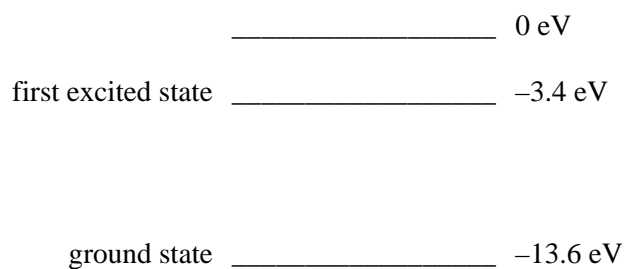


1. Below is a simplified energy level diagram for atomic hydrogen.



(a) A free electron with 12 eV of kinetic energy collides with an atom of hydrogen. As a result the atom is raised to its first excited state. Calculate the kinetic energy of the free electron, in eV, after the collision.

Kinetic energy = eV (2)

(b) Calculate the wavelength of the photon emitted when the atom returns to its ground state.

Wavelength = (3)
(Total 5 marks)

2. Until the early 20th century, the wave theory of light was successful at explaining different properties of light such as reflection, refraction and diffraction. With the discovery of the photoelectric effect, scientists had a problem. The wave theory of light assumes that the energy of the wave is spread over the whole wavefront. Using the wave theory, scientists calculated that, if light of very low intensity is shone onto the metal, it should take a very long time for an electron to gain sufficient energy to break free from a metal. It was discovered that, providing the light was above a certain frequency, electrons could escape from a metal surface instantly. The new model that was introduced treated light as being made of particles called photons.

(a) What is meant by diffraction?

.....
.....
.....

(2)

(b) How did considering light as photons enable scientists to explain why electrons could be emitted instantly from a metal surface?

.....
.....
.....
.....

(2)

(c) Explain why this effect only happens when the light is above a certain frequency.

.....
.....
.....
.....

(2)

(Total 6 marks)

3. (a) Magnesium has a work function of 5.89×10^{-19} J. Explain the meaning of this statement.

.....
.....
.....

(2)

(b) Ultraviolet radiation from an extremely faint source is incident normally on a magnesium plate. The intensity of the radiation is 0.035 W m^{-2} . A single magnesium atom occupies an area of about $8 \times 10^{-20} \text{ m}^2$ on the surface of the plate.

(i) Show that, if the radiation is regarded as a wave motion, it should take at least 200 s for a magnesium atom to absorb 5.89×10^{-19} J of energy.

.....
.....
.....
.....

(3)

(ii) In practice, it is found that photoemission from the plate begins as soon as the radiation source is switched on. Explain how the photon model of electromagnetic radiation accounts for this. You may be awarded a mark for the clarity of your answer.

.....
.....
.....
.....
.....
.....
.....
.....
.....
.....

(4)

(Total 9 marks)

4. Modern technology makes wide use of light-emitting devices. For many years, however, their use was limited by the lack of materials that could emit blue light efficiently.

(a) State one property of blue light which is different from red light.

.....

(1)

(b) Physicists found that by adding indium to the semiconductor gallium nitride they could vary the band gap energy of the material from 2.0 to 3.4 eV and so produce a range of light from red to blue.

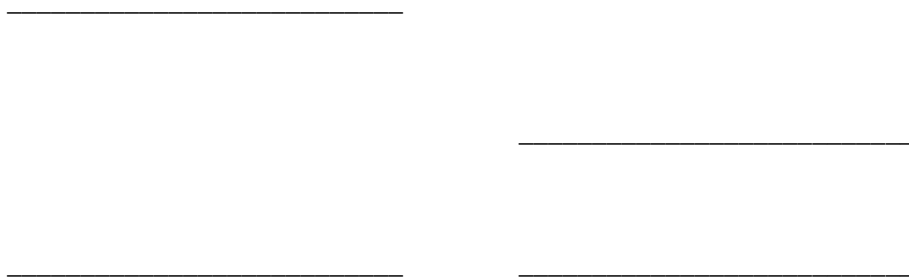
(i) Calculate the frequency range which corresponds to the above band gap energies.

.....
.....
.....
.....
.....

Frequency range =

(3)

(ii) The following diagrams show the ground state and one excited state for the semiconductor when it is being used to emit red and blue light. Decide which diagram is showing the band gap of the blue light emitter and add an arrow to show the electron transition that occurs during the emission of a blue light photon.



(2)

(c) The physicists also found that after this semiconductor material had been heated strongly in nitrogen its resistivity had dropped from $106 \Omega \text{ cm}$ to just $2 \Omega \text{ cm}$.

(i) State one advantage of this drop in resistivity when the semiconductor is in use.

.....

(1)

(ii) The length of a rectangular sample of the semiconductor is 0.5 cm . Its width is 0.3 cm and its thickness is 0.4 mm . Calculate the resistance across its length when the resistivity is $2 \Omega \text{ cm}$.

.....
.....
.....
.....
.....
.....

Resistance =

(3)

(Total 10 marks)

5. (a) The maximum wavelength of electromagnetic radiation which can release photoelectrons from the surface of caesium is $6.5 \times 10^{-7} \text{ m}$.

(i) State the part of the electromagnetic spectrum to which this radiation belongs.

.....

(1)

(ii) Show that caesium has a work function ϕ of about 3×10^{-19} J.

.....

.....

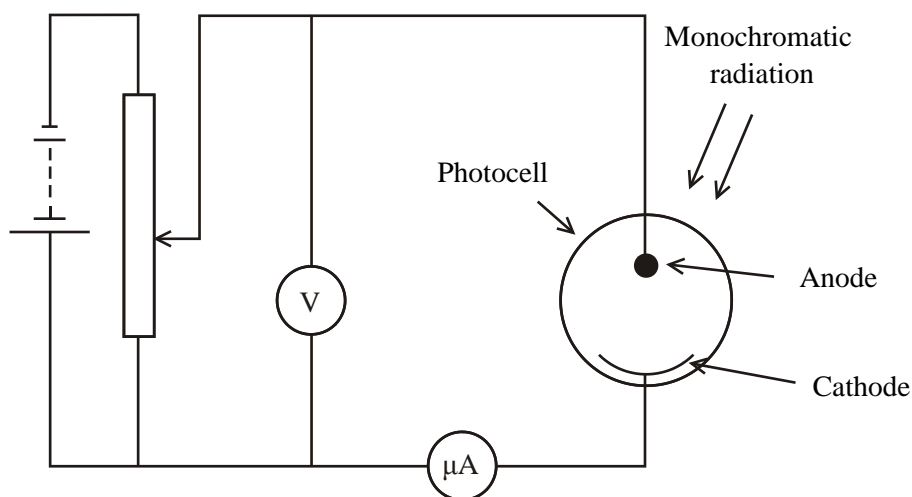
.....

.....

.....

(2)

(b) The caesium cathode of a photocell is illuminated by radiation of frequency f . The circuit shown is used to measure the stopping potential V_s for a range of frequencies.



(i) Explain what is meant by the term **stopping potential**.

.....

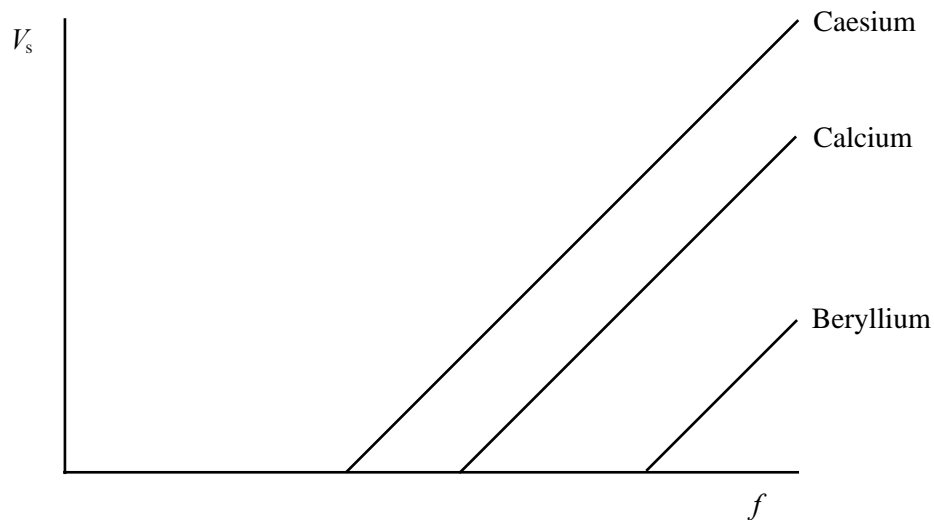
.....

.....

.....

(2)

- (ii) The experiment is repeated, using different photocells, to measure the stopping potentials of calcium and beryllium. The graph shows how the stopping potentials V_s for all three metals vary with frequency f .



Use the relationship

$$hf = eV_s + \phi$$

to explain why all three graphs are parallel.

.....

.....

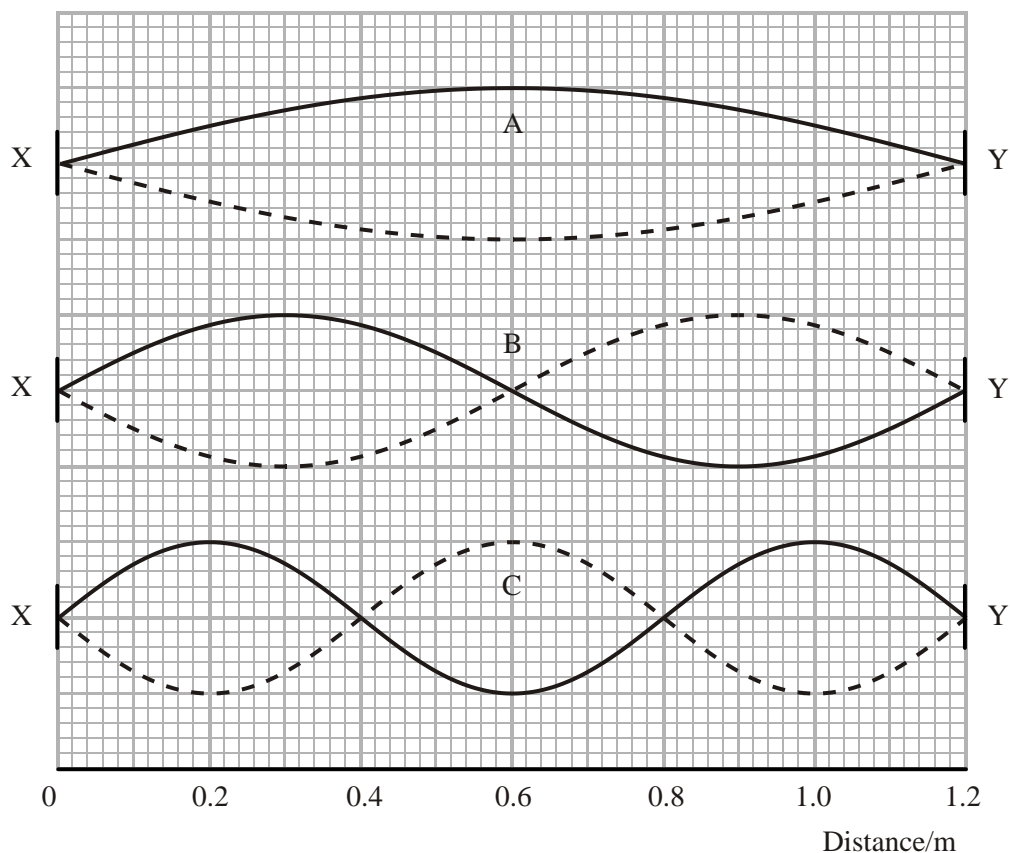
.....

.....

.....

(2)
(Total 7 marks)

6. (a) The diagram shows three possible stationary waves on a string of length 1.20 m stretched between fixed points X and Y.



- (i) Wave A has a frequency of 110 Hz.

Complete the table below to show the wavelengths and frequencies of the three waves.

Wave	Wavelength / m	Frequency / Hz
A		110
B		
C		

(3)

- (ii) Each of the waves has nodes at X and Y. Explain why these points must be nodes.

.....

(1)

- (b) There is a similarity between the behaviour of the string in part (a) and that of the electron in a hydrogen atom. Electron states can be represented by stationary waves which have to fit inside the atom.

Stationary waves with greater numbers of nodes represent electrons in higher energy levels. Explain why this is the case.

.....

.....

.....

.....

.....

(2)
(Total 6 marks)

7. The table gives information about two beams of monochromatic light.

	Intensity / Wm^{-2}	Colour
Beam A	6.0	red
Beam B	0.2	blue

Each beam is shone in turn onto a barium plate. Beam B causes photoemission but beam A does not. A student says that this is because “the blue beam is more energetic than the red beam”.

- (a) In one sense the student’s statement is correct. In another sense the statement is incorrect. Explain how it is:

correct

.....

.....

.....

incorrect

.....

.....

.....

(3)

(b) Barium has a work function of 3.98×10^{-19} J.

(i) Explain the meaning of the term **work function**.

.....
.....
.....

(2)

(ii) Calculate the photoelectric threshold frequency for the barium plate.

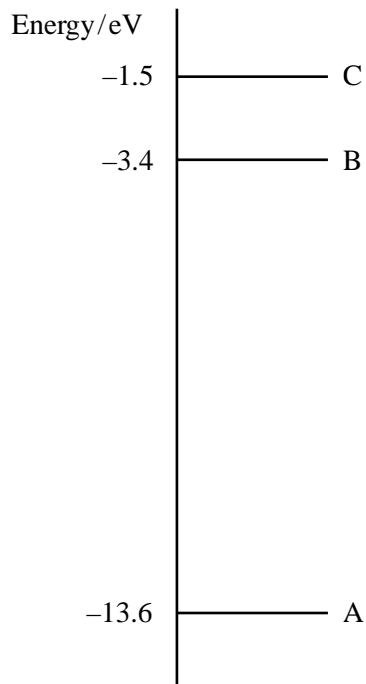
.....
.....
.....

Threshold frequency =

(2)

(Total 7 marks)

8. The diagram shows the lowest three energy levels of atomic hydrogen.



- (a) Excited hydrogen atoms can emit light of wavelength 656 nm. By means of a suitable calculation, determine which transition between energy levels is responsible for this emission.

.....
.....
.....
.....
.....

Transition: from level to level

(4)

- (b) The spectrum of light from the Sun contains a dark line at a wavelength of 656 nm. With reference to the energy level diagram, explain how this line is produced. You may be awarded a mark for the clarity of your answer.

.....
.....
.....
.....
.....
.....
.....
.....
.....

(4)

- (c) In the spectrum of light received from another galaxy, the same line appears at a wavelength of 695 nm.

How can we deduce from this that the galaxy is receding from the Earth?

.....
.....

(1)

(Total 9 marks)

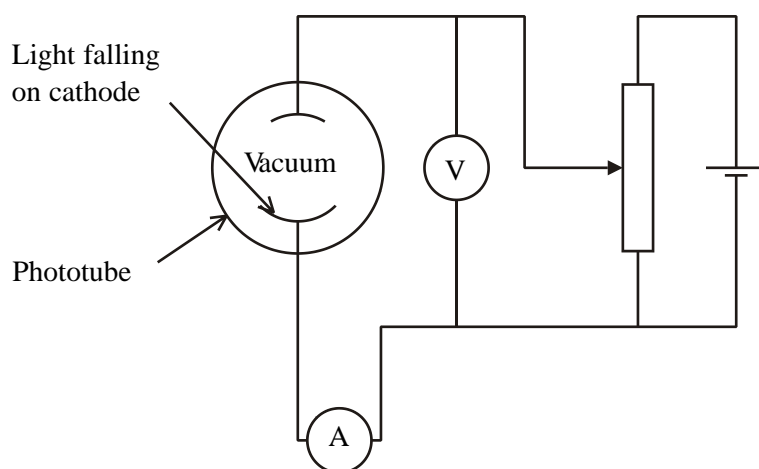
9. Heinrich Hertz first observed the photoelectric effect in 1887. He detected a current when light fell on a metal surface. In later research scientists measured the work function ϕ of several metals.

(a) What is meant by work function?

.....

(1)

(b) To measure the work function, the scientists used a phototube, consisting of a metal cathode and anode in an evacuated tube. Light falling on the cathode produced a current in the circuit.



Explain the production of this current. Use the terms photon and photoelectron in your explanation.

.....

(3)

(c) State the effect on the released photoelectrons of an increase in

(i) the intensity of the light used,

.....

(ii) the frequency of the light used.

.....

(2)

(d) Light of wavelength 4.2×10^{-7} m is shone onto the metal cathode. Calculate the photon energy.

.....

.....

Photon energy =

(2)

(e) The metal is sodium, with a work function of 2.7 eV. Calculate the maximum kinetic energy in eV that a photoelectron could gain from this photon.

.....

.....

.....

Maximum kinetic energy = eV

(2)

(f) When the potential difference between the cathode and anode was reversed the current was reduced.

(i) Why does reversing the potential difference reduce this current?

.....

.....

.....

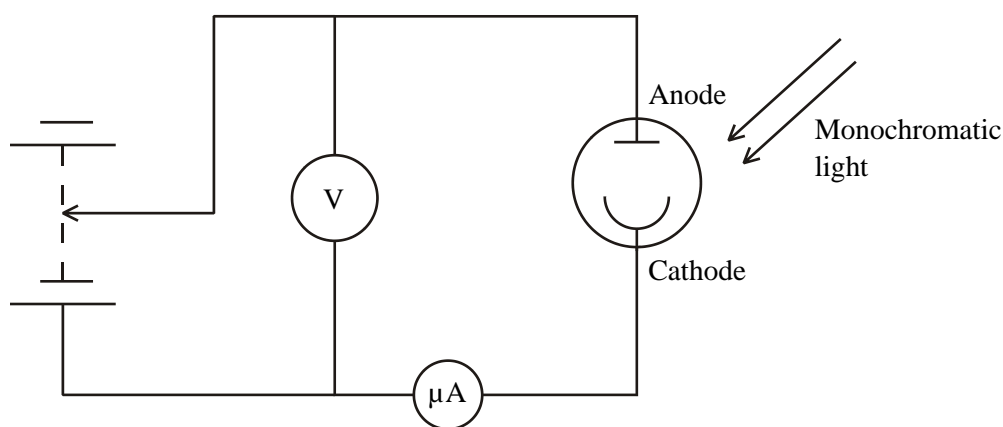
(1)

- (ii) State the stopping potential that would result in zero current being detected for the sodium metal.

.....

(1)
 (Total 12 marks)

10. The diagram shows monochromatic light falling on a photocell.



The photocell is connected so that there is a reverse potential difference across the cathode and the anode.

- (a) Explain the following observations.
- (i) Initially there is a current which is measured by the microammeter. As the reverse potential difference is increased the current reading on the microammeter decreases.

.....

- (ii) When the potential difference reaches a certain value V_s , the stopping potential, the current is zero.

.....
.....
.....
.....
.....
.....

(5)

- (b) What would be the effect on the value of the stopping potential V_s of

- (i) increasing the intensity of the incident radiation whilst keeping its frequency constant

.....
.....

- (ii) increasing the frequency of the incident radiation whilst keeping its intensity constant?

.....
.....

(2)

(Total 7 marks)

11. Sodium street lamps are usually red when first switched on in the evening. After several minutes they take on their normal yellow colour.

In these lamps, light is emitted as a current passes through the sodium vapour. However, when the lamp is first switched on the sodium is solid, so little vapour is present until it warms up. The red colour in the first few minutes is due to neon gas which the lamp also contains.

- (a) Explain how atoms in a vapour emit light.

.....
.....
.....
.....
.....

(2)

- (b) The light appears yellow because the spectrum of the sodium is dominated by two lines with wavelengths of 589.0×10^{-9} m and 589.6×10^{-9} m respectively.

- (i) Explain what is meant by a spectral line.

.....
.....
.....
.....

(1)

- (ii) Calculate the frequency of the light with a wavelength of 589.0×10^{-9} m.

.....
.....

Frequency =

(2)

(c) The light emitted by neon vapour appears red. Explain why atoms of different elements produce light of different colours.

.....
.....
.....
.....
.....
.....

(3)

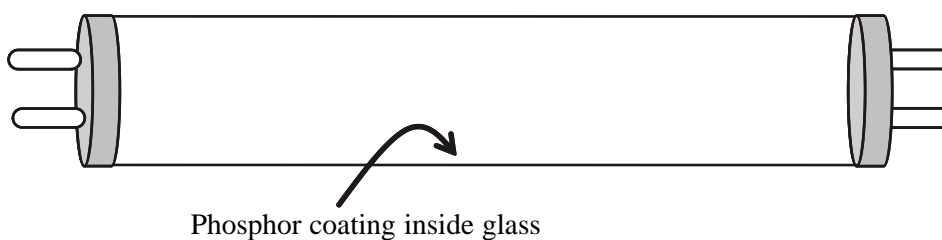
(d) Light is a transverse wave. Explain the meaning of transverse.

.....
.....

(1)

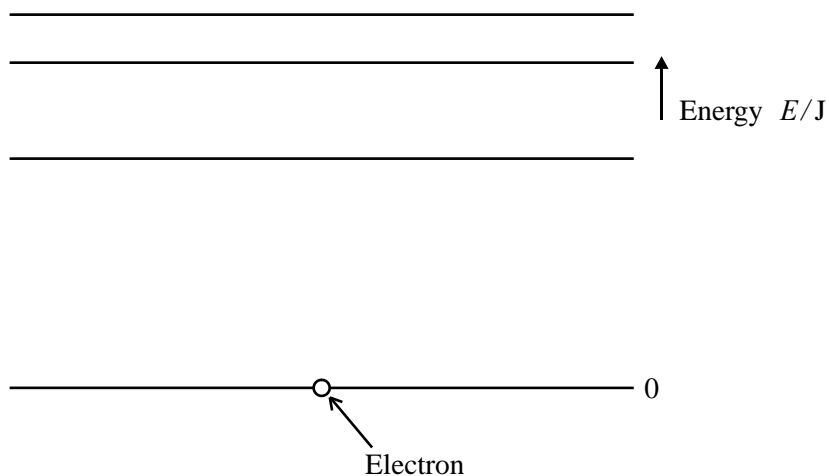
(Total 9 marks)

12. A fluorescent lamp consists of a glass tube containing a small amount of mercury vapour. When the lamp is switched on the mercury atoms emit photons of ultraviolet (UV) radiation. A phosphor coating inside the tube converts this radiation into visible light.



When a UV photon hits the coating it excites an electron into a higher energy level. As the electron falls back down, it emits a photon of visible light.

- (a) (i) Add labelled arrows to the following electron energy level diagram for an atom of the phosphor coating, to illustrate this process. Start with the absorption of a UV photon and end with the emission of a photon of visible light.



(2)

- (ii) The visible light photon emitted has less energy than the UV photon. What has happened to the rest of the energy?

.....

.....

.....

(1)

- (iii) UV radiation with wavelengths in the range 320 nm–400 nm is emitted by the mercury atoms. Show that the emitted photons have a minimum energy of about 3eV.

$$1\text{nm}=1 \times 10^{-9} \text{ m}$$

.....

.....

.....

.....

.....

.....

.....

.....

.....

(4)

- (b) ‘Black lights’ are basically the same tubes without the phosphor coating. These have many applications; for example, they can be used to detect forgeries of old paintings, as older paints did not contain phosphors.

What difference would you see between a real painting and a forgery when viewed with a black light?

.....

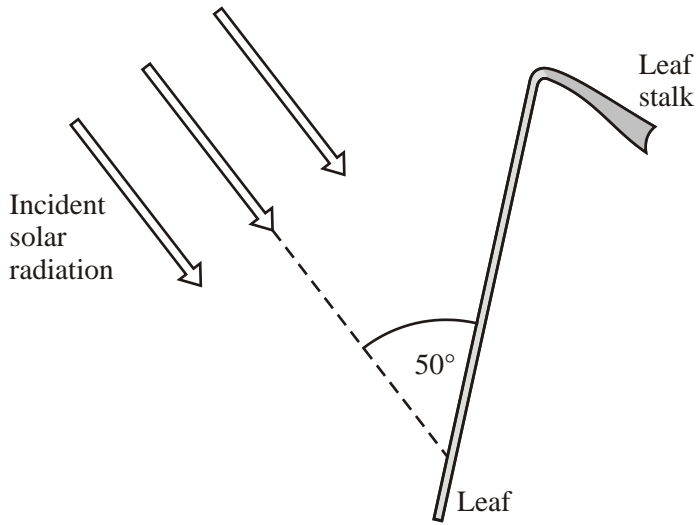
.....

.....

(1)

(Total 8 marks)

13. A leaf of a plant tilts towards the Sun to receive solar radiation of intensity 1.1 kW m^{-2} , which is incident at 50° to the surface of the leaf.



- (a) The leaf is almost circular with an average radius of 29 mm. Show that the power of the radiation perpendicular to the leaf is approximately 2 W.

.....

(3)

- (b) Calculate an approximate value for the amount of solar energy received by the leaf during 2.5 hours of sunlight.

.....

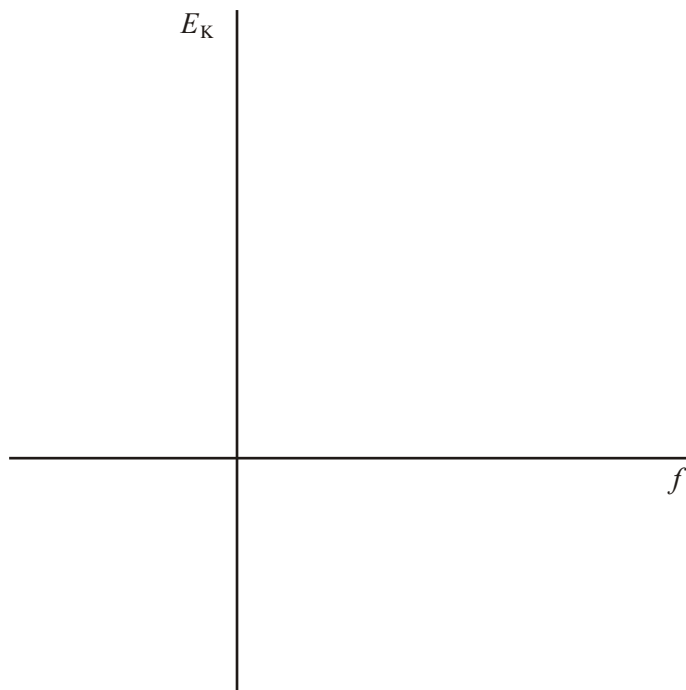
Energy =

(2)

(Total 5 marks)

14. Photoelectrons are emitted from the surface of a metal when radiation above a certain frequency, f_0 , is incident upon it. The maximum kinetic energy of the emitted electrons is E_K .

(a) On the axes below sketch a graph to show how E_K varies with frequency f .



(2)

(b) State how the work function, ϕ , of the metal can be obtained from the graph.

.....
.....

(1)

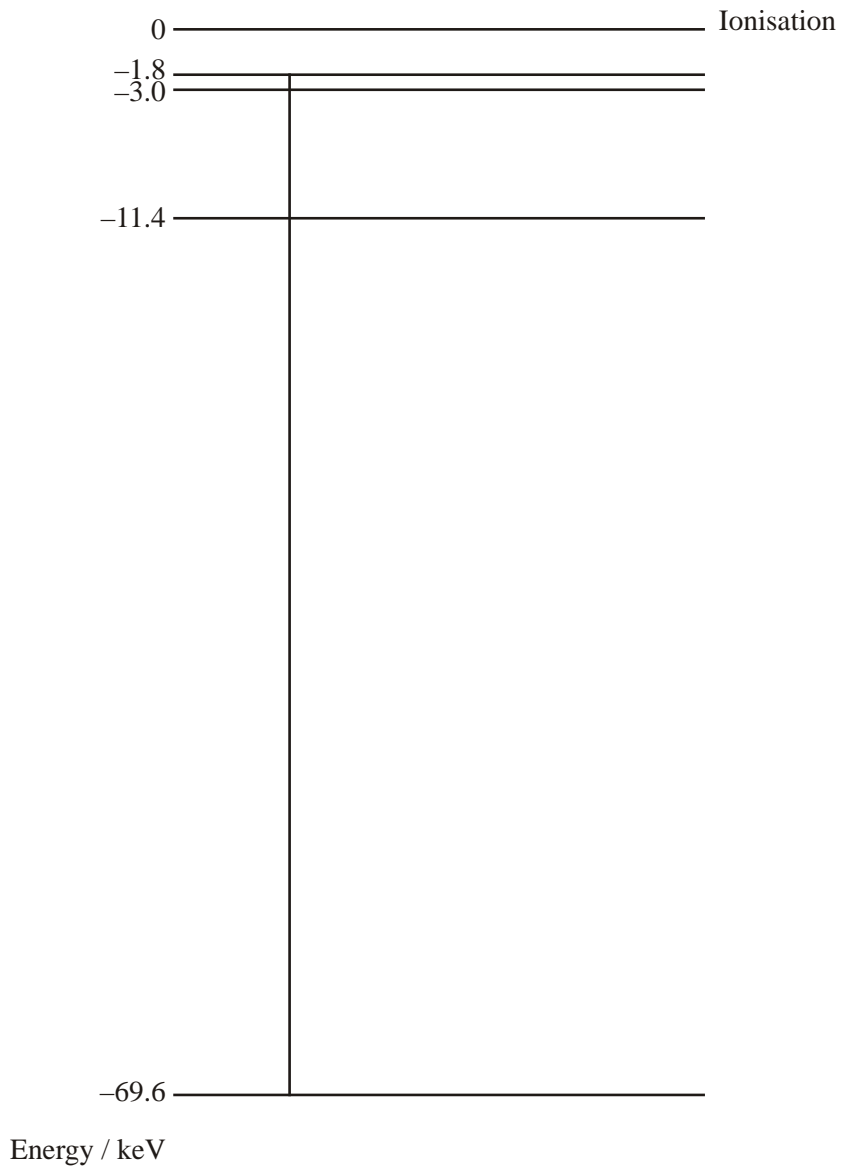
(c) Explain why this graph always has the same gradient irrespective of the metal used.

.....
.....

(1)

(Total 4 marks)

15. The diagram shows some of the energy levels of a tungsten atom.



- (a) An excited electron falls from the -1.8 keV level to the -69.6 keV level. Show that the wavelength of the emitted radiation is approximately 0.02 nm .

.....

.....

.....

.....

.....

.....

.....

.....

.....

(4)

- (b) To which part of the electromagnetic spectrum does this radiation belong?

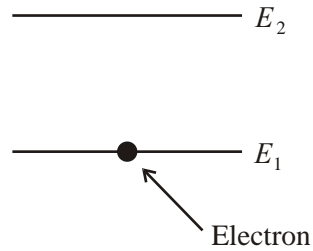
.....

(1)

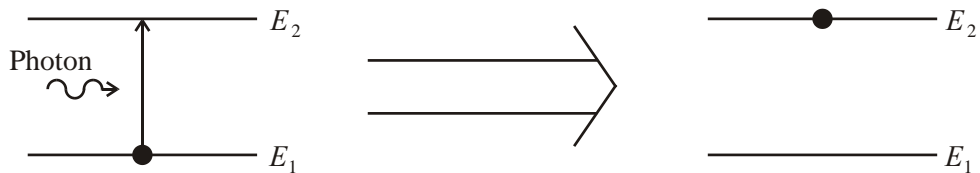
(Total 5 marks)

16. 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.

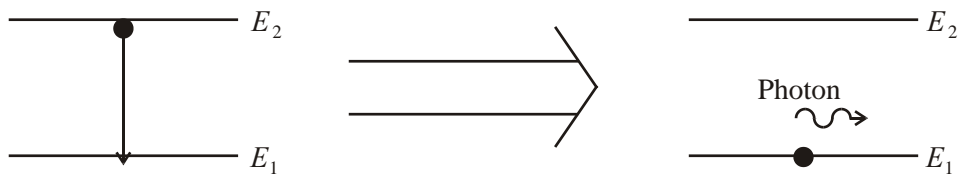
A two energy level system



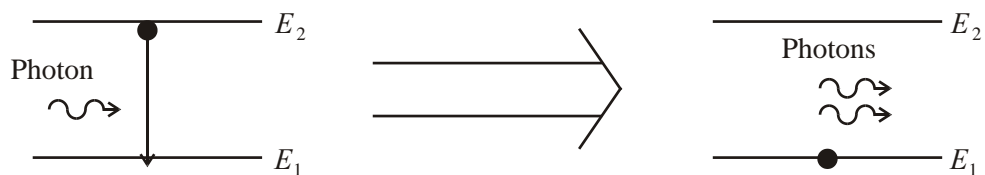
Absorption



Spontaneous emission



Stimulated emission (laser)



What is meant by energy level?

.....

.....

(1)

What is a photon?

.....
.....

(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.

.....
.....
.....

(1)

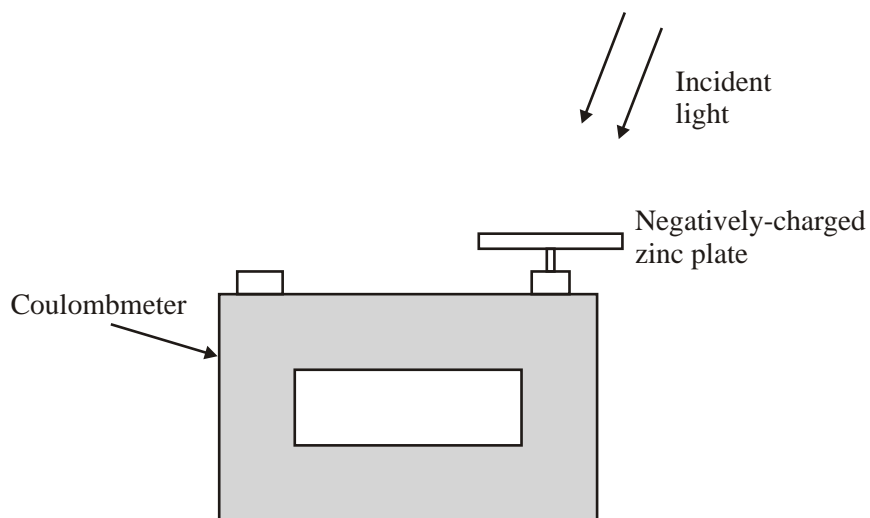
The laser light is said to be coherent. Explain the meaning of coherent.

.....
.....
.....

(1)

(Total 5 marks)

17. The diagram shows a coulombmeter (an instrument for measuring charge) set up to demonstrate the photoelectric effect.



The clean zinc plate is negatively charged. When ultraviolet light is shone onto the zinc plate, the plate discharges. The coulombmeter reading gradually falls to zero. When the experiment is repeated with red light the plate does not discharge.

- (a) Explain these effects in terms of the particle theory of light. You may be awarded a mark for the clarity of your answer.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(4)

(b) What would happen to the charged plate if

(i) the intensity of the red light were increased

.....
.....
.....

(ii) the intensity of the ultraviolet light were increased?

.....
.....
.....

(2)

(c) Zinc has a work function of 3.6 eV. Calculate the maximum kinetic energy of the photoelectrons when the zinc is illuminated with ultraviolet light of wavelength 250 nm.

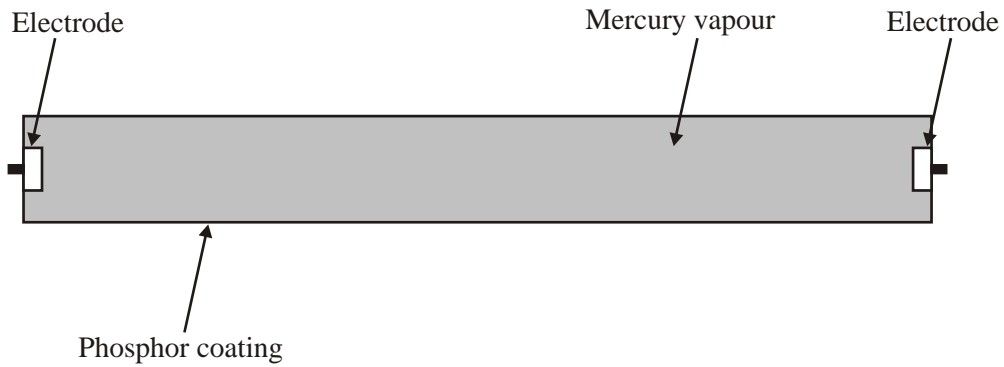
.....
.....
.....
.....
.....
.....

Maximum kinetic energy =

(4)

(Total 10 marks)

18. 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.

.....
.....
.....

(2)

Explain how the excited mercury atoms emit radiation.

.....
.....
.....
.....
.....

(2)

Explain why only certain wavelengths of radiation are emitted.

.....
.....
.....
.....
.....

(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.

.....
.....

(1)

A typical fluorescent tube has a current of 0.15 A.

Calculate the amount of charge which flows in 20 minutes.

.....
.....
.....

Charge =

(2)

(Total 10 marks)

19. 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.

.....

(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**?

.....

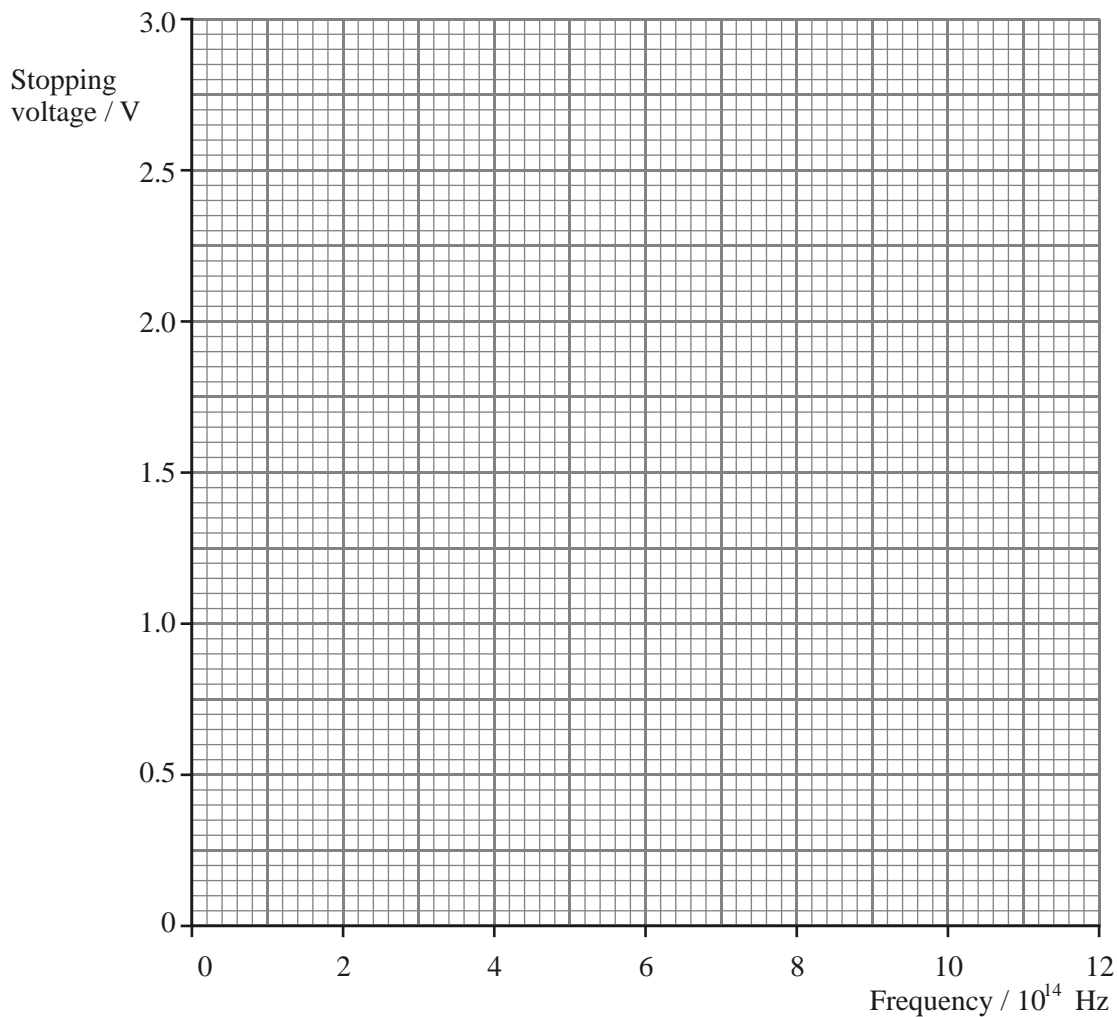
(1)

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?

.....
.....

(2)

Use your graph to determine the threshold frequency for sodium.

..... (1)

Hence calculate the work function of sodium.

.....
.....
Work function = (2)

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

.....
.....
..... (2)
(Total 12 marks)

20. The photoelectric effect supports a particle theory of light but not a wave theory of light.

Below are two features of the photoelectric effect. For each feature explain why it supports the particle theory and not the wave theory.

(a) Feature 1: The emission of photoelectrons from a metal surface can take place instantaneously.

Explanation
.....
.....
.....
.....
..... (2)

- (b) Feature 2: Incident light with a frequency below a certain threshold frequency cannot release electrons from a metal surface.

Explanation

.....

.....

.....

.....

.....

(2)
(Total 4 marks)

21. 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?

.....

.....

(2)

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

.....

.....

(2)

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

.....

Efficiency =

(2)

(Total 6 marks)

22. Four of the energy levels of a lithium atom are shown below.

Energy / eV

-1.85 _____

-3.84 _____

-4.53 _____

-5.02 _____

Draw on the diagram all the possible transitions which the atom could make when going from the -3.84 eV level to the -5.02 eV level.

(2)

Photons of energy 3.17 eV are shone onto atoms in lithium vapour. Mark on the diagram, and label with a T, the transition which could occur.

(1)

One way to study the energy levels of an atom is to scatter electrons from it and measure their kinetic energies before and after the collision. If an electron of kinetic energy 0.92 eV is scattered from a lithium atom which is initially in the -5.02 eV level, the scattered electron can have only two possible kinetic energies.

State these two kinetic energy values, and explain what has happened to the lithium atom in each case. (You should assume that the lithium atom was at rest both before and after the collision.)

Kinetic energy 1

Explanation

.....

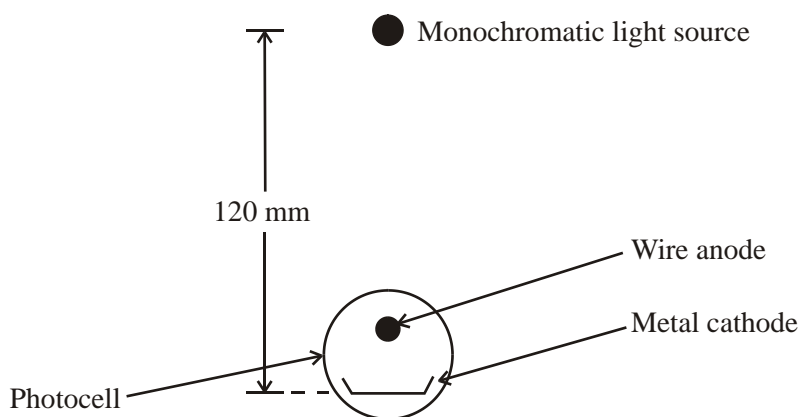
Kinetic energy 2

Explanation

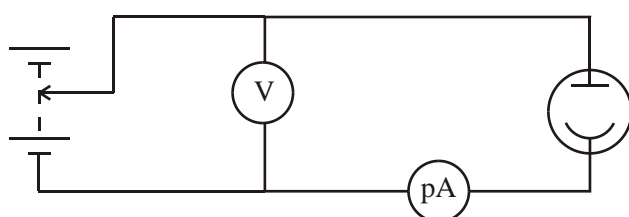
.....

(4)
(Total 7 marks)

23. A monochromatic light source is placed 120 mm above the cathode of a photocell.



A potential difference is applied between the cathode and the anode of the photocell and the sensitive ammeter detects the current.



The table below shows the currents which are obtained with this apparatus for two different intensities and two different wavelengths of light, using two different cathode materials. Work function energies are given.

Wavelength of incident radiation /nm	Cathode material	Work function /eV	Photocurrent /A when intensity of incident radiation is	
			1 W m ⁻²	5 W m ⁻²
320	Aluminium	4.1	0	0
640	Aluminium	4.1	0	0
320	Lithium	2.3	0.2×10^{-12}	1.0×10^{-12}
640	Lithium	2.3	0	0

Show that the incident photons of $\lambda = 320$ nm and $\lambda = 640$ nm have energies of approximately 4 eV and 2 eV respectively.

.....

.....

.....

.....

.....

.....

(4)

Account for the photocurrent readings shown in the table.

.....
.....
.....
.....
.....
.....
.....
.....

(3)

Calculate the stopping potential for the photoelectrons released by lithium when irradiated by light of wavelength 320 nm.

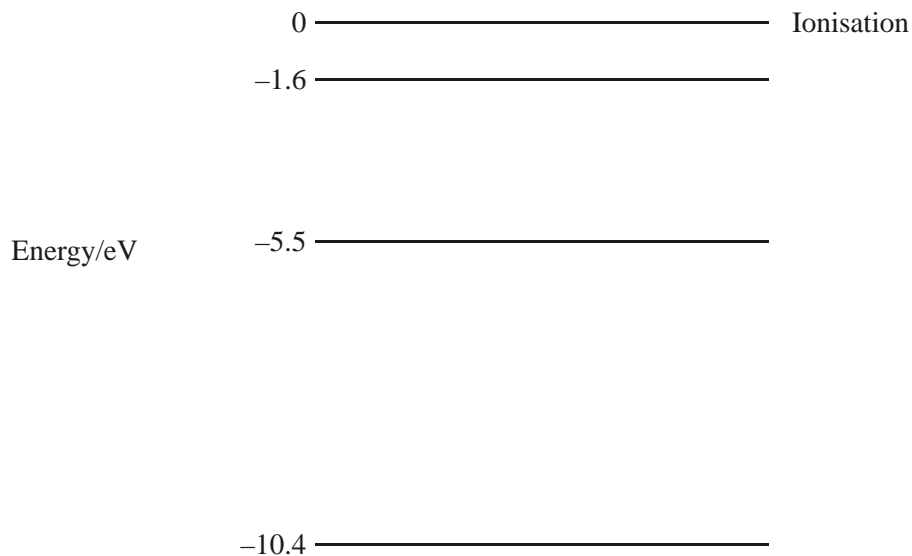
.....
.....
.....

Stopping potential =

(2)

(Total 9 marks)

24. The diagram shows some of the energy levels of a mercury atom.



Calculate the ionisation energy in joules for an electron in the -10.4 eV level.

.....

Ionisation energy = J

(2)

A proton of kinetic energy 9.2 eV collides with a mercury atom. As a result, an electron in the atom moves from the -10.4 eV level to the -1.6 eV level. What is the kinetic energy in eV of the proton after the collision?

.....

Kinetic energy =

(1)

A transition between which two energy levels in the mercury atom will give rise to an emission line of wavelength 320 nm?

.....

.....

.....

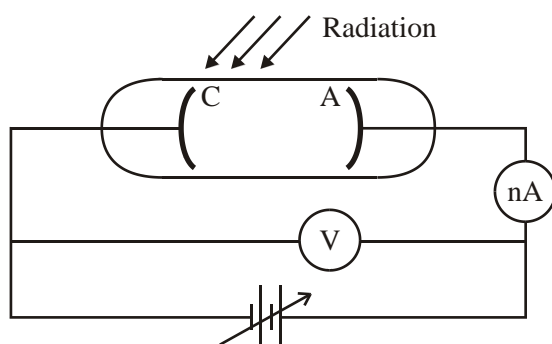
.....

.....

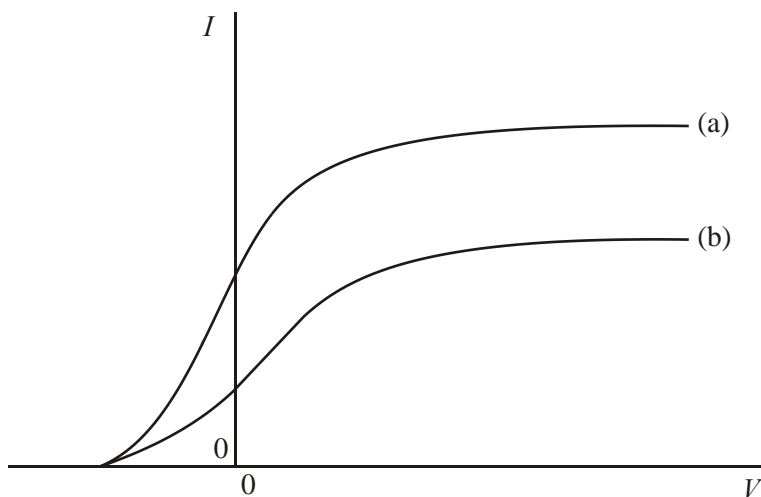
.....

(3)
(Total 6 marks)

25. The diagram shows apparatus for an experiment on the photoelectric effect.



Monochromatic radiation strikes the cathode C and photoelectrons are emitted towards the anode A. When a potential difference V is applied, a current I is measured on the very sensitive ammeter. Data can also be obtained with the polarity of the supply reversed. Using this apparatus, graph (a) below was obtained. After making a change to the incident radiation, graph (b) was obtained.



What can be deduced about the incident radiations from

- (i) the fact that both curves start from the same point on the negative V axis,

.....

- (ii) the higher final value of the current I in (a) compared to (b)?

.....

(2)

The cathode is now replaced by one made from a metal with a higher work function. On the same axes, sketch a graph labelled (c) showing what would be observed if the original radiation were used.

(1)

The work function of the metal of the cathode is 7.2×10^{-19} J. Calculate the maximum speed of the photoelectrons emitted when the incident radiation has a frequency of 7.9×10^{15} Hz.

.....
.....
.....
.....
.....
.....

Maximum speed =

(4)

(Total 7 marks)

26. Ultraviolet radiation from the sun can cause sunburn. However, not all ultraviolet wavelengths cause sunburn to the same extent.

What is meant by wavelength?

.....
.....
.....

(2)

Explain why ultraviolet radiation is more likely to cause sunburn than visible light, which has a longer wavelength.

.....
.....
.....
.....

(2)

Scientists put a lot of effort into developing suncreams which absorb the damaging wavelengths of ultraviolet radiation. Suggest what might be happening to the atoms within the suncream when they absorb ultraviolet photons.

.....

.....

.....

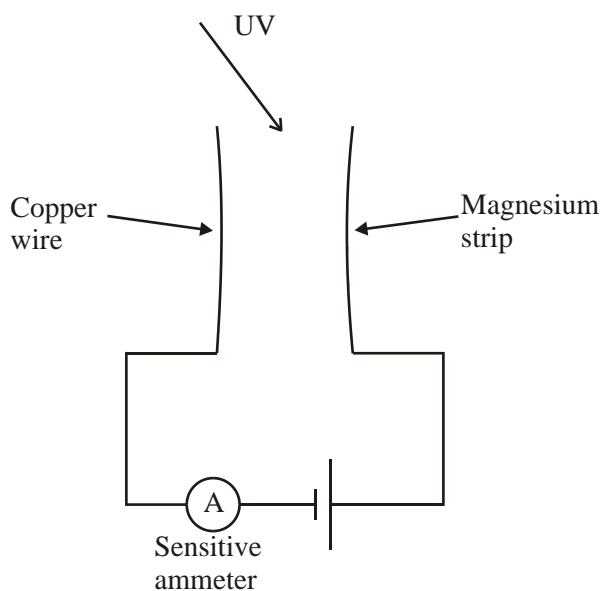
.....

(2)
(Total 6 marks)

27. A student writes up an experiment on the photoelectric effect.

We scratched the surface of a magnesium strip and set it up in front of a UV light. When we switched on the UV light, the ammeter showed a current but, when we put a sheet of glass in between the light and the magnesium, the current stopped. There was also no current when visible light shone on the magnesium.

The student included this circuit diagram:



However, the experiment would not work with this circuit. State the error in the circuit diagram, giving your reasoning.

.....
.....
.....
.....

(2)

The student gives the following wrong explanation:

This shows that UV light is made up of particles called electrons. Visible light is just transverse waves, since there was no current when this was used.

Finish the first sentence correctly:

This shows that UV

.....

(1)

The student has not understood the difference between UV and visible light. How are UV and visible light.

- (i) different
-
- (ii) similar?
-

(2)

Low-intensity UV produces a current in this experiment but even bright visible light does not. Explain why this is.

.....

.....

.....

.....

.....

.....

.....

(3)

Suggest why the current stopped when the sheet of glass was used.

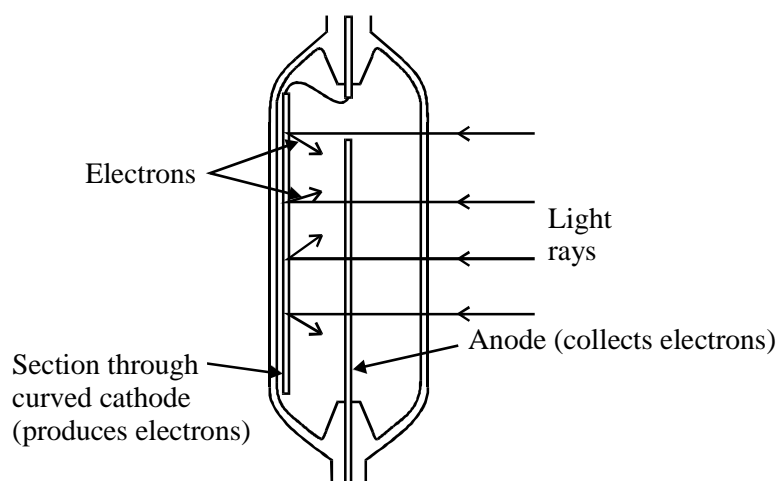
.....

.....

(1)

(Total 9 marks)

28. Many modern 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.

.....
.....
.....
.....
.....
.....

(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.

.....
.....
.....
.....

(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.

.....
.....
.....
.....
.....

(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.

.....
.....
.....
.....
.....
.....

(3)

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

.....
.....
.....
.....

(1)

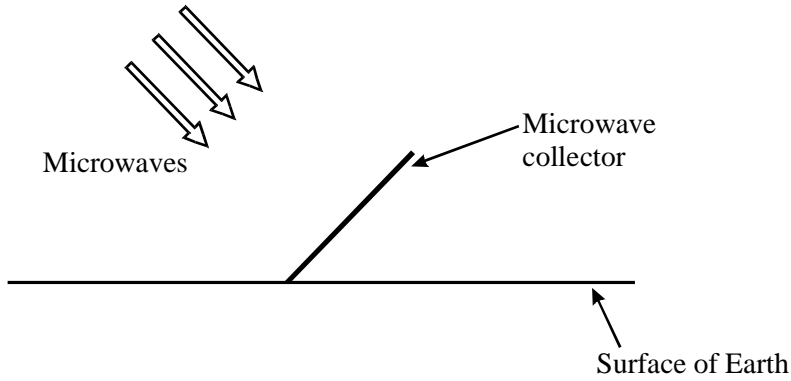
(Total 12 marks)

29. Radio waves and sound waves are sometimes confused by the general public. Complete the table to give **three** ways in which they differ.

Radio waves	Sound waves

(3)

It is proposed to place a solar power station in orbit around the Earth. The solar power station will convert sunlight to microwave energy. Microwave collectors on Earth will convert the microwaves into electricity.



The solar power station orbits the Earth at a constant distance from the surface of 36 000 km. The total area of the collectors is equivalent to a rectangle with dimensions of 120 m by 250 m.

The collectors are used to generate 600 kW of power. Calculate the intensity of the microwaves at the collectors. State any assumption that you make.

.....

Intensity =

(3)

Calculate the total power which the orbiting station would have to emit if it transmitted microwaves equally in all directions. State any assumption that you make.

.....

Power =

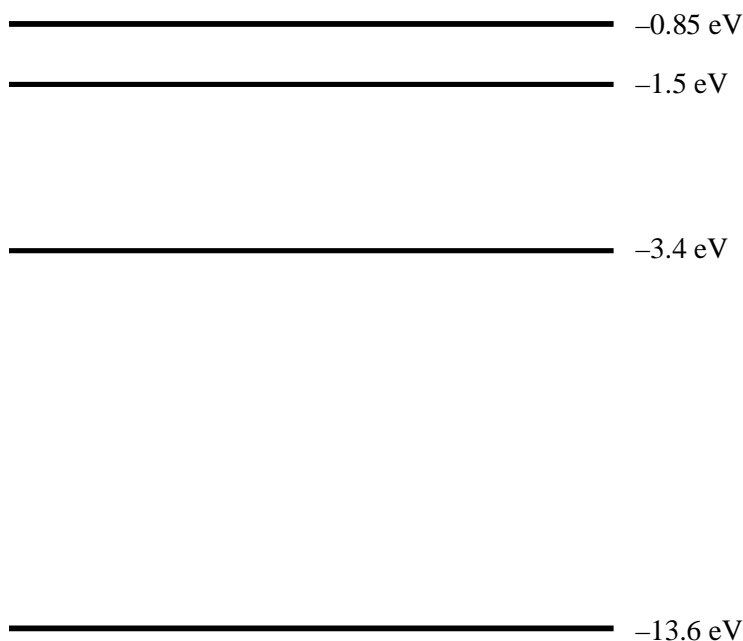
(3)

Suggest a more efficient method of transmitting the microwave energy to the collectors on Earth.

.....

(1)
(Total 10 marks)

30. The following diagram shows the lowest four energy levels of atomic hydrogen.



Calculate the ionisation energy in joules for atomic hydrogen.

.....

.....

Ionisation energy = J

(2)

On the diagram above draw

- (i) a transition marked with an R which shows a photon **released** with the **longest** wavelength,
- (ii) a transition marked with an A which shows a photon **absorbed** with the **shortest** wavelength.

(2)

Describe how you would produce and observe the emission spectrum of hydrogen in the laboratory.

.....
.....
.....
.....

What would such a spectrum look like?

.....
.....

(3)

The 211 nm line of atomic hydrogen is often used in studying stars or galaxies. To which region of the electromagnetic spectrum does this line belong?

.....

(1)

A galaxy is observed with the 211 nm line shifted to a wavelength of 203 nm. Calculate the speed of this galaxy.

.....
.....
.....
.....
.....

Speed of galaxy =

What else can be deduced about the motion of this galaxy?

.....
.....

(4)
(Total 12 marks)

31. The photoelectric effect supports a particle theory of light but not a wave theory of light.

State two features of the photoelectric effect which support the particle theory of light but which do not support the wave theory of light. For each feature explain why it supports particle theory and not wave theory.

Feature 1:
.....
.....

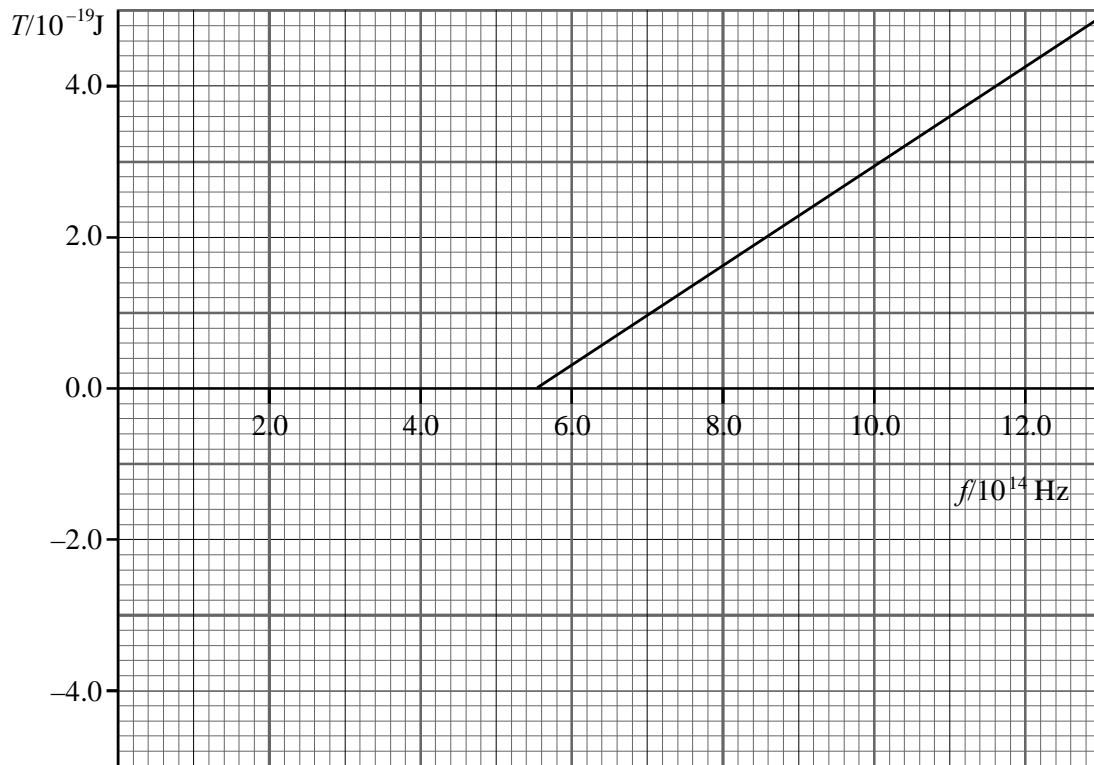
Explanation:
.....
.....
.....
.....

Feature 2:
.....
.....

Explanation:
.....
.....
.....

(Total 5 marks)

32. The graph shows how the maximum kinetic energy T of photoelectrons emitted from the surface of sodium metal varies with the frequency f of the incident electromagnetic radiation.



Use the graph to find a value for the Planck constant.

.....

.....

.....

.....

Planck constant =

(3)

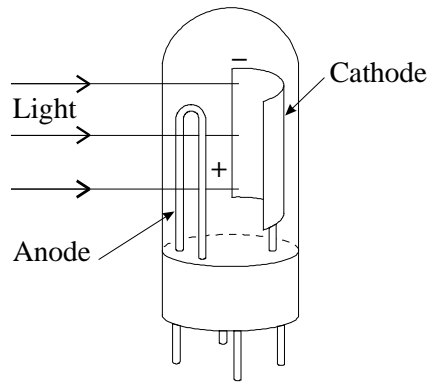
Use the graph to find the work function ϕ of sodium metal.

.....
.....
.....

Work function =

(2)
(Total 5 marks)

33. 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.

.....
.....

(1)

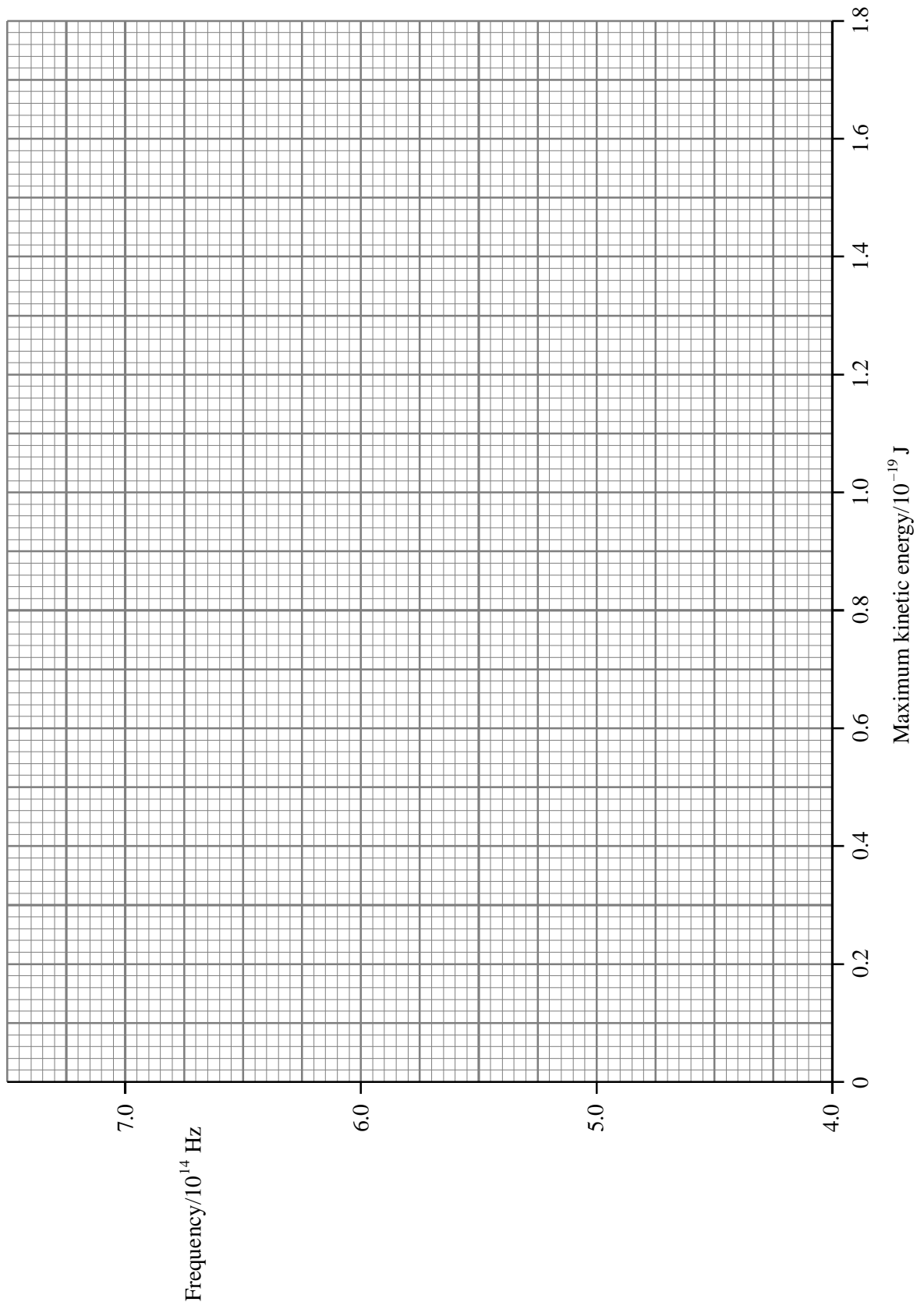
A student is investigating the photoelectric effect and selects light of various frequencies to shine on to a metal surface. Using his experimental data, he calculates the maximum kinetic energy of the electrons emitted from the surface. The results are given below.

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

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



(4)

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

.....
.....
.....
.....
.....
.....

(3)

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

.....
.....
.....

(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.

.....
.....
.....
.....

(2)

(Total 12 marks)

34. The possibility of nuclear fusion experiments in your living room is getting closer! Lasers could be used to deliver a huge pulse of energy in a very short time to a small volume of deuterium (an isotope of hydrogen) to produce the conditions for fusion for just an instant.

A neodymium laser produces 40 J of coherent light of wavelength 1050 nm for a period of 400 fs (1 fs = 10^{-15} s).

Explain the meaning of the word **coherent**.

.....
.....
.....

(1)

Calculate the power delivered by this laser.

.....
.....
.....
.....

Power =

(2)

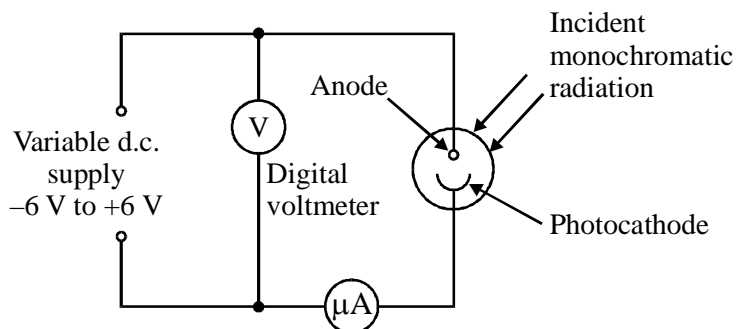
Calculate the energy level change taking place in atoms of neodymium when emitting light of the above wavelength.

.....
.....
.....
.....
.....
.....

(3)

(Total 6 marks)

35. The diagram shows monochromatic radiation falling on a photocell connected to a circuit.



The incident radiation has a wavelength of 215 nm. The metal surface of the photocathode has a work function of 2.26 eV.

Calculate the energy in eV of a photon of the incident radiation.

.....

Energy = eV (4)

What is the maximum kinetic energy in eV of the emitted electrons?

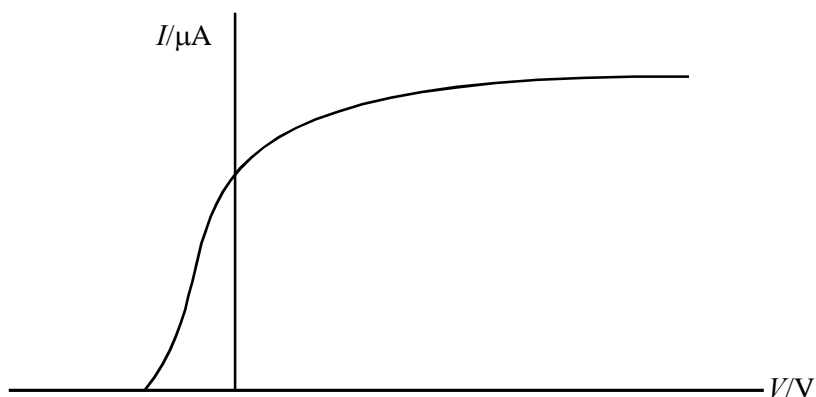
.....

Maximum k.e. = eV

Write down the value of the stopping potential.

Stopping potential = (2)

If the wavelength and intensity of the incident radiation is kept constant, a graph of the current I through the photocell against applied p.d. V is as shown.



Mark a letter S on the graph to show the stopping potential.

The photocathode is replaced with one whose metal surface has a greater work function. On the graph above, sketch how I would vary with V given that the wavelength and intensity of the incident radiation remain unchanged.

(3)

(Total 9 marks)

36. High temperatures in the Sun's atmosphere cause particles such as electrons and protons to be thrown out far into space. When these particles reach the Earth they can cause spectacular colour effects in the sky known as an aurora.



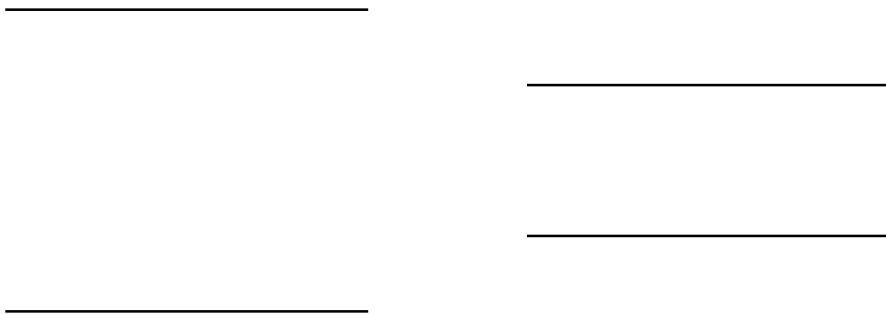
The particles interact with electrons in atoms in the upper atmosphere. As a result, coloured light is emitted. Green light of wavelength 5.58×10^{-7} m is given out from oxygen atoms and red light of wavelength 6.48×10^{-7} m from nitrogen.

Show that the energy of a photon of green light emitted from oxygen is about 3.6×10^{-19} J.

.....
.....
.....
.....

(2)

The diagrams below show the ground state and one excited state for electrons in oxygen and nitrogen. Transitions between these levels give the red and green light in the aurora. Add an arrow to show the electron transition that occurs when a photon of green light is emitted.



(2)

(Total 4 marks)

37.

Quantum Balls

BUCKYBALLS - spherical molecules made up of 60 carbon atoms - can behave like waves, blurring the boundary between the everyday world and the realm of quantum mechanics.

Markus Arndt and his colleagues at the University of Vienna sent buckyballs through a diffraction grating. A detector beyond the grating showed a clear interference pattern, where waves superimpose, indicating wavelike behaviour. "The interference pattern can only be explained if, in effect, each molecule goes through at least two of the openings" says Anton Zeilinger, who supervised the research.

Zeilinger predicts similar results with objects as large as viruses. He suggests that people think that quantum physics deals with small particles and classical physics deals with large things but that really the quantum world has no boundary.

Based on New Scientist Magazine, vol. 164, issue 2208.

Explain the words below.

Diffraction

.....
.....
.....

Superposition

.....
.....
.....

Quantum

.....
.....
.....

(4)

State one other particle you have met in your course which exhibits similar wavelike behaviour.

.....

(1)

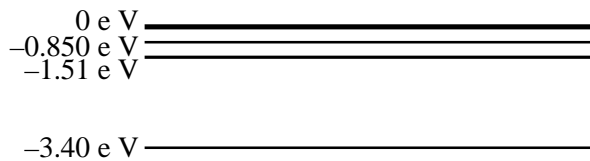
What does this passage tell us about classical and quantum physics?

.....
.....
.....
.....

(2)

(Total 7 marks)

38. The following is a simplified energy level diagram for atomic hydrogen.



-13.6 e V ————— Ground state

State the ionisation energy of atomic hydrogen.

.....
.....

Account for the labelling of the energy levels with negative numbers.

.....
.....
.....
.....
.....

(3)

Calculate the wavelength of the photon emitted when an electron moves from the -1.51 eV energy level to the -3.40 eV energy level.

.....
.....
.....
.....

Wavelength = (3)

Describe how you would produce a line spectrum of atomic hydrogen in a laboratory.

.....
.....
.....
.....

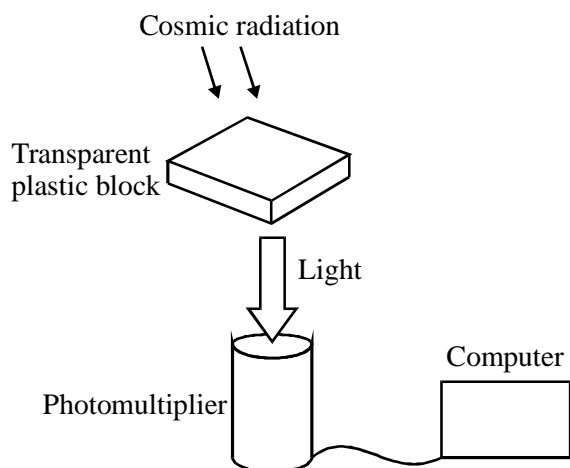
(2)

Sketch what you would expect to see.

(1)
(Total 9 marks)

39. 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.

.....

.....

.....

.....

.....

(4)

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

.....

.....

.....

.....

(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.

.....
.....

(1)

(Total 10 marks)

40. Ultraviolet light of wavelength 12.2 nm is shone on to a metal surface. The work function of the metal is 6.20 eV.

Calculate the maximum kinetic energy of the emitted photoelectrons.

.....
.....
.....
.....

Kinetic energy =.....

Show that the maximum speed of these photoelectrons is approximately $6 \times 10^6 \text{ ms}^{-1}$.

.....
.....
.....

(Total 5 marks)

41. 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*.

.....
.....
.....
.....

(2)

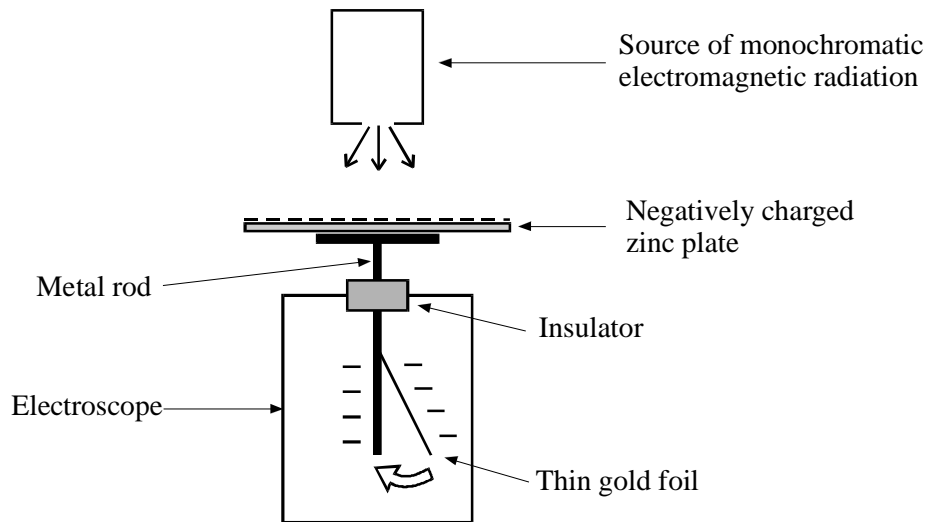
Explain how line spectra provide evidence for the existence of energy levels in atoms.

.....
.....
.....
.....
.....
.....

(3)

(Total 5 marks)

42. The diagram shows apparatus which can be used to demonstrate the photoelectric effect.



The deflection of the thin gold foil is a measure of the charge stored on the zinc plate.

When ultraviolet light is directed towards the zinc plate, the thin gold foil gradually returns to the vertical.

When red light is used the thin gold foil stays in the position shown.

How does the particle theory of light explain these observations?

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(4)

What would be observed if electromagnetic radiation of greater intensity were used?

Ultraviolet of greater intensity

.....

Red light of greater intensity

.....

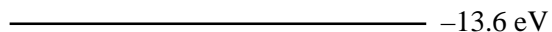
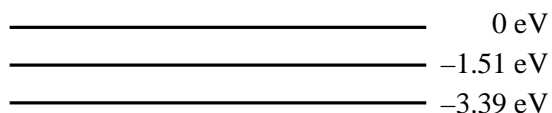
(2)

What would be observed if the zinc plate and electroscope were positively charged? Explain your answer.

.....
.....
.....
.....

(2)
(Total 8 marks)

43. The diagram shows some of the energy levels for atomic hydrogen.



Add arrows to the diagram showing all the single transitions which could ionise the atom.

(2)

Why is the level labelled -13.6eV called the ground state?

.....
.....
.....

(1)

Identify the transition which would result in the emission of light of wavelength 660 nm.

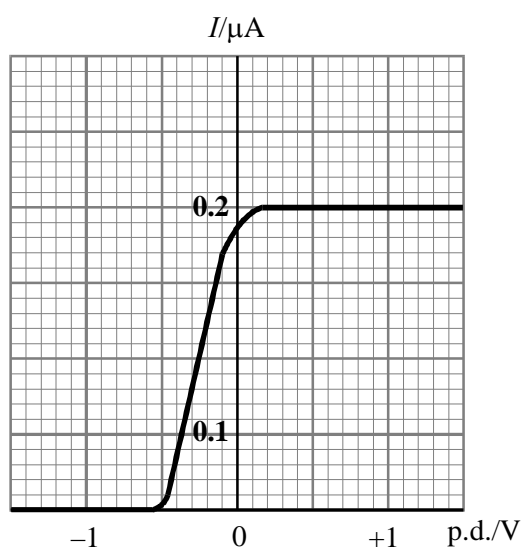
.....
.....
.....
.....

Transition =

(4)

(Total 7 marks)

44. Monochromatic light of constant intensity falls on a photocell. The graph shows how the current in the photocell varies with the potential difference applied across it.



The frequency of the incident light is 6.0×10^{14} Hz. Use the graph to estimate the work function of the metal which forms the cathode of the photocell.

.....
.....
.....
.....
.....

Work function =

(3)

Add to the axes above the graph obtained when only the intensity of the light is increased. Label this graph A.

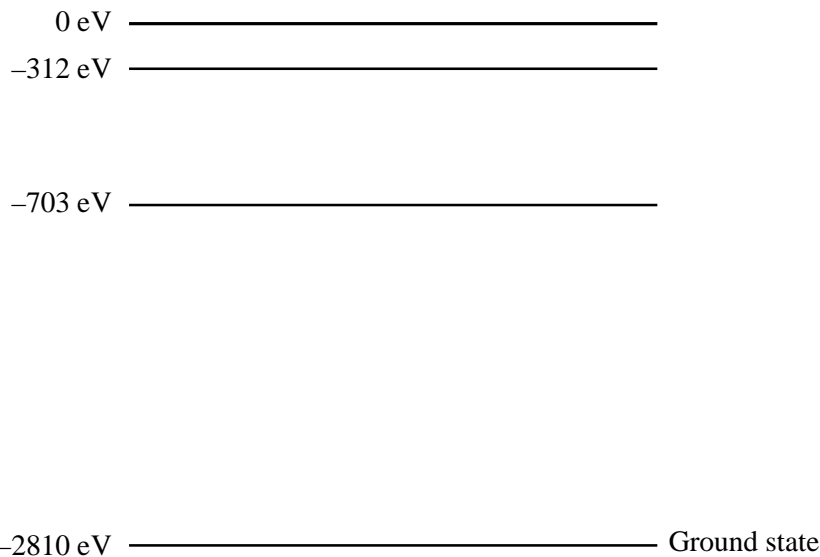
Add to the axes above the graph obtained when only the frequency of the light is increased. Label this graph B.

(4)

(Total 7 marks)

45. A muon is a particle which has the *same charge* as an electron but its *mass* is 207 times the mass of an electron.

An unusual atom similar to hydrogen has been created, consisting of a muon orbiting a single proton. An energy level diagram for this atom is shown.



State the ionisation energy of this atom.

.....

Calculate the maximum possible wavelength of a photon which, when absorbed, would be able to ionise this atom.

.....

.....

.....

.....

Maximum wavelength =.....

To which part of the electromagnetic spectrum does this photon belong?

.....

(5)

Calculate the de Broglie wavelength of a muon travelling at 11% of the speed of light.

.....
.....
.....
.....

Wavelength =.....

(3)
(Total 8 marks)

46. Experiments on the photoelectric effect show that

- the kinetic energy of photoelectrons released depends upon the frequency of the incident light and not on its intensity,
- light below a certain threshold frequency cannot release photoelectrons.

How do these conclusions support a particle theory but not a wave theory of light?

.....
.....
.....
.....
.....

(6)

Calculate the threshold wavelength for a metal surface which has a work function of 6.2 eV.

.....
.....
.....
.....

Threshold wavelength =

To which part of the electromagnetic spectrum does this wavelength belong?

.....

(4)
(Total 10 marks)