \frac{\phi}{h} + \frac{\frac{1}{2}mv_{max}^2}{h}$$


Frequency/10^{14} Hz
7.0
6.0
5.0
4.0
Maximum kinetic energy/10^{-19} J
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8

(4)

Use the graph you have plotted to find a value for *h*.

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(3)

Hence show that ϕ is about 3×10^{-19} J.

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(2)

The student continues the experiment and shines light with a frequency of 4.5×10^{14} Hz on to the surface but finds that he cannot detect any photoelectrons. Explain why photoelectrons are not being emitted from the surface.

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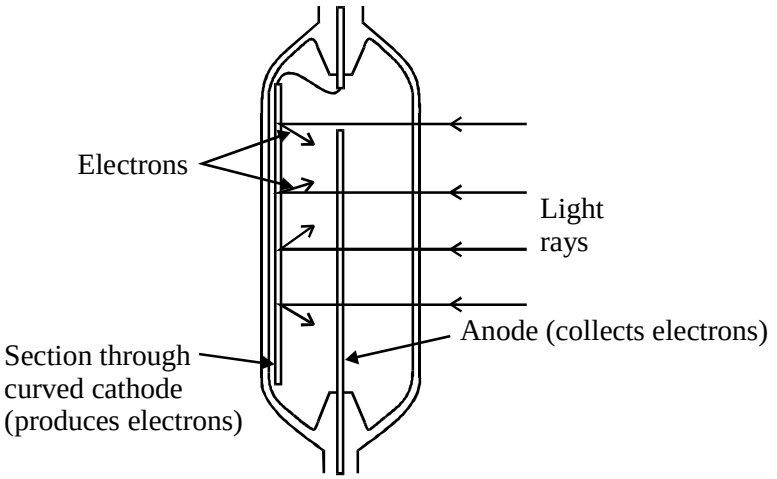
(2)
(Total 12 marks)

7. Many modem cameras have built-in exposure meters. These can detect the intensity of light falling, on to the film and automatically adjust how long the film is exposed to the light. One type of device that can be used is the photocell below.



Photons hitting the cathode cause **photoelectrons** to be released from the surface of the cathode if it is made from a material with a suitable **work function**.

Describe how an electron escapes from the surface of the cathode. Include the terms in **bold** from the passage above.

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(3)

Potassium has a work function of 2.90×10^{-19} J. Calculate the lowest frequency of radiation that will produce photoelectrons from a potassium surface.

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(3)

The exposure meter will produce the best results if it responds to light over most of the visible spectrum. This has a range of wavelengths from 4.0×10^{-7} m to 7.0×10^{-7} m.

Explain with the aid of an appropriate calculation whether potassium is a suitable material for use in an exposure meter.

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(2)

A potassium cathode is exposed to visible light, with a complete range of wavelengths. Show that the maximum kinetic energy of an emitted photoelectron is about 2×10^{-19} J.

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(3)

Give one reason why some photoelectrons will be emitted with less than this kinetic energy.

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(1)
(Total 12 marks)

8. Polymers have been developed which absorb ultraviolet (UV) light and emit visible blue light. They could be used for large posters.

What is a polymer?

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(2)

Calculate the energy of a photon of UV light of wavelength 2.5×10^{-7} m.

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Energy = ...

(3)

Explain with the aid of an energy level diagram the process of absorbing UV and emitting blue light.

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(4)

The polymers can absorb a **range** of wavelengths of UV light. What does this imply about the energy level diagram for these polymers?

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(1)

Why would the poster using the polymer look brighter than an ordinary poster?

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(2)

(Total 12 marks)

9. When a photon of sunlight is incident on a photovoltaic cell, an electron in the cell gains sufficient energy to move through a potential difference of 0.48 V.

What is a photon?

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(2)

Show that the energy required to move an electron through a potential difference of 0.48 V is about 8×10^{-20}J.

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(2)

Photons of sunlight typically have energy 4.0×10^{-19} J. Calculate the efficiency of conversion of the energy of the photon.

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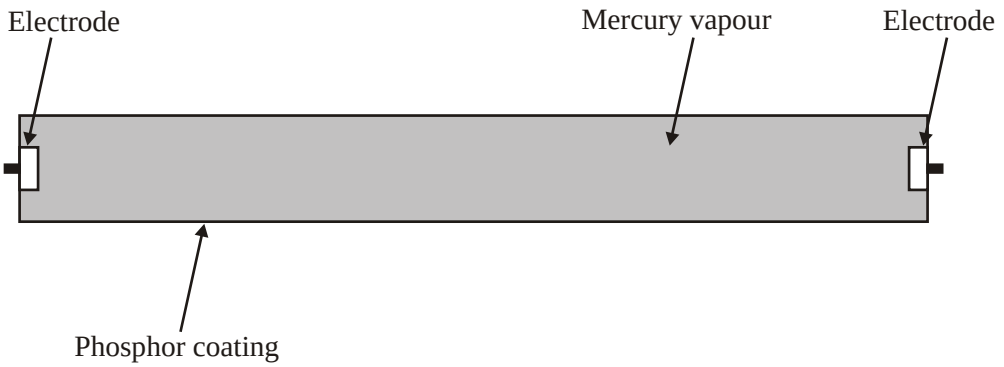
Efficiency = ...

(2)

(Total 6 marks)

10. The diagram shows some of the main components of one type of fluorescent light tube.



When the tube is switched on a charge flows between the electrodes and the mercury atoms become excited. The mercury atoms then emit radiation.

Explain the meaning of the word **excited** as used above.

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(2)

Explain how the excited mercury atoms emit radiation.

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(2)

Explain why only certain wavelengths of radiation are emitted.

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(3)

Some of the radiation emitted by the mercury atoms is in the ultraviolet part of the spectrum.

Humans cannot see ultraviolet radiation, so the tube is coated with phosphor. The atoms of phosphor absorb the ultraviolet radiation and then emit visible light.

Suggest why the phosphor emits different wavelengths from the mercury.

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(1)

A typical fluorescent tube has a current of 0.15 A.

Calculate the amount of charge which flows in 20 minutes.

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Charge = ...

(2)

(Total 10 marks)

11. Most physicists believe that light can behave as both a wave and a particle. Name a property of light which shows it can behave as a wave.

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(1)

In 1916, Millikan published the results of an experiment on the photoelectric effect. This proved that light also behaves as particles.

He shone **monochromatic** light onto plates made of different types of metal.

What is meant by the term **monochromatic**?

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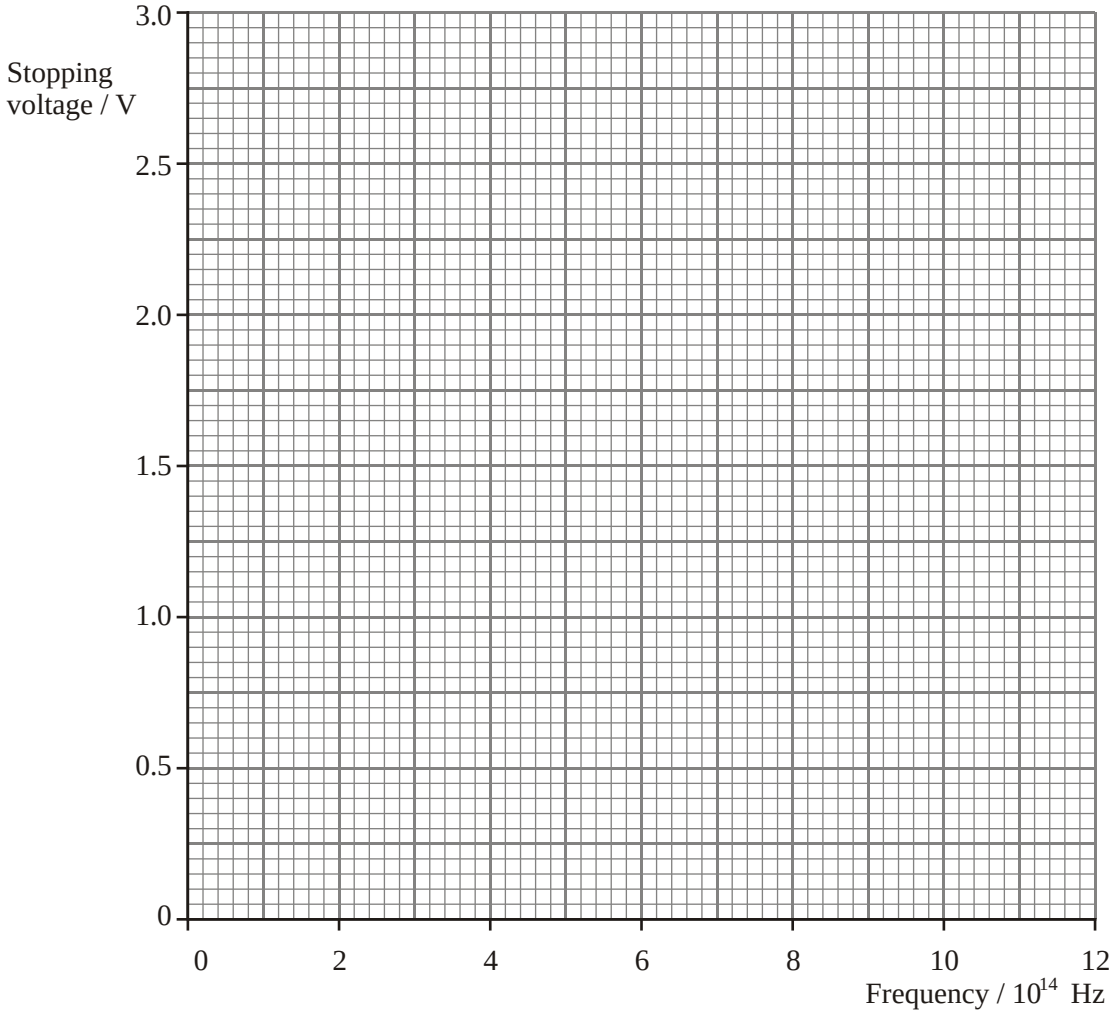
(1)

When the light hit the plates, photoelectrons were produced. Millikan found the potential difference that was just large enough to stop these electrons being released. He also investigated how this stopping voltage varied with the frequency of light used.

The table below shows the results of an experiment like Millikan's using sodium as the metal plate.

Stopping voltage V_s /V	Frequency of light f / 10^{14} Hz
0.43	5.49
1.00	6.91
1.18	7.41
1.56	8.23
2.19	9.61
3.00	11.83

On the grid below, plot a graph of V_s against f.



(3)

The following equation applies to the photoelectric effect:

$$hf = \phi + eV_s$$

where ϕ is the work function of the metal and e is the charge on an electron.

What information about the electrons emitted does the value of the term eV_s give?

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(2)

Use your graph to determine the threshold frequency for sodium.

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(1)

Hence calculate the work function of sodium.

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Work function = ...

(2)

No electrons are emitted below a threshold frequency. Explain why this is so.

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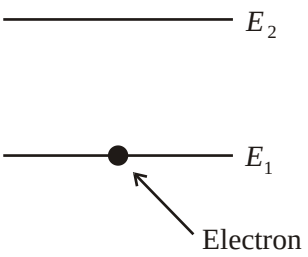
(2)

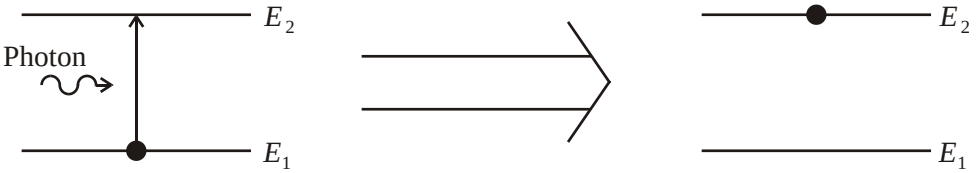
(Total 12 marks)

12. The diagrams below are taken from a description of how a laser works. Each diagram illustrates some aspect of a "two energy level system". The system consists of an electron in an isolated atom.

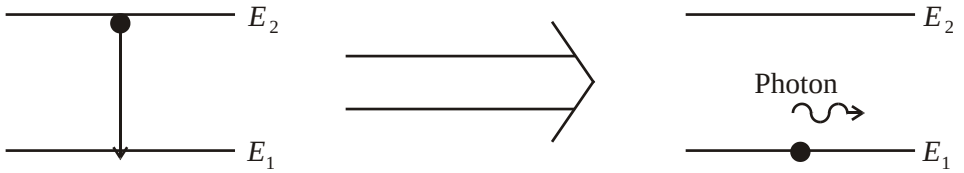
A two energy level system



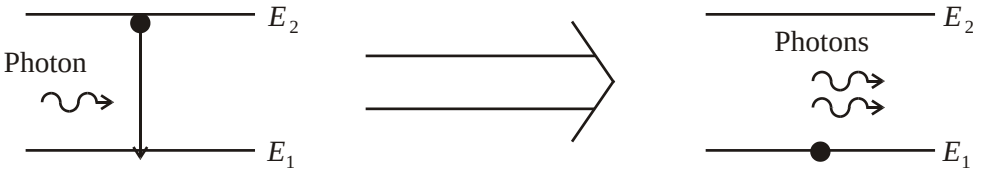
Absorption



Spontaneous emission



Stimulated emission (laser)



What is meant by energy level?

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(1)

What is a photon?

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(1)

Write down a formula in terms of E_1 and E_2 for the energy of the photon in the absorption diagram.

Energy = ...

(1)

The laser light emitted by the stimulated emission process must have the same wavelength as the photon in the spontaneous emission diagram. Explain this.

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(1)

The laser light is said to be coherent. Explain the meaning of coherent.

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(1)

(Total 5 marks)