PEARSON EDEXCEL A-LEVEL PHYSICS · 9PH0

PHYSICS



EXAM QUESTION PACK

TOPIC 5: WAVES AND PARTICLE NATURE OF LIGHT

PARTICLE NATURE OF LIGHT AND THE WAVE-PARTICLE DUALITY

SCORE	PERCENTAGE
/925	%

STEMUP

These questions belong to Pearson Edexcel, not to us.

The examination questions and mark schemes in this pack were written and published by Pearson Edexcel. They are past assessment materials, reproduced here so that students can revise from them.

What we do not own

STEMUP is not affiliated with Pearson Edexcel and does not own, and makes no claim to own, any of the question or mark scheme material in this pack. Pearson has not endorsed, approved or been involved in the production of it. Pearson, Edexcel and the qualification titles used here belong to their respective owners and appear for identification only.

Where to find the originals

Pearson publishes its past papers and mark schemes free of charge. Always check the current specification at qualifications.pearson.com before you revise, because content and wording can change between series.

If you hold the rights to any material in this pack and would like it amended or removed, contact admin@stemup.co.uk and we will act on it.

Q1.

In the 19th century experiments with magnetic and electric field deflections were used to determine the charge to mass ratio of electrons.
Later experiments showed the diffraction of electrons as they passed through thin metal foils.
Deduce what these experiments tell us about electrons.

(3)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 3 marks)

Q2.

A beam of electrons spreads out into several distinct beams after passing through a crystalline material.

This demonstrates that

☒ **A** electrons behave as particles.

☒ **B** electrons behave as waves.

☒ **C** electrons exist in energy levels.

☒

D electrons have negative charge.

(Total for question = 1 mark)

Q3.

Answer the question with a cross in the box you think is correct (☒). If you change your mind about an answer, put a line through the box (☒) and then mark your new answer with a cross (☒).

The image shows a diffraction pattern formed when a beam of electrons passes through thin metal foil.



Which of the following would cause the diameter of the rings to increase?

☒ **A** Decreasing the number of electrons in the beam.

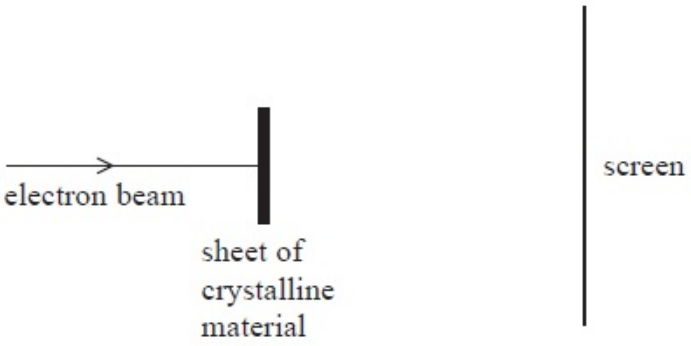
☒ **B** Decreasing the speed of electrons in the beam.

☒ **C** Increasing the number of electrons in the beam.

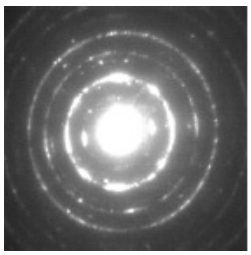
☒ **D** Increasing the speed of electrons in the beam.

(Total for question = 1 mark)

Q4. A beam of electrons is directed towards a section of crystalline material.



The following pattern is produced by the electrons on the screen.



This pattern demonstrates

- ☒ **A** diffraction.
- ☒ **B** polarisation.
- ☒ **C** reflection.
- ☒ **D** refraction.

(Total for Question = 1 mark)

Q5.

An electron beam is directed onto crystalline graphite. A fluorescent screen on the other side of the crystal shows the pattern in Figure 1. The brighter areas correspond to higher electron intensity.

The speed of the electrons is increased and the resulting pattern is shown in Figure 2.

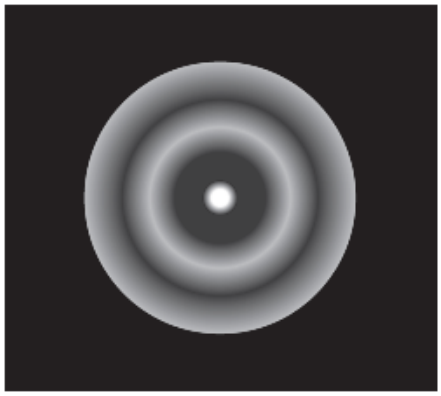


Figure 1

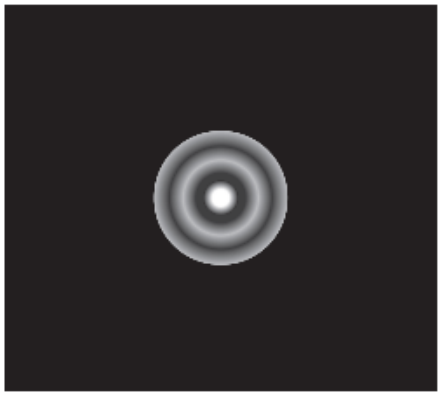


Figure 2

* Discuss the conclusions that can be drawn from this information about the behaviour of electrons and the structure of graphite.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

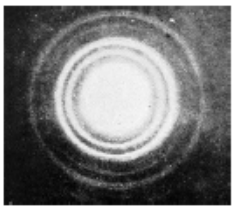
.....

(Total for question = 6 marks)

Q6.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

The image shows a diffraction pattern observed when a beam of electrons is fired at thin gold foil.



(Source: © The Reading Room/Alamy Stock Photo)

What property of electrons does this observation demonstrate?

☒ **A** they exist in discrete energy levels

☒ **B** they have a negative charge

☒ **C** their small mass

☒ **D** their wave nature

(Total for question = 1 mark)

Q1.

Our understanding of the atom has developed over time, from early models in which atoms were considered to be hard incompressible spheres, through to the nuclear model of the atom and the ladder model in which electrons exist in a discrete number of allowed energy states.

The nuclear model of the atom was established following a series of experiments in which alpha particles were directed at thin gold foil.

(i) An alpha particle approaching a gold nucleus, $^{197}_{79}Au$, head-on will be brought to rest and returned along its original path.

Calculate the minimum distance between the alpha particle and the nucleus for alpha particles of energy of 5.5 MeV.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

Minimum distance = ...

(ii) It is observed that electrons, with energy of 5.5 keV, are diffracted as they pass through the thin gold foil.

Explain a conclusion about the electrons that can be made from this observation.

(3)

.....

.....

.....

.....

.....

.....

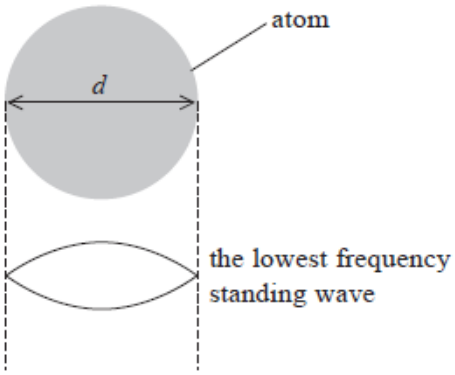
(Total for question = 7 marks)

Q2.

The Planck constant is an important universal constant used in the study of wave–particle duality.

Atomic electrons are confined within the atom. One model of atomic electrons suggests that the wave associated with an atomic electron forms a standing wave that fits exactly into the diameter *d* of the atom.

(i) The diagram shows the lowest frequency standing wave that fits into the diameter of the atom.



Calculate the momentum of the electron.

$d = 2.00 \times 10^{-10}$m

(3)

.....

.....

.....

.....

.....

Momentum = ...

(ii) Electrons in an atom can only exist at discrete energy levels.

Explain how this standing wave model can account for this.

(2)

.....

.....

.....

.....

.....

(Total for question = 5 marks)

Q3.

In the 1920s Louis de Broglie proposed that an electron could behave as a wave.

Calculate the wavelength of an electron that is travelling at a speed of $2.2 \times 10^{7} ms^{-1}$.

(3)

.....

.....

.....

.....

.....

.....

Wavelength = ...

(Total for question = 3 marks)

Q4.

Which variables are linked in the de Broglie equation?

☒ **A** frequency and wavelength of a photon

☒ **B** wavelength and momentum of a moving electron

☒ **C** energy and frequency of a photon

☒ **D** work function and threshold frequency of a metal

(Total for question = 1 mark)

Q5.

Read the extract and answer the question that follows.

In the 17th century there were two proposed theories to explain the refraction of light. Using a wave model, Huygens stated that light slows down when it passes from air to water. Using a particle model, Newton stated that light speeds up when it passes from air to water. Newton's theory was more readily accepted until the speed of light in water was measured in the 19th century.

In the early 20th century, Einstein used observations from the photoelectric effect to provide evidence for the particle model of light.

Nowadays, both the wave model of light and the particle model of light are accepted, as each can be used to explain different aspects of the behaviour of light.

In the 1920s, experiments demonstrating diffraction of electrons confirmed de Broglie's work on the wave nature of particles.

In one such experiment an electron had a momentum of 4.8×10^{-24} kg m s^{-1}.
Measurements confirmed that the de Broglie wavelength of the electron was 1.40×10^{-10} m.

Deduce that these observations are consistent with the value of *h* given on the data sheet provided.

(3)

.....

.....

.....

.....

.....

.....

(Total for question = 3 marks)

Q6. The de Broglie wavelength for neutrons used to study crystal structure is 1.2 nm. mass of a neutron = 1.67×10^{-27} kg

The speed of these neutrons would be

- ☒ **A** 3.0×10^{6} m s^{-1}
- ☒ **B** 3.3×10^{2} m s^{-1}
- ☒ **C** 3.0×10^{-3} m s^{-1}
- ☒ **D** 3.3×10^{-7} m s^{-1}

(Total for Question = 1 mark)

Q7. The de Broglie wavelength associated with electrons moving at 2.5×10^{6} m s^{-1} is

- ☒ **A** 2.9×10^{-4} m
- ☒ **B** 2.4×10^{-8} m
- ☒ **C** 2.9×10^{-10} m
- ☒ **D** 2.4×10^{-39} m

(Total for Question = 1 mark)

Q8.

The electron in a hydrogen atom can be described by a stationary wave which is confined within the atom. This means that the de Broglie wavelength associated with it must be similar to the size of the atom which is of the order of 10^{-10} m.

(a) (i) Calculate the speed of an electron whose de Broglie wavelength is 1.00×10^{-10} m.

(3)

.....

.....

.....

.....

Speed = ...

(ii) Calculate the kinetic energy of this electron in electronvolts.

(3)

.....

.....

.....

.....

Kinetic energy = ... eV

(b) When β radiation was first discovered, it was suggested that there were electrons in the atomic nucleus, but it was soon realised that this was impossible because the energy of such an electron would be too great.

Suggest why an electron confined within a nucleus would have a much greater energy than the energy calculated in (a)(ii).

(2)

.....

.....

.....

.....

.....

.....

(Total for question = 8 marks)

Q9.

(a) State what is meant by the de Broglie wavelength.

(2)

.....

.....

.....

.....

(b) An electron is accelerated from rest, in a vacuum, through a potential difference of 500 V.

(i) Show that the final momentum of the electron is about 1×10^{-23} N s.

(3)

.....

.....

.....

.....

.....

.....

(ii) Calculate the de Broglie wavelength for this electron.

(2)

.....

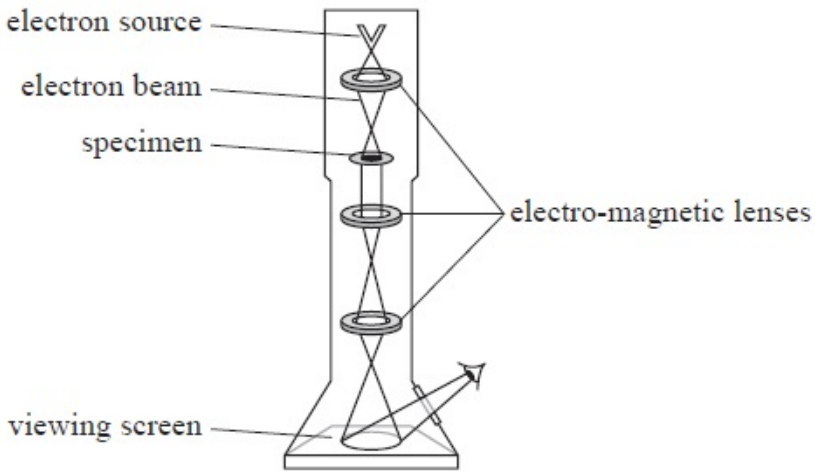
.....

.....

de Broglie wavelength = ...

(Total for question = 7 marks)

Q10. A transmission electron microscope passes a beam of electrons through a tiny specimen to form an image on a viewing screen.



Due to the wave nature of electrons, diffraction occurs which can blur the image. To reduce this effect when viewing a smaller object the beam must contain

☒ **A** more electrons per second.

☒ **B** fewer electrons per second.

☒ **C** faster moving electrons.

☒ **D** slower moving electrons.

(Total for Question = 1 mark)

Q11.

Answer the question with a cross in the box you think is correct (☒). If you change your mind about an answer, put a line through the box (☒) and then mark your new answer with a cross (☒).

The image shows a diffraction pattern formed when a beam of electrons passes through thin metal foil.



Which of the following would cause the diameter of the rings to increase?

☒ **A** Decreasing the number of electrons in the beam.

☒ **B** Decreasing the speed of electrons in the beam.

☒ **C** Increasing the number of electrons in the beam.

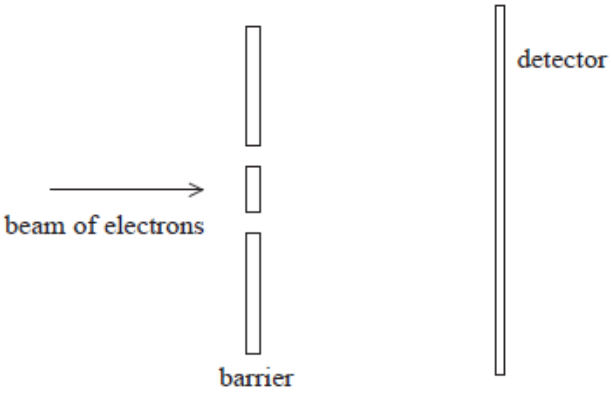
☒ **D** Increasing the speed of electrons in the beam.

(Total for question = 1 mark)

Q12.

In 1965, Richard Feynman proposed a double slit experiment to investigate the wave properties of electrons.

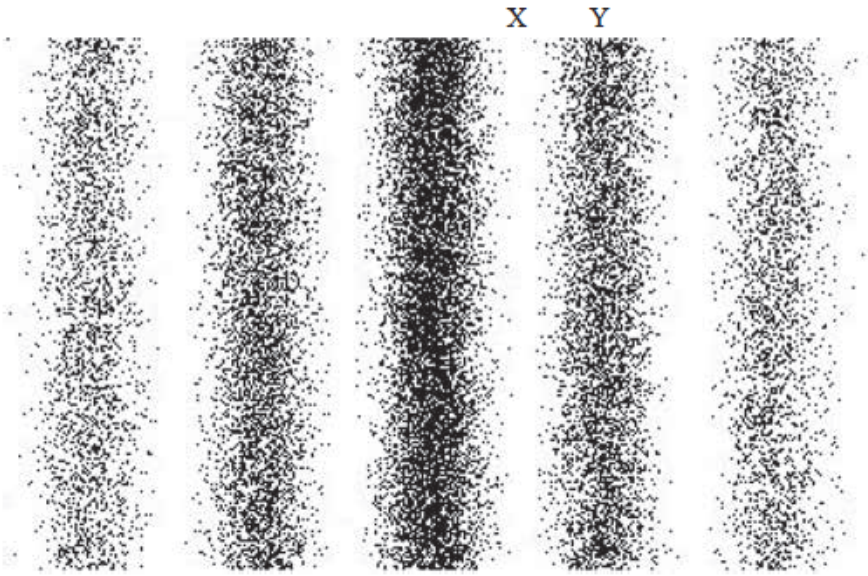
The experiment was later carried out using the arrangement shown.



A beam of electrons was directed at a barrier with two slits.

The detector recorded the positions where electrons arrived after passing through the slits.

The following pattern was obtained. Black dots represent points where electrons were detected. A band where electrons were not detected has been labelled X and a band where electrons were detected has been labelled Y.



The path difference for electrons arriving at band X from the separate slits was 2.5×10^{-1} m. For electrons arriving at band Y the path difference was 5.0×10^{-1} m.

Explain why this pattern is observed when the electron energy is 9.6×10^{-1} J.

The electrons are travelling at non-relativistic speeds.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q13.

When a sound wave passes from water into air it slows down. As the wave crosses the boundary from water to air its

☒ **A** frequency decreases.

☒ **B** frequency increases.

☒ **C** wavelength decreases.

☒ **D** wavelength increases.

(Total for question = 1 mark)

Q14.

Answer the question with a cross in the box you think is correct ☒. If you change your

mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

An electron travels at a velocity v.

Which of the following is the correct expression for the de Broglie wavelength λ of the electron?

☐ **A** $\lambda = \dfrac{3.00 \times 10^{8}}{9.11 \times 10^{-31} \times v}$

☐ **B** $\lambda = \dfrac{9.11 \times 10^{-31} \times v}{3.00 \times 10^{8}}$

☐ **C** $\lambda = \dfrac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times v}$

☐ **D** $\lambda = \dfrac{9.11 \times 10^{-31} \times v}{6.63 \times 10^{-34}}$

(Total for question = 1 mark)

Q15.

Our understanding of the atom has developed over time, from early models in which atoms were considered to be hard incompressible spheres, through to the nuclear model of the atom and the ladder model in which electrons exist in a discrete number of allowed energy states.

* The model of atoms as hard incompressible spheres, moving rapidly and randomly, can be used to explain why gases exert a pressure.

Explain, using ideas of momentum, why the pressure exerted by a gas increases as the temperature of the gas increases.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q16.

An electron beam is directed onto crystalline graphite. A fluorescent screen on the other side of the crystal shows the pattern in Figure 1. The brighter areas correspond to higher electron intensity.

The speed of the electrons is increased and the resulting pattern is shown in Figure 2.

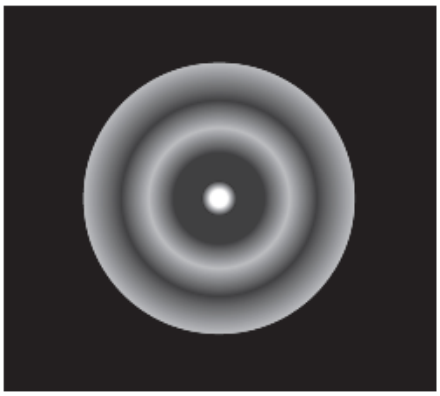


Figure 1



Figure 2

* Discuss the conclusions that can be drawn from this information about the behaviour of electrons and the structure of graphite.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q17.

(a) Solar sails are a form of propulsion for spacecraft. The sail is made of a thin sheet of reflective material. When photons of light from the Sun reflect from the material a force is exerted on the sail. The photons reflect with a momentum equal to their initial momentum but in the opposite direction.

(i) Show that a single photon of frequency 1.5×10^{15} Hz has a momentum of about 3×10^{-27} N s.

(2)

.....

.....

.....

.....

(ii) Hence determine the momentum transferred to the solar sail by this photon.

(1)

.....

Momentum transferred = ...

(b) An alternative method of producing a momentum change is being investigated. Researchers

have suggested that 'larger changes in momentum could be produced by directing laser light at graphene oxide'. Electrons are emitted from the graphene oxide surface, resulting in a force being exerted on the graphene oxide in the opposite direction.

A researcher has suggested that one possible mechanism for the emission of the electrons is the photoelectric effect.

(i) Show that the maximum velocity for a photoelectron emitted after absorption of a photon of light of frequency 1.5×10^{15} Hz is about 8×10^{5} m s^{-1}.

work function of graphene oxide = 6.7×10^{-19} J

(3)

.....

.....

.....

.....

.....

.....

(ii) Hence calculate the momentum of the photoelectron.

(2)

.....

.....

.....

Momentum of photoelectron = ...

(c) Explain whether the suggestion in (b) that 'larger changes in momentum could be produced by directing laser light at graphene oxide' is true.

(2)

.....

.....

.....

.....

.....

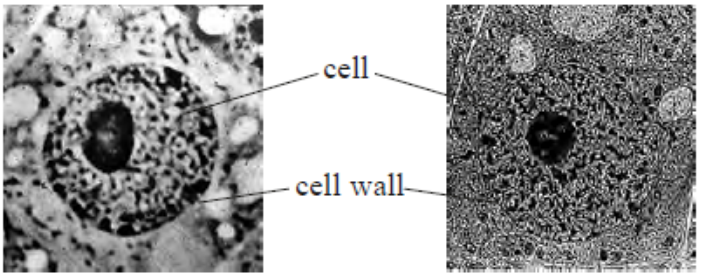
.....

(Total for question = 10 marks)

Q18.

An optical microscope uses a beam of visible light. An electron microscope uses a beam of electrons.

A biologist looked at an animal cell using both microscopes. The two images are shown; both have the same magnification.



using optical microscope using electron microscope

www.udel.edu

An electron in the beam of the electron microscope has a velocity of 2% of the speed of light.

Calculate the de Broglie wavelength of the electron.

(3)

.....

.....

.....

.....

.....

.....

de Broglie wavelength = ...

(Total for question = 3 marks)

Q19.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Which of the following is the SI base unit for the Planck constant?

☒ **A** N m^{-1} s^{-1}

☒ **B** N m s

☒ **C** kg m^{2} s^{-1}

☒ **D** kg m^{-2} s

(Total for question = 1 mark)

Q1.

Helium was first discovered because of dark lines observed in the continuous spectrum of light from the Sun. The lines were caused by a few specific frequencies of light in the spectrum being present at very much lower intensity than the rest.

Scientists deduced that this was due to an unknown element in the Sun's atmosphere.

(a) Explain how helium in the Sun's atmosphere caused this set of dark lines.

(5)

.....

.....

.....

.....

.....

.....

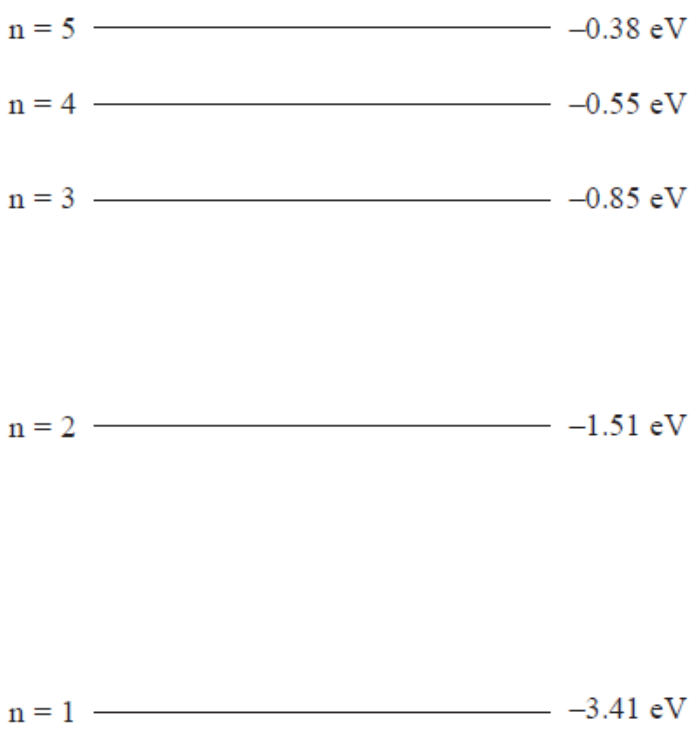
.....

.....

.....

.....

(b) The diagram shows some of the energy levels for an atom of another element.



(i) Determine which energy levels are associated with photons of frequency 4.6×10^{14} Hz.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

(ii) Suggest why the energy levels all have a negative value.

(2)

.....

.....

.....

.....

(c) Lines such as those described in (a) can be used to determine the motion of stars relative to the Earth.

Suggest how these lines may be used to determine the motion of stars.

(3)

.....

.....

.....

.....

.....

.....

(Total for question = 14 marks)

Q2. Analysing the light from a star allows elements present in its outer atmosphere to be identified because each element produces a distinctive set of spectral lines.

*(a) Describe how a spectral line is produced by a hot gas, explaining why a particular element can only give rise to particular frequencies.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

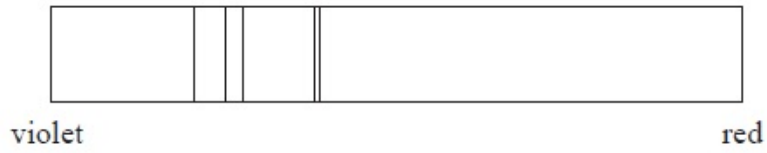
.....

.....

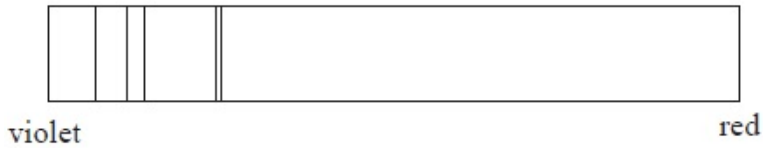
.....

.....

(b) The diagram shows the spectral lines produced by a particular element when observed in a laboratory.



The diagram below shows the spectral lines obtained by analysing the light from a star. This shows the same pattern of lines, but in a different part of the spectrum.



Name this effect and explain what may be deduced about the motion of this star relative to the Earth.

(3)

.....

.....

.....

.....

.....

.....

(c) Suggest what the phenomena in parts (a) and (b) imply about the nature of light.

(1)

.....

.....

(Total for Question = 10 marks)

Q3.

A coulombmeter is used to measure charge.



In a laboratory demonstration of the photoelectric effect, a sheet of zinc was placed on top of a coulombmeter and the zinc was given a negative charge.

* The following observations were made:

- under normal lighting conditions the charge remained constant
- when the zinc was illuminated with ultraviolet light, the magnitude of the charge on the zinc decreased as time passed
- when a larger sheet of zinc was used the charge on the zinc decreased more rapidly.

In each case the initial charge on the zinc was the same.

Explain these observations.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

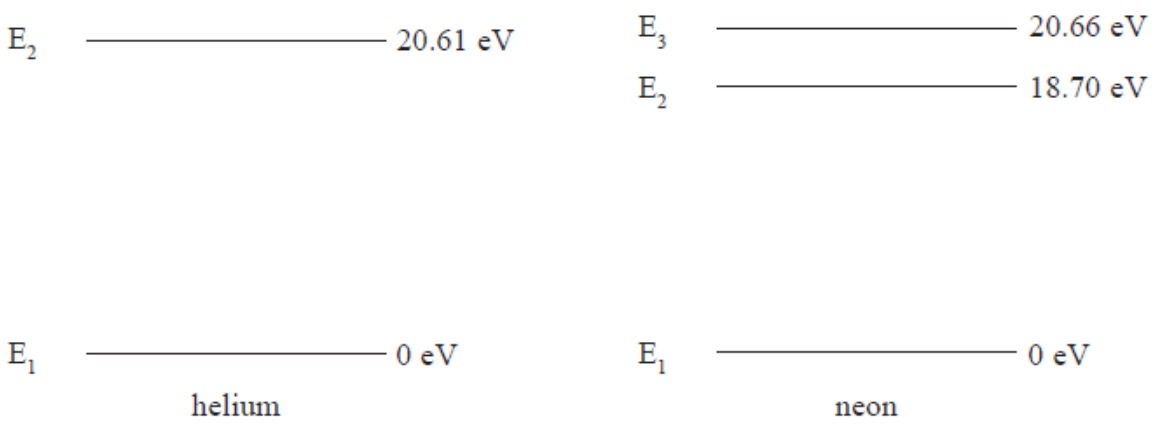
.....

(Total for question = 6 marks)

Q4.

A helium-neon gas laser is often used in the laboratory as a source of high intensity, coherent, monochromatic light.

The diagram shows some of the energy levels above the ground level E_3 for helium atoms and for neon atoms. The highest shown levels for helium atoms and neon atoms are almost identical.



Helium atoms in the gas are excited to level E_2 by the current passing through the laser. They collide at high speed with neon atoms. Because the energies are so similar, the energy is transferred from the helium atoms to the neon atoms. The neon atoms become excited in turn to

level E^3. As the neon atoms subsequently drop to level E_2 they emit photons.

(a) Explain what is meant by a photon.

(2)

.....

.....

.....

(b) Calculate the frequency of the photons produced as the neon atoms drop from level E_3 to level E_2.

(3)

.....

.....

.....

.....

Frequency = ...

(c) An electron in level E_3 of neon has 0.05 eV more energy than an electron in level E_2 of helium.

Suggest the source of the energy to make up this difference.

(1)

.....

.....

(d) The photograph shows a device for making a vertical slit with variable width.



© THORLABS, Inc.

When the slit is fully open a laser beam is shone through it and a single point of light is seen on a screen.

As the slit is reduced in width the point of light becomes a horizontal line that gets longer as the

slit gets narrower.

Explain this observation

(3)

.....

.....

.....

.....

.....

.....

(Total for question = 9 marks)

Q5.

Light can be modelled as a wave.

Diffraction provides evidence for the wave nature of light.

Use Huygens' construction to describe what happens to light waves after passing through a narrow gap.

(3)

.....

.....

.....

.....

.....

(Total for question = 3 marks)

Q6.

Read the extract and answer the question that follows.

In the 17th century there were two proposed theories to explain the refraction of light. Using a wave model, Huygens stated that light slows down when it passes from air to water. Using a particle model, Newton stated that light speeds up when it passes from air to water. Newton's theory was more readily accepted until the speed of light in water was measured in the 19th century.

In the early 20th century, Einstein used observations from the photoelectric effect to provide evidence for the particle model of light.

Nowadays, both the wave model of light and the particle model of light are accepted, as each can be used to explain different aspects of the behaviour of light.

Give two reasons why Huygens' theory for the refraction of light eventually became accepted.

(2)

.....

.....

.....

.....

.....

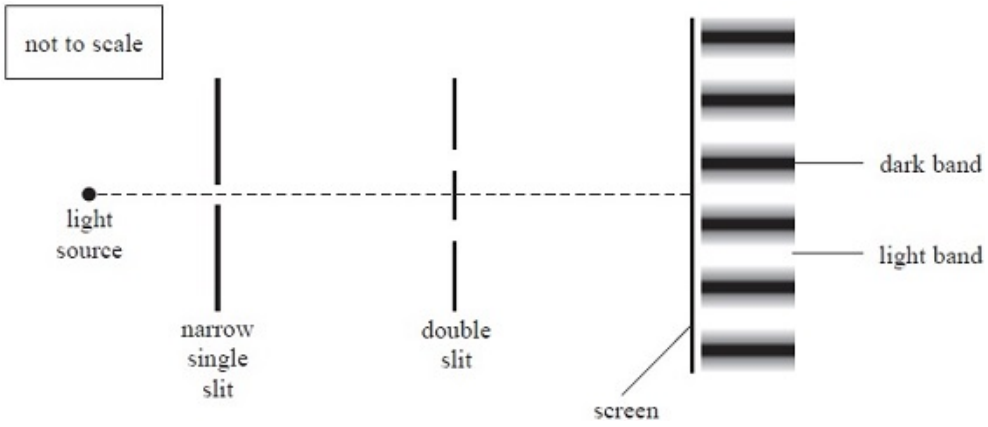
.....

(Total for question = 2 marks)

Q7. In the 17th century, Isaac Newton suggested that light was made up of very small particles which he called corpuscles.

Newton's theory was favoured in England throughout the 18th century because of his great reputation although scientists elsewhere applied the wave theory.

In 1801 Thomas Young demonstrated his double slit experiment. Monochromatic light from a narrow single slit was passed through a double slit and a pattern of light and dark bands was seen on a screen, as shown in the diagram.



*(a) Explain how the light and dark bands are formed in the double slit experiment.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

(b) The observation of light and dark bands with the double slit experiment depends on the light from the slits being coherent.

Explain why coherence is necessary to observe the light and dark bands.

(2)

.....

.....

.....

.....

.....

(c) State why Young's experiment disproved Newton's corpuscular theory.

(1)

.....

.....

(Total for Question = 7 marks)

Q8.

Light can be modelled as a wave.

Describe how light is transmitted as a transverse wave.

(2)

.....

.....

.....

.....

(Total for question = 2 marks)

Q9.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

Which of the following provides evidence for the particle model of electromagnetic radiation?

☒ **A** diffraction

☒ **B** interference

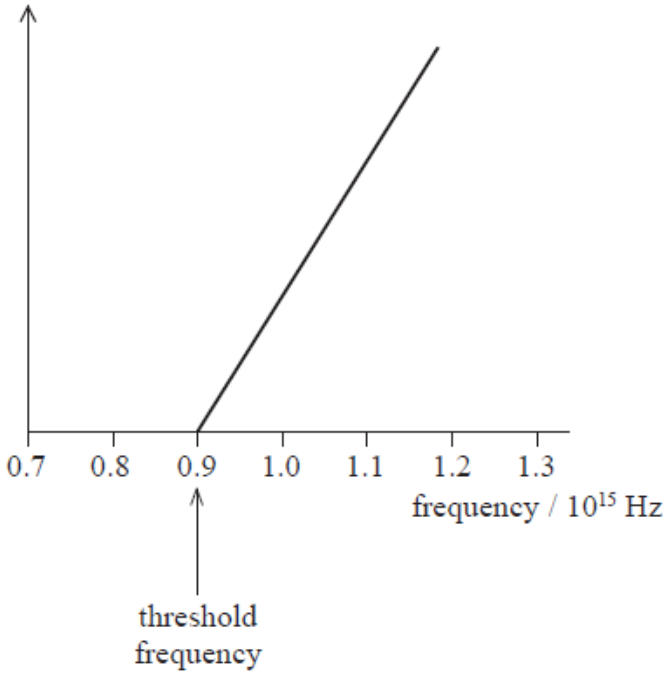
☒ **C** polarisation

☒ **D** visible line spectra

(Total for question = 1 mark)

Q10.

The graph shows the results for an experiment to demonstrate the photoelectric effect by illuminating a clean metal sheet with light of increasing frequency.



(a) State a quantity, and its unit, which could have been plotted on the Y-axis to produce this graph.

(2)

.....

.....

(b) The threshold frequency is shown on the graph.

Explain why there is a threshold frequency.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q11.

When light is incident on the surface of a metal, electrons may be emitted by the photoelectric effect. Observations of the photoelectric effect helped to establish that light can exhibit particle behaviour.

Which of the following observations of the photoelectric effect could also be explained by light behaving as a wave?

☒ **A** Emission of photoelectrons occurs immediately the surface is illuminated.

☒ **B** Photoelectrons are only emitted when the frequency of the light is more than a certain minimum value.

☒ **C** The maximum kinetic energy of the photoelectrons is independent of the intensity of the incident light.

☒ **D** When the intensity of the incident light increases, photoelectrons are emitted at a greater rate.

(Total for question = 1 mark)

Q12.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

The photoelectric effect provides evidence for the particle nature of electromagnetic radiation.

Which of the following observations of the photoelectric effect could also be explained using the wave nature of electromagnetic radiation?

☒ **A** The emission of photoelectrons is instantaneous.

☒ **B** The maximum kinetic energy of photoelectrons depends on frequency.

☒ **C** The rate of emission of photoelectrons depends on intensity.

☒ **D** There is a minimum frequency for emission of photoelectrons to occur.

(Total for question = 1 mark)

Q13.

*****In 1905 Einstein published his equation for the photoelectric effect.

In 1916 Millikan demonstrated that the maximum kinetic energy of photoelectrons is consistent with Einstein's equation.

Discuss the extent to which our current understanding of observations of the photoelectric effect supports the idea that light behaves as photons rather than as waves.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q14. When the photoelectric effect was first observed in the nineteenth century, scientists could not explain it using the wave theory of light.

In 1905 Albert Einstein published a paper, for which he won a Nobel Prize, explaining the photoelectric effect by using a photon model of light, rather than a wave model.

(a) Explain what is meant by a photon.

(2)

.....

.....

.....

.....

*(b) Explain why the following observations may be understood by using a photon model of light, rather than a wave model.

- Light above a certain frequency causes the emission of electrons from the surface of a metal. This emission occurs instantaneously.
- Light below a certain frequency will not result in the emission of electrons however long it illuminates the surface.

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(c) Zinc has a work function of 4.3 eV.

(i) Calculate the threshold frequency for zinc.

(3)

.....

.....

.....

.....

.....

Threshold frequency = ...

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

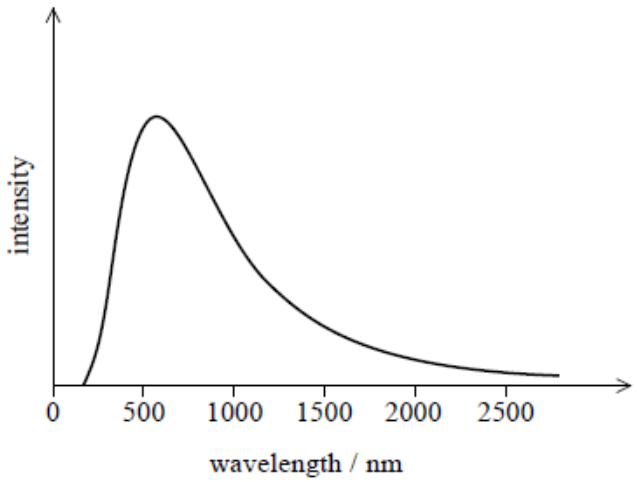
(1)

.....

(Total for Question = 11 marks)

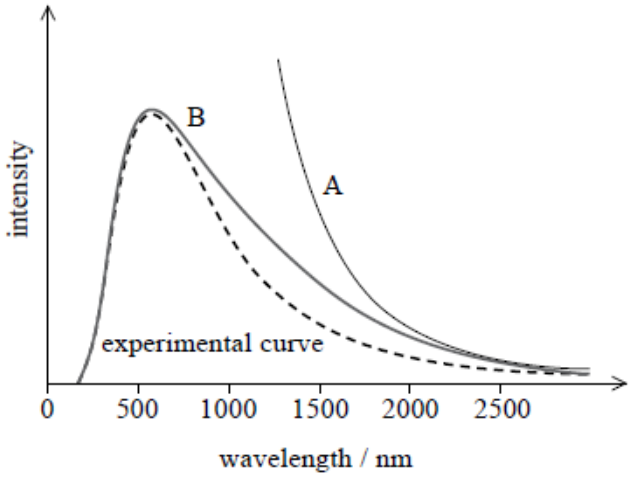
Q15.

The diagram shows the radiation curve for a black body radiator. The diagram was obtained from experimental data.



Experimental curve

In the late 19th century, scientists struggled to explain this experimental curve. One model used ideas of classical physics and produced curve A. Another model incorporated the idea of energy quantisation in the mechanism of energy emission and produced curve B. Both curve A and curve B are shown below, with the experimental curve for comparison.



(i) Explain how energy quantisation applies to the emission of radiation of energy from a black body radiator.

(2)

.....

.....

.....

.....

(ii) Assess the extent to which each model is successful at explaining the experimental curve.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

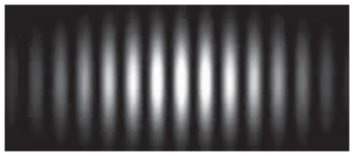
.....

(Total for question = 6 marks)

Q16.

Huygens' principle states that every point on a wavefront is a source of wavelets which spread out at the same speed.

In an experiment to demonstrate interference of light, monochromatic light from a laser is shone onto two narrow slits. A series of light and dark lines is observed on a screen placed a distance away from the slits.



(i) State one safety precaution that should be taken with this procedure.

(1)

.....

.....

(ii) Thomas Young first demonstrated the principle of this experiment in 1803 in support of the theory that light behaves as a wave.

Give a reason why some scientists at the time did not accept the wave theory of light.

(1)

.....

.....

(Total for question = 2 marks)

Q17.

* The behaviour of electromagnetic radiation can be described in terms of a photon model or a wave model.

In the photoelectric effect, electromagnetic radiation is incident on a metal plate and under certain conditions electrons are emitted.

It is observed that, for a given metal,

- no electrons are emitted if the frequency of the incident radiation is below a certain threshold frequency.
- electrons are emitted instantaneously if the frequency of the incident radiation is above a certain threshold frequency.
- the kinetic energy of the emitted electrons depends only on the frequency of the incident radiation.

Discuss how the photon model of electromagnetic radiation can explain these observations and why the wave model of electromagnetic radiation cannot.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

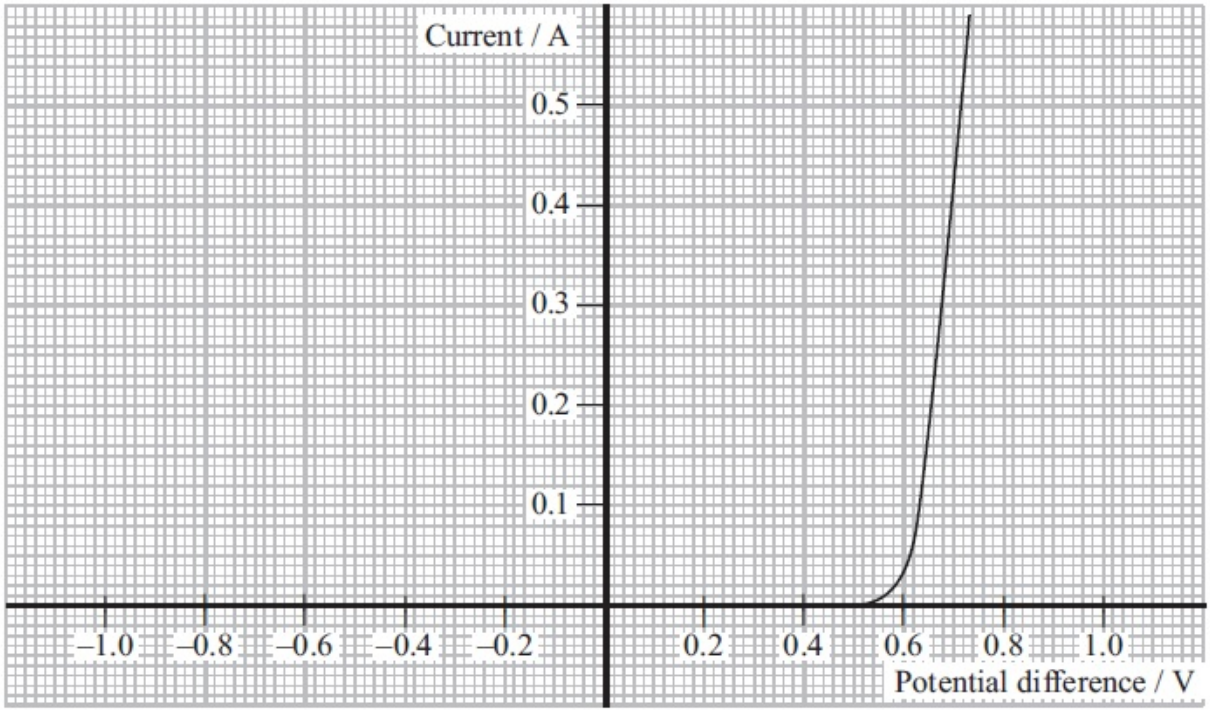
.....

.....

(Total for question = 6 marks)

Q18.

The graph shows the current−potential difference characteristic for an electrical component.



(a) State the name of the component.

(1)

.....

(b) State the resistance of the component when the potential difference is - 0.7 V.

(1)

.....

(c) Calculate the resistance of the component when the potential difference is + 0.7 V.

(2)

.....

.....

.....

Resistance = ...

(d) State a practical use for this component.

(1)

.....

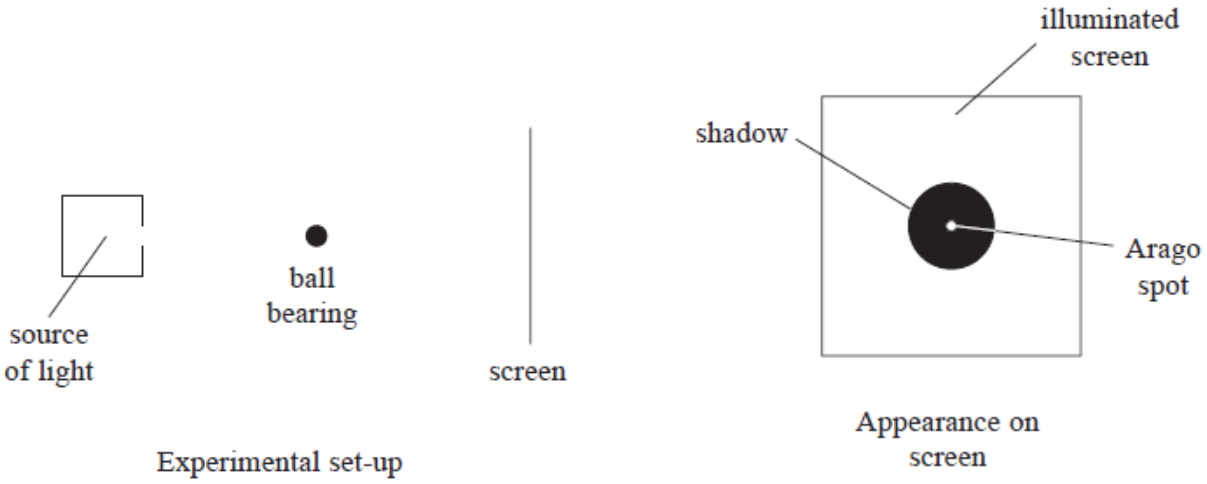
.....

(Total for question = 5 marks)

Q19.

The diagram shows a coherent beam of light incident on a metal ball bearing.

A dark shadow is seen on a screen behind the ball bearing. There is a small spot of light in the centre of the shadow. This spot of light is known as the Arago spot.



François Arago first demonstrated this experiment in 1818 for a group of eminent scientists, to show the behaviour of light.

State the model for the behaviour of light that this experiment demonstrated and explain why the scientific community accepted this model.

(3)

.....

.....

.....

.....

.....

(Total for question = 3 marks)

Q20.

The wave and particle models of light have both contributed to our understanding of light.

Which row of the table correctly matches properties of light to the model that best explains them?

	Wave model	Particle model
☒ **A**	photoelectric effect	refraction
☒ **B**	diffraction	atomic line spectra
☒ **C**	atomic line spectra	photoelectric effect
☒ **D**	refraction	diffraction

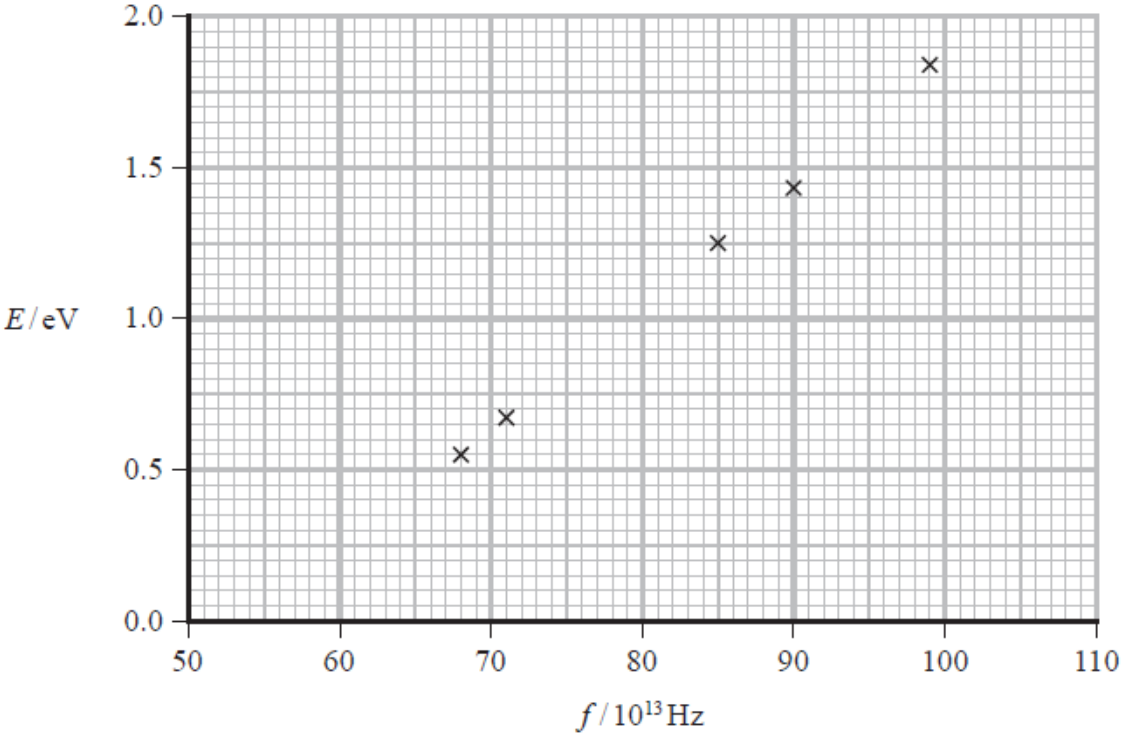
(Total for question = 1 mark)

	Total for question	**14**

Q1.

In an investigation of the photoelectric effect, electromagnetic radiation of frequency f was directed onto a metal plate. The maximum kinetic energy E of the photoelectrons emitted from the metal plate was determined. The procedure was repeated for a range of frequencies.

The graph shows how E depended upon f.



Determine a value for the Planck constant, h, in J s.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

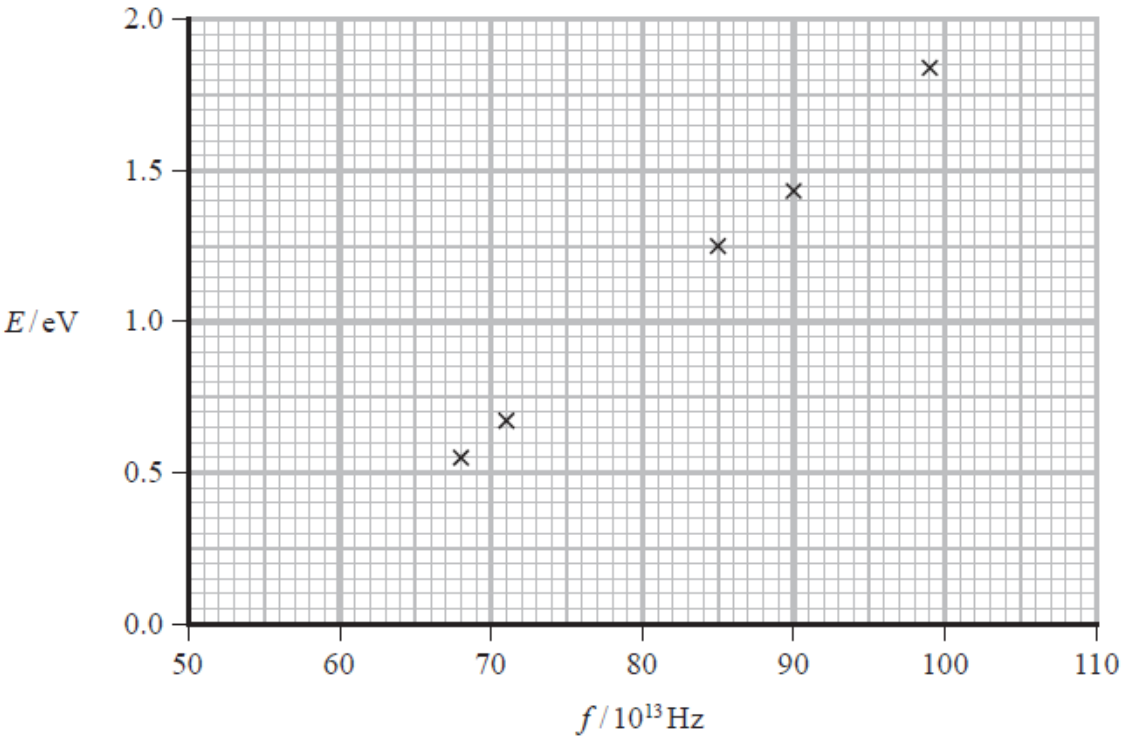
h = ... J s

(Total for question = 4 marks)

Q2.

In an investigation of the photoelectric effect, electromagnetic radiation of frequency *f* was directed onto a metal plate. The maximum kinetic energy *E* of the photoelectrons emitted from the metal plate was determined. The procedure was repeated for a range of frequencies.

The graph shows how *E* depended upon *f*.



The table gives data for different metal surfaces.

Metal surface	Work function / eV
Caesium	2.0
Calcium	2.9
Magnesium	3.7

Deduce which metal was being used in the investigation.

(3)

.....

.....

.....

.....

.....

.....

.....

(Total for question = 3 marks)

Q3.

Helium was first discovered because of dark lines observed in the continuous spectrum of light from the Sun. The lines were caused by a few specific frequencies of light in the spectrum being present at very much lower intensity than the rest.

Scientists deduced that this was due to an unknown element in the Sun's atmosphere.

(a) Explain how helium in the Sun's atmosphere caused this set of dark lines.

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(b) The diagram shows some of the energy levels for an atom of another element.

n = 5 ——————————— –0.38 eV

n = 4 ——————————— –0.55 eV

n = 3 ——————————— –0.85 eV

n = 2 ——————————— –1.51 eV

n = 1 ——————————— –3.41 eV

(i) Determine which energy levels are associated with photons of frequency 4.6×10^{14} Hz.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

(ii) Suggest why the energy levels all have a negative value.

(2)

.....

.....

.....

.....

(c) Lines such as those described in (a) can be used to determine the motion of stars relative to

the Earth.

Suggest how these lines may be used to determine the motion of stars.

(3)

.....

.....

.....

.....

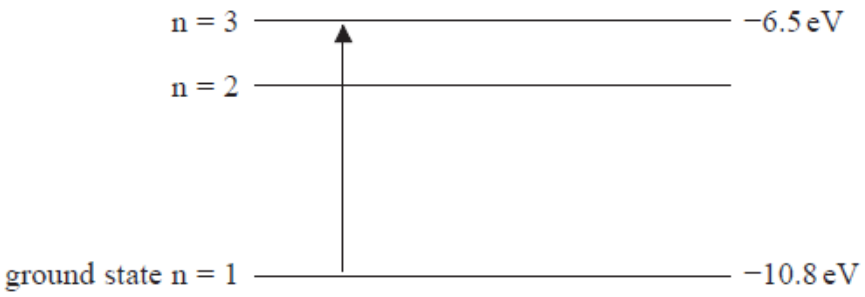
.....

.....

(Total for question = 14 marks)

Q4.

An electron in its ground state absorbs electromagnetic radiation of wavelength λ.
The energy level diagram represents the resulting energy transition of the electron.



Calculate the wavelength of radiation absorbed by the electron.

(3)

.....

.....

.....

.....

.....

.....

Wavelength = ...

(Total for question = 3 marks)

Q5.

A coulombmeter is used to measure charge.



In a laboratory demonstration of the photoelectric effect, a sheet of zinc was placed on top of a coulombmeter and the zinc was given a negative charge.

* The following observations were made:

- under normal lighting conditions the charge remained constant
- when the zinc was illuminated with ultraviolet light, the magnitude of the charge on the zinc decreased as time passed
- when a larger sheet of zinc was used the charge on the zinc decreased more rapidly.

In each case the initial charge on the zinc was the same.

Explain these observations.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q6.

The photoelectric effect was discovered by Hertz who investigated the effect of ultraviolet radiation incident upon the surface of zinc. The effect was found to depend on the frequency of the radiation.

(a) State what is meant by threshold frequency.

(1)

.....

.....

.....

(b) Light of frequency 8.9×10^{14} Hz is incident upon the surface of a different metal. The photoelectrons have a maximum speed of 6.7×10^{5} m s^{-1}.

Calculate the work function of the metal in eV.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

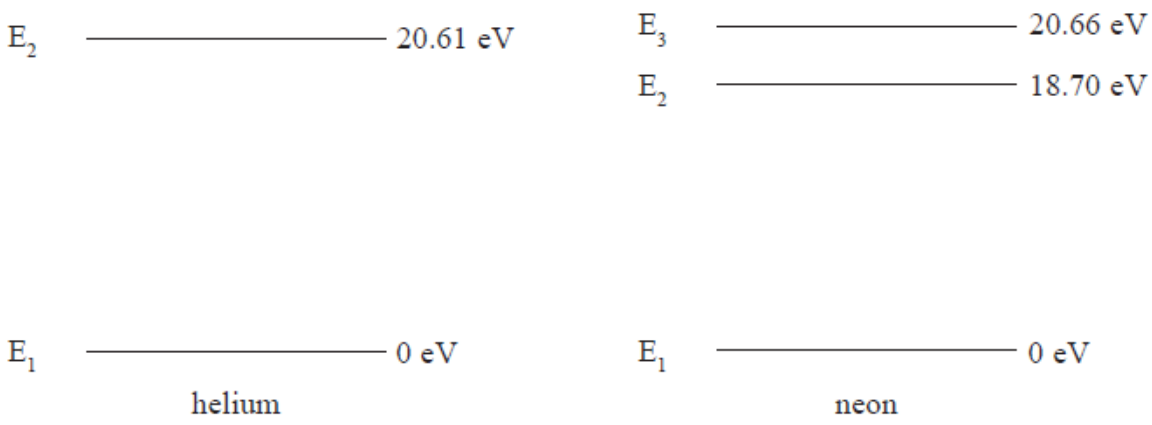
Work function = ... eV

(Total for question = 5 marks)

Q7.

A helium-neon gas laser is often used in the laboratory as a source of high intensity, coherent, monochromatic light.

The diagram shows some of the energy levels above the ground level E_3 for helium atoms and for neon atoms. The highest shown levels for helium atoms and neon atoms are almost identical.



Helium atoms in the gas are excited to level E_2 by the current passing through the laser. They collide at high speed with neon atoms. Because the energies are so similar, the energy is transferred from the helium atoms to the neon atoms. The neon atoms become excited in turn to level E_3. As the neon atoms subsequently drop to level E_2 they emit photons.

(a) Explain what is meant by a photon.

(2)

.....

.....

.....

(b) Calculate the frequency of the photons produced as the neon atoms drop from level E_3 to level E_2.

(3)

.....

.....

.....

.....

Frequency = ...

(c) An electron in level E_3 of neon has 0.05 eV more energy than an electron in level E_2 of helium.

Suggest the source of the energy to make up this difference.

(1)

.....

.....

(d) The photograph shows a device for making a vertical slit with variable width.



© THORLABS, Inc.

When the slit is fully open a laser beam is shone through it and a single point of light is seen on a screen.

As the slit is reduced in width the point of light becomes a horizontal line that gets longer as the slit gets narrower.

Explain this observation

(3)

.....

.....

.....

.....

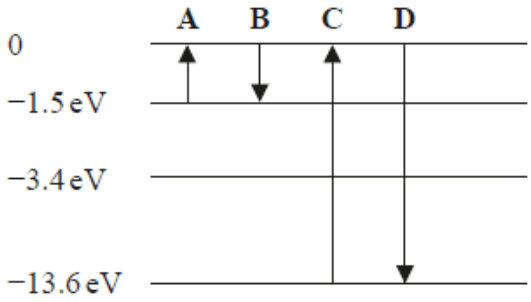
.....

.....

(Total for question = 9 marks)

Q8.

Some of the energy levels of an atom of a gas are shown.



During which transition, A, B, C or D, is electromagnetic radiation with the shortest wavelength emitted?

☒ **A**

☒ **B**

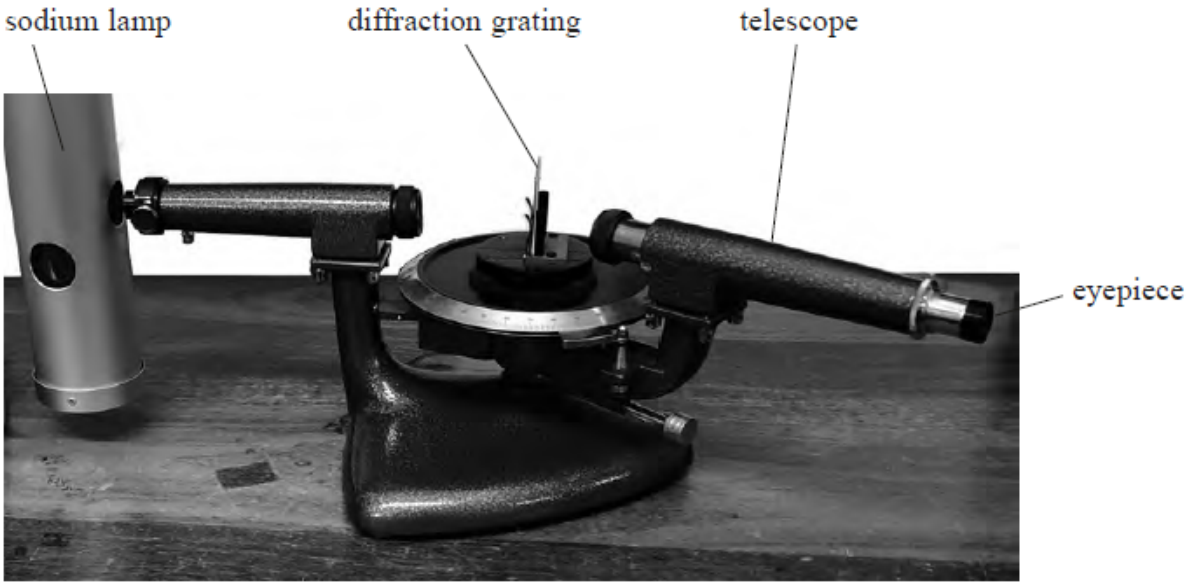
☒ **C**

☒ **D**

(Total for question = 1 mark)

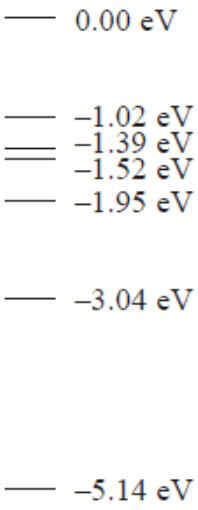
Q9.

The photograph shows a school spectrometer.



The spectrometer allows parallel rays of light to be passed through a diffraction grating and the resulting angles of diffraction to be measured.

The diagram shows some of the energy levels in a sodium atom.



Add an arrow to the diagram to show the transition involved in the emission of yellow light of wavelength 589 nm.

Show your working below.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

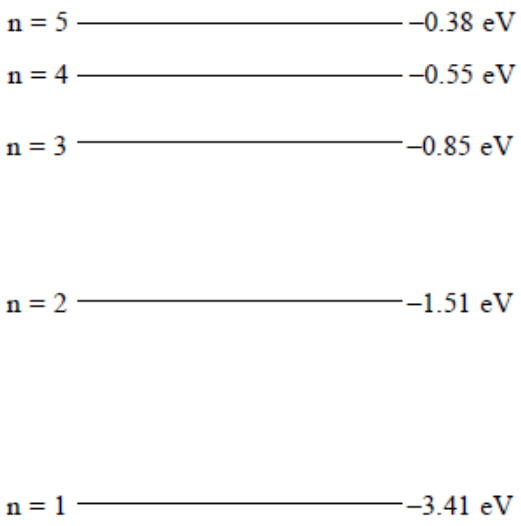
.....

.....

(Total for question = 4 marks)

Q10.

The diagram represents some of the energy levels for an atom.



Calculate the lowest frequency of light that would be absorbed by an electron with energy −0.85 eV in the atom shown.

(3)

.....

.....

.....

.....

.....

.....

.....

Frequency = ...

(Total for question = 3 marks)

Q11.

In the late 1880s it was discovered that a negatively-charged zinc plate loses its charge when exposed to ultraviolet radiation.

Explain why this happens, but only with ultraviolet radiation and not white light. You are expected to complete a calculation to support your answer.

work function of zinc = 6.9×10^{-19} J

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

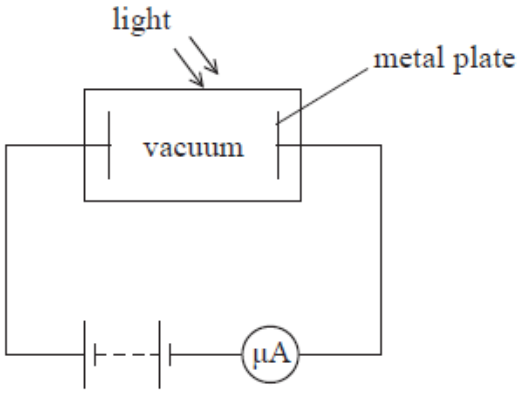
.....

.....

(Total for question = 6 marks)

Q12.

The diagram shows apparatus that can be used to investigate the photoelectric effect.



Light is shone onto the metal plate.

For a particular metal there will only be a current for frequencies of light greater than 8.17×10^{14} Hz.

* Explain how this observation supports the particle theory of light rather than the wave theory.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

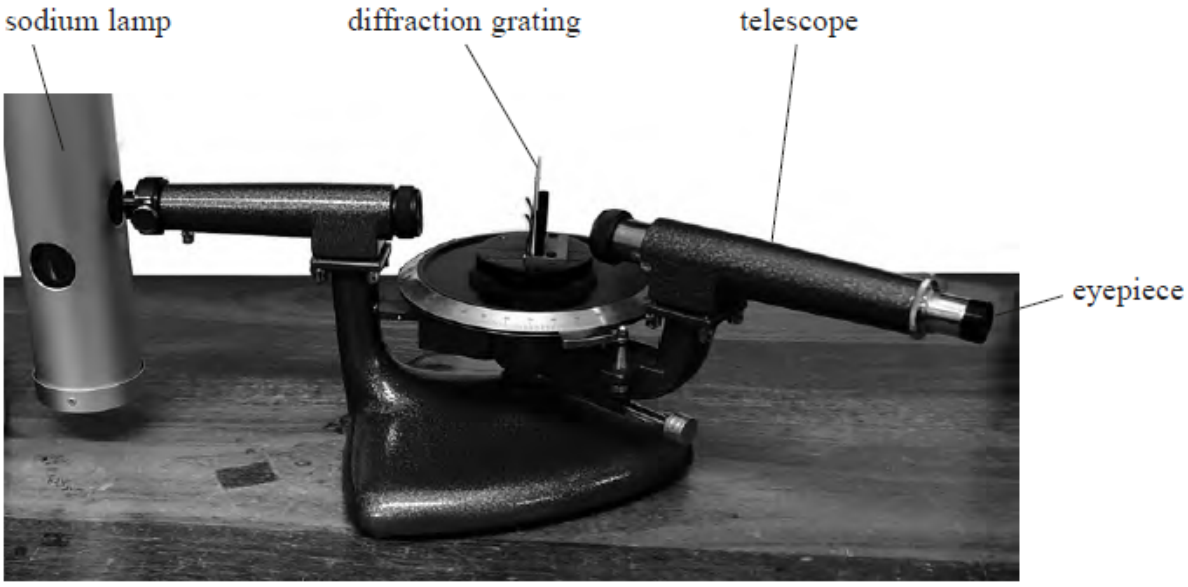
.....

.....

.....

Q13.

The photograph shows a school spectrometer.



The spectrometer allows parallel rays of light to be passed through a diffraction grating and the resulting angles of diffraction to be measured.

The spectrometer and diffraction grating are used to analyse the light from a sodium lamp. In the sodium lamp, sodium is heated until it becomes a vapour and an electric current is passed through it. The vapour then emits light.

After the light passes through the diffraction grating a line spectrum is observed.

(i) Explain why only certain wavelengths are observed.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(ii) Diffraction gratings with the following spacings are available:

$d / 10^{-6}$ m	1.0	1.7	2.0	3.3

Explain which would be the best spacing to use to measure the diffraction angle for the third order maximum for yellow light of wavelength 589 nm.

(3)

.....

.....

.....

.....

.....

.....

(Total for question = 9 marks)

Q14.

In 2010, Andre Geim and Konstantin Novoselov were awarded the Nobel Prize in Physics for producing, identifying and studying graphene.

Graphene is a form of carbon which exists only as a single atomic layer of graphite. It has a breaking stress of 130 GPa compared to 0.5 GPa for steel. Some scientists claim that graphene is the strongest material ever measured.

(a) Explain why graphene, despite its greater strength, is unlikely to replace steel in many applications.

(2)

.....

.....

.....

.....

.....

.....

.....

.....

(b) Graphite used in pencils consists of many layers of carbon. It can be assumed that a pencil deposits approximately 100 layers of carbon atoms when drawn across a piece of paper.

A student carried out an experiment to determine the resistivity of the graphite in a pencil.

A line of length 0.200m and width 0.50mm was drawn on a piece of paper. An ohmmeter was then used to measure the resistance of the graphite line.



Calculate the resistivity of graphite.

resistance = $1.029 \times 10^{6}\ \Omega$
diameter of carbon atom = 1.4×10^{-10} m

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Resistivity of graphite = ...

(c) Photocells traditionally use silicon to generate electricity using visible light. Research demonstrates that unlike silicon, graphene is able to respond at all wavelengths and releases multiple electrons as it absorbs one photon.

Deduce why it would be an advantage to use graphene in photocells to generate electricity.

(3)

.....

.....

.....

.....

.....

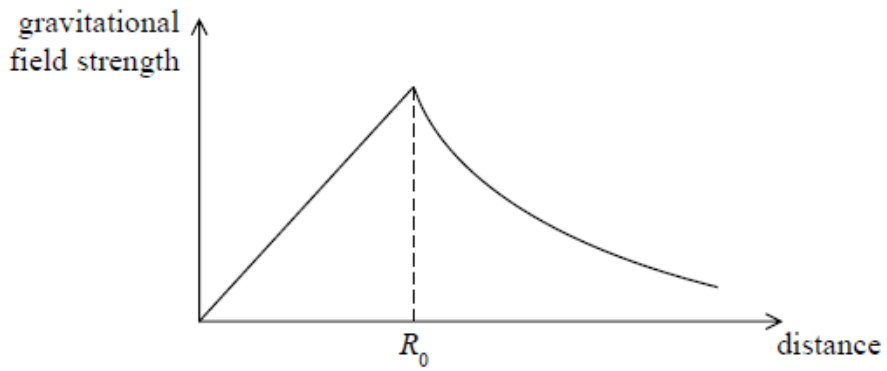
.....

.....

(Total for question = 9 marks)

Q15.

The graph shows the variation of the gravitational field strength with distance from the centre of the Earth. R_0 is the radius of the Earth.



A scientist suggests that the period of oscillation for a body dropped through the tunnel would be the same as the orbital period for a body orbiting just above the surface of the Earth. Its radius

of orbit is assumed to be R_0.

(i) Derive an expression for the period of oscillation of the body dropped through the tunnel.

(4)

.....

.....

.....

.....

.....

.....

(ii) Derive an expression for the orbital period for a body that is orbiting the Earth with radius R_0.

(3)

.....

.....

.....

.....

.....

.....

(Total for question = 7 marks)

Q16.

A student has been learning about the photoelectric effect.

This experiment demonstrates the particle nature of light.

Explain what is meant by the particle nature of light.

(2)

.....

.....

.....

.....

.....

(Total for question = 2 marks)

Q17.

Pions (π^+, π^-, π^0) are created in the upper atmosphere when cosmic rays collide with protons. Pions are unstable and decay rapidly.

(a) Pions are the lightest of the hadrons. Charged pions (π^+ and π^-) decay to produce muons which then decay to positrons or electrons.

(i) A positive pion π^+ has a quark composition $u\bar{d}$.

State with a justification the possible quark compositions of a neutral pion π^0.

(2)

.....

.....

.....

(ii) Muons are examples of leptons whereas pions are examples of mesons.
State a structural difference between leptons and mesons.

(1)

.....

.....

(b) Muons with a speed of 0.99*c* travel a distance of 15 km to reach the surface of the Earth from the upper atmosphere.

(i) Show that the time it takes a muon to travel this distance is about 51 μs.

(2)

.....

.....

.....

(ii) The muons are unstable particles.
Calculate the fraction of muons which would remain after a time of 51 μs.

half-life of muon = 2.2 μs

(4)

.....

.....

.....

.....

.....

.....

.....

.....

Fraction = ...

(iii) In fact the fraction of muons reaching the surface of the Earth is about 0.1 Explain the discrepancy.

(4)

.....

.....

.....

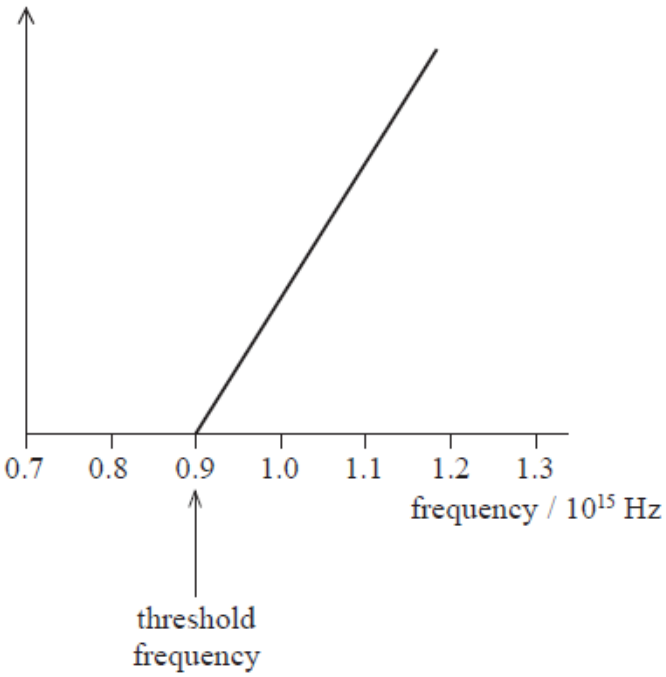
.....

.....

(Total for question = 11 marks)

Q18.

The graph shows the results for an experiment to demonstrate the photoelectric effect by illuminating a clean metal sheet with light of increasing frequency.



(a) State a quantity, and its unit, which could have been plotted on the Y-axis to produce this graph.

(2)

.....

.....

(b) The threshold frequency is shown on the graph.

Explain why there is a threshold frequency.

(4)

.....

.....

.....

.....

.....

.....

.....

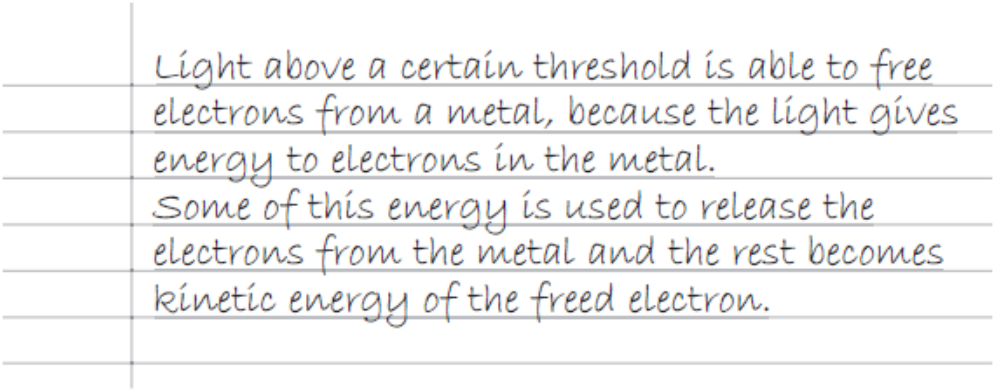
.....

(Total for question = 6 marks)

Q19.

A student has been learning about the photoelectric effect.

The student was asked by his teacher to explain the photoelectric effect. He gave the following explanation:



Discuss whether the student's answer fully explains the photoelectric effect.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

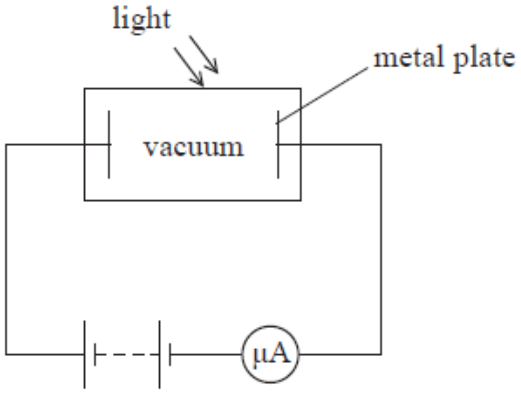
.....

.....

(Total for question = 4 marks)

Q20.

The diagram shows apparatus that can be used to investigate the photoelectric effect.



Light is shone onto the metal plate.

For a particular metal there will only be a current for frequencies of light greater than 8.17×10^{14} Hz.

If the applied potential difference is reversed and increased, the current will decrease and at a certain value of potential difference the current will be zero.

Calculate this potential difference when the frequency of the incident light is 9.62×10^{14} Hz.

(4)

.....

.....

.....

.....

.....

.....

.....

Potential difference = ...

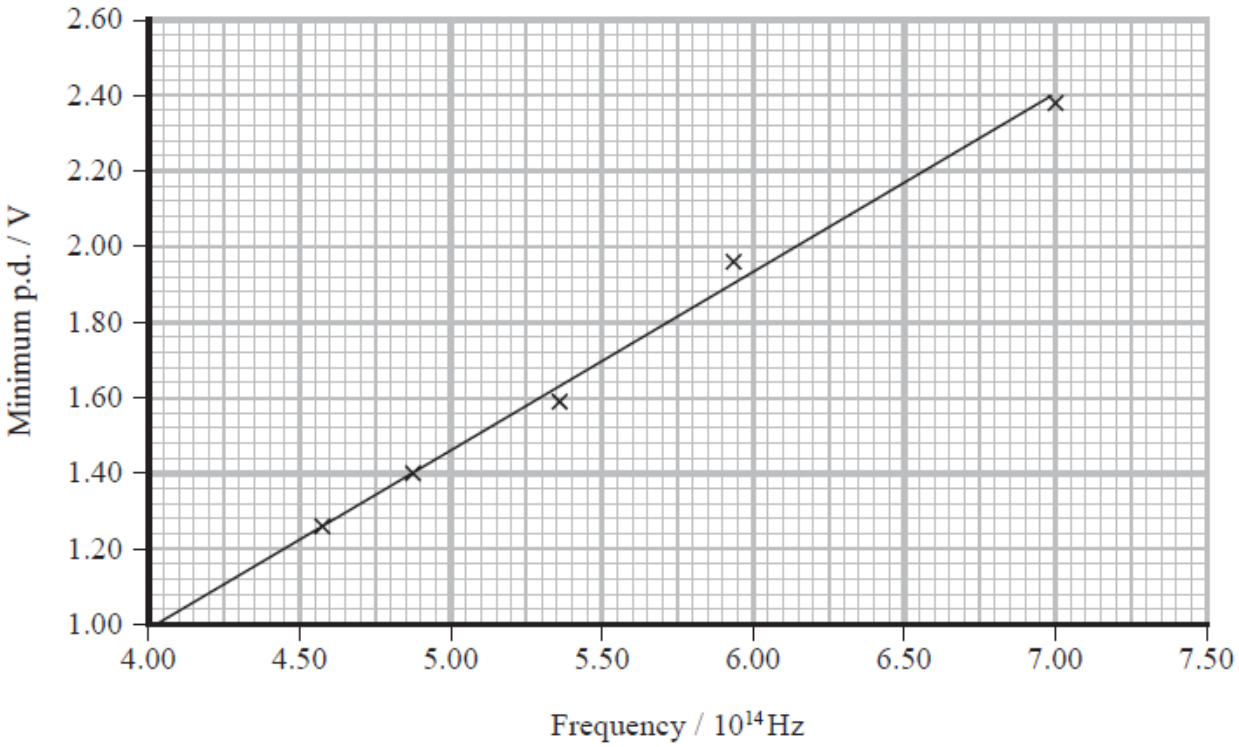
Q21.

The Planck constant can be determined in a school laboratory using light emitting diodes (LEDs).

An LED emits light when the potential difference (p.d.) across it is large enough to transfer sufficient energy to an electron to result in the emission of a photon.
The electron must have energy greater than or equal to the photon energy.

The minimum p.d. required to produce light from LEDs emitting different frequencies was measured by increasing the p.d. from zero until light was first seen.

The graph shows the results.



Determine the value of the Planck constant given by this graph.

(4)

.....

.....

.....

.....

.....

.....

.....

Value of Planck constant given by graph = ...

(Total for question = 4 marks)

Q22.

(a) Solar sails are a form of propulsion for spacecraft. The sail is made of a thin sheet of reflective material. When photons of light from the Sun reflect from the material a force is exerted on the sail. The photons reflect with a momentum equal to their initial momentum but in the opposite direction.

(i) Show that a single photon of frequency 1.5×10^{15} Hz has a momentum of about 3×10^{-27} N s.

(2)

.....

.....

.....

.....

(ii) Hence determine the momentum transferred to the solar sail by this photon.

(1)

.....

Momentum transferred = ...

(b) An alternative method of producing a momentum change is being investigated. Researchers have suggested that 'larger changes in momentum could be produced by directing laser light at graphene oxide'. Electrons are emitted from the graphene oxide surface, resulting in a force being exerted on the graphene oxide in the opposite direction.

A researcher has suggested that one possible mechanism for the emission of the electrons is the photoelectric effect.

(i) Show that the maximum velocity for a photoelectron emitted after absorption of a photon of light of frequency 1.5×10^{15} Hz is about 8×10^{5} m s^{-1}.

work function of graphene oxide = 6.7×10^{-19} J

(3)

.....

.....

.....

.....

.....

.....

(ii) Hence calculate the momentum of the photoelectron.

(2)

.....

.....

.....

Momentum of photoelectron = ...

(c) Explain whether the suggestion in (b) that 'larger changes in momentum could be produced by directing laser light at graphene oxide' is true.

(2)

.....

.....

.....

.....

.....

.....

(Total for question = 10 marks)

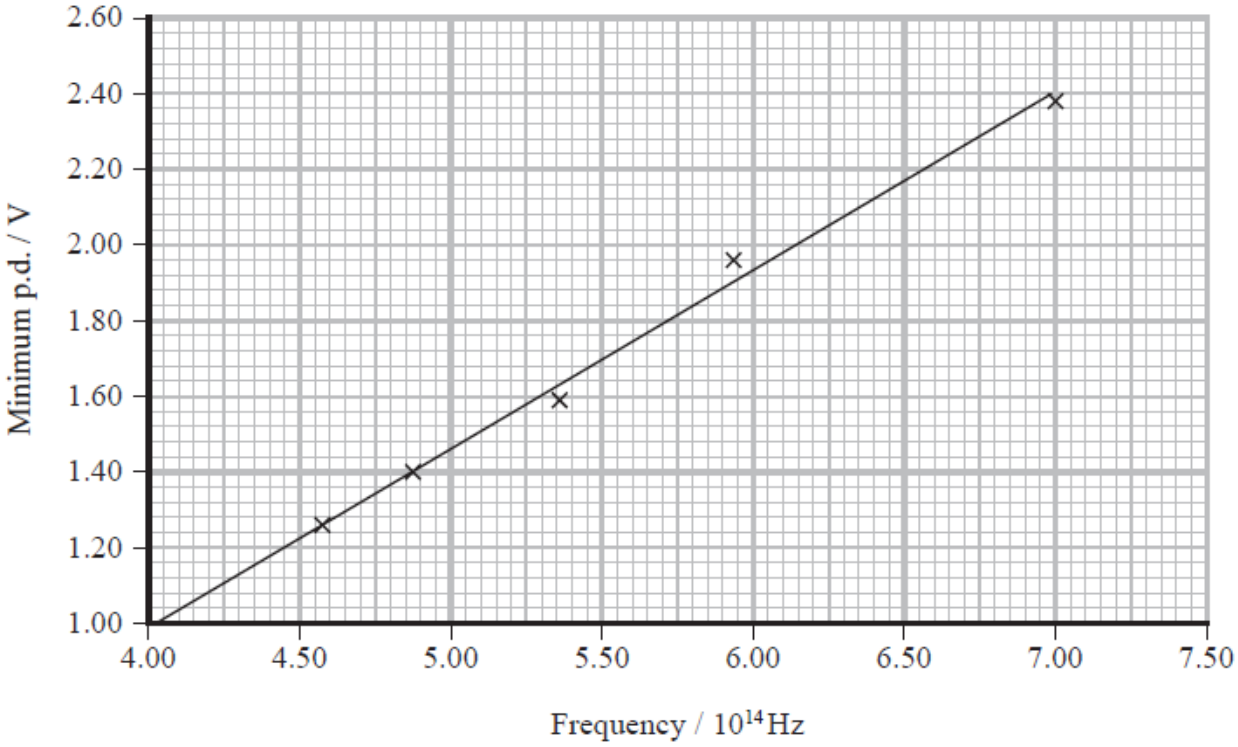
Q23.

The Planck constant can be determined in a school laboratory using light emitting diodes (LEDs).

An LED emits light when the potential difference (p.d.) across it is large enough to transfer sufficient energy to an electron to result in the emission of a photon.
The electron must have energy greater than or equal to the photon energy.

The minimum p.d. required to produce light from LEDs emitting different frequencies was measured by increasing the p.d. from zero until light was first seen.

The graph shows the results.



There are two problems with using LEDs to determine the Planck constant:

- when the p.d. is increased and the LED first emits light it is difficult to see
- the LEDs do not emit a single frequency but also light of frequencies slightly above and below the recorded frequency.

Discuss the extent to which these problems are consistent with obtaining a result from this graph for the Planck constant which is higher than the accepted value.

(3)

.....

.....

.....

.....

.....

.....

.....

(Total for question = 3 marks)

Q24.

In 1925 Franck and Hertz were awarded the Nobel Prize in Physics "for their discovery of the laws governing the impact of an electron upon an atom".
In one of their experiments, a beam of high-speed electrons is fired through mercury vapour.

An electron in the beam collides with a mercury atom, which becomes excited. The atom returns to its initial state by emitting electromagnetic radiation of a single frequency.

An electron travelling with a speed of 2.5×10^6 m s^{-1} collides with a stationary mercury atom and continues at a speed of 2.1×10^6 m s^{-1}.

The table gives a range of wavelengths for ultraviolet, visible and infrared radiation.

Type of radiation	Typical range of wavelengths / m
ultraviolet	2.0×10^{-7} to 4.0×10^{-7}
visible	4.0×10^{-7} to 7.8×10^{-7}
infrared	7.8×10^{-7} to 1.0×10^{-3}

Deduce the type of radiation that is emitted by the stationary mercury atom.

(4)

.....

.....

.....

.....

.....

.....

.....

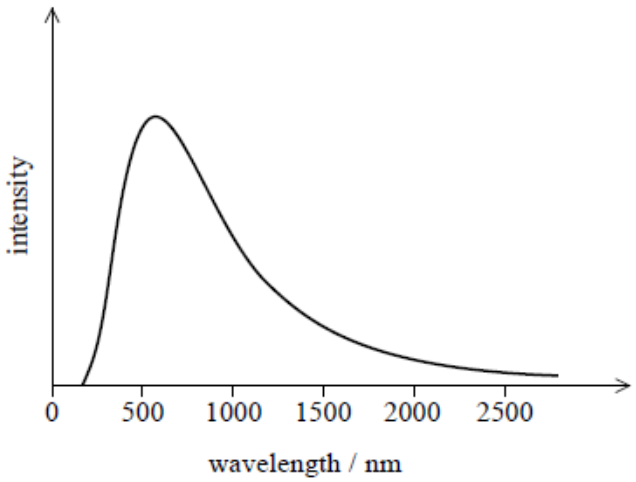
.....

Type of radiation .....

(Total for question = 4 marks)

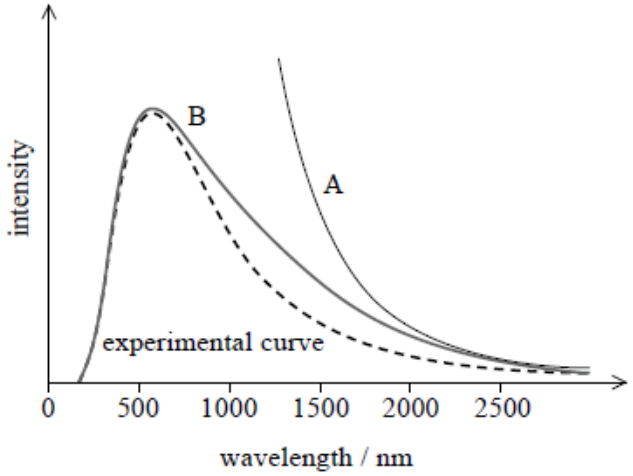
Q25.

The diagram shows the radiation curve for a black body radiator. The diagram was obtained from experimental data.



Experimental curve

In the late 19th century, scientists struggled to explain this experimental curve. One model used ideas of classical physics and produced curve A. Another model incorporated the idea of energy quantisation in the mechanism of energy emission and produced curve B. Both curve A and curve B are shown below, with the experimental curve for comparison.



(i) Explain how energy quantisation applies to the emission of radiation of energy from a black body radiator.

(2)

.....

.....

.....

.....

(ii) Assess the extent to which each model is successful at explaining the experimental curve.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q1.

Read the passage and answer the question below.



© Reuters

The Solar Impulse 2 is a solar-powered plane that completed a round the world trip in 2016 without using fossil fuels.
The wings are covered in thin solar panels, keeping the total mass of the plane and pilot at 1600 kg. The need to reduce the weight limits the efficiency of the solar panels to 23%. However, in daylight, these panels generate enough energy to run the four 7.5 kW electric motors that keep the plane airborne and to fully charge the batteries that power the plane during the night. The batteries take about 6 hours to fully charge.
In daylight the plane flies at a height of 8500 m to harness the most sunlight, and at night descends to 1500 m. This descent makes use of the gravitational potential energy gained during the day to help the plane get through the night.
(Source: www.solarimpulse.com)

The solar panels consist of a series of photocells connected to an external circuit that includes the batteries. When light strikes the photocells, electrons gain energy and are able to move through the external circuit so that the batteries charge up.

Explain why the batteries charge more quickly in high intensity light.

(4)

.....

.....

.....

.....

.....

.....

.....

(Total for question = 4 marks)

Q2.

A coulombmeter is used to measure charge.



In a laboratory demonstration of the photoelectric effect, a sheet of zinc was placed on top of a coulombmeter and the zinc was given a negative charge.

* The following observations were made:

- under normal lighting conditions the charge remained constant
- when the zinc was illuminated with ultraviolet light, the magnitude of the charge on the zinc decreased as time passed
- when a larger sheet of zinc was used the charge on the zinc decreased more rapidly.

In each case the initial charge on the zinc was the same.

Explain these observations.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q3.

When electromagnetic radiation is incident on a metal plate, electrons may be emitted.

(a) State what is meant by threshold frequency.

(1)

.....

.....

(b) Calculate the threshold frequency for a metal with a work function of 2.28 eV.

(3)

.....

.....

.....

.....

.....

.....

Threshold frequency = ...

(Total for question = 4 marks)

Q4.

The photoelectric effect was discovered by Hertz who investigated the effect of ultraviolet radiation incident upon the surface of zinc. The effect was found to depend on the frequency of the radiation.

(a) State what is meant by threshold frequency.

(1)

.....

.....

.....

(b) Light of frequency 8.9×10^{14} Hz is incident upon the surface of a different metal. The photoelectrons have a maximum speed of 6.7×10^{5} m s^{-1}.

Calculate the work function of the metal in eV.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

Work function = ... eV

(Total for question = 5 marks)

Q5.

In the late 1880s it was discovered that a negatively-charged zinc plate loses its charge when exposed to ultraviolet radiation.

Explain why this happens, but only with ultraviolet radiation and not white light. You are expected to complete a calculation to support your answer.

work function of zinc = 6.9×10^{-19} J

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q6.

A simple model of the hydrogen atom consists of an electron moving in a circular path around a proton.

(i) In this simple model it is the electrostatic force, rather than the gravitational force, that is responsible for keeping the electron in a circular path.

By means of calculations justify this statement.

radius r of the hydrogen atom = 5.3×10^{-11} m

(4)

.....

.....

.....

.....

.....

(ii) Ignoring the gravitational force, calculate the velocity of the electron in this simple model of the hydrogen atom.

(3)

.....

.....

.....

.....

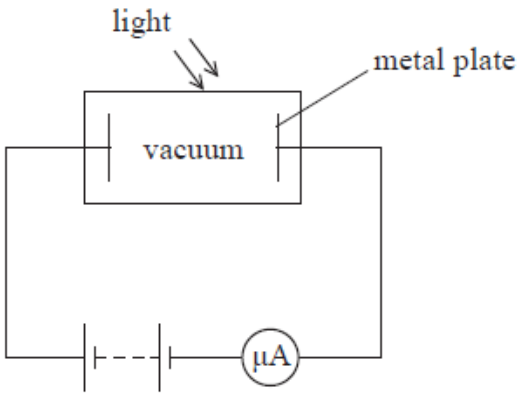
.....

Velocity = ...

(Total for question = 7 marks)

Q7.

The diagram shows apparatus that can be used to investigate the photoelectric effect.



Light is shone onto the metal plate.

For a particular metal there will only be a current for frequencies of light greater than 8.17×10^{14} Hz.

* Explain how this observation supports the particle theory of light rather than the wave theory.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Q8. Dolphins use ultrasound when hunting prey. They emit short pulses of ultrasound, known as clicks, and detect the ultrasound reflected from their prey.

(a) Describe how ultrasound travels through water.

(2)

.....

.....

.....

.....

(b) Suggest why the dolphins emit a series of clicks rather than a continuous sound.

(1)

.....

.....

.....

.....

(c) When searching for prey the dolphins emit 16 clicks per second.

(i) Show that the time between clicks when searching for prey is about 0.06 s.

(1)

.....

.....

(ii) Calculate the maximum distance that can be determined by the dolphin when searching for prey.

speed of sound in seawater = 1530 m s^{-1}

(3)

.....

.....

.....

.....

.....

.....

Maximum distance = ...

(iii) The dolphin increases the number of clicks per second to 125 when near to capturing its prey.

Suggest why.

(1)

.....

.....

(d) Bats use ultrasound in air when hunting prey. The ultrasound frequency and the duration of the click is the same for both bats and dolphins.

Explain whether bats or dolphins would be able to locate their prey more precisely.

speed of sound in air = 330 m s^{-1}

(3)

.....

.....

.....

.....

.....

.....

(Total for Question = 11 marks)

Q9.

In 2010, Andre Geim and Konstantin Novoselov were awarded the Nobel Prize in Physics for producing, identifying and studying graphene.

Graphene is a form of carbon which exists only as a single atomic layer of graphite. It has a breaking stress of 130 GPa compared to 0.5 GPa for steel. Some scientists claim that graphene is the strongest material ever measured.

(a) Explain why graphene, despite its greater strength, is unlikely to replace steel in many applications.

(2)

.....

.....

.....

.....

.....

.....

.....

.....

(b) Graphite used in pencils consists of many layers of carbon. It can be assumed that a pencil deposits approximately 100 layers of carbon atoms when drawn across a piece of paper.

A student carried out an experiment to determine the resistivity of the graphite in a pencil.

A line of length 0.200m and width 0.50mm was drawn on a piece of paper. An ohmmeter was then used to measure the resistance of the graphite line.



Calculate the resistivity of graphite.

resistance = $1.029 \times 10^{6}\ \Omega$
diameter of carbon atom = 1.4×10^{-10} m

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Resistivity of graphite = ...

(c) Photocells traditionally use silicon to generate electricity using visible light. Research demonstrates that unlike silicon, graphene is able to respond at all wavelengths and releases multiple electrons as it absorbs one photon.

Deduce why it would be an advantage to use graphene in photocells to generate electricity.

(3)

.....

.....

.....

.....

.....

.....

.....

(Total for question = 9 marks)

Q10.

Read the extract and answer the question that follows.

In the 17th century there were two proposed theories to explain the refraction of light. Using a wave model, Huygens stated that light slows down when it passes from air to water. Using a particle model, Newton stated that light speeds up when it passes from air to water. Newton's theory was more readily accepted until the speed of light in water was measured in the 19th century.

In the early 20th century, Einstein used observations from the photoelectric effect to provide evidence for the particle model of light.

Nowadays, both the wave model of light and the particle model of light are accepted, as each can be used to explain different aspects of the behaviour of light.

In a demonstration of the photoelectric effect, electromagnetic radiation is shone onto a clean metal surface. It can be shown that the metal loses negative charge when the radiation has a frequency above a certain threshold frequency.

Explain how the particle model of light is consistent with this observation.

(3)

.....

.....

.....

.....

.....

.....

(Total for question = 3 marks)

Q11.

When light is incident on the surface of a metal, electrons may be emitted by the photoelectric effect. Observations of the photoelectric effect helped to establish that light can exhibit particle behaviour.

Which of the following observations of the photoelectric effect could also be explained by light behaving as a wave?

☒ **A** Emission of photoelectrons occurs immediately the surface is illuminated.

☒ **B** Photoelectrons are only emitted when the frequency of the light is more than a certain minimum value.

☒ **C** The maximum kinetic energy of the photoelectrons is independent of the intensity of the incident light.

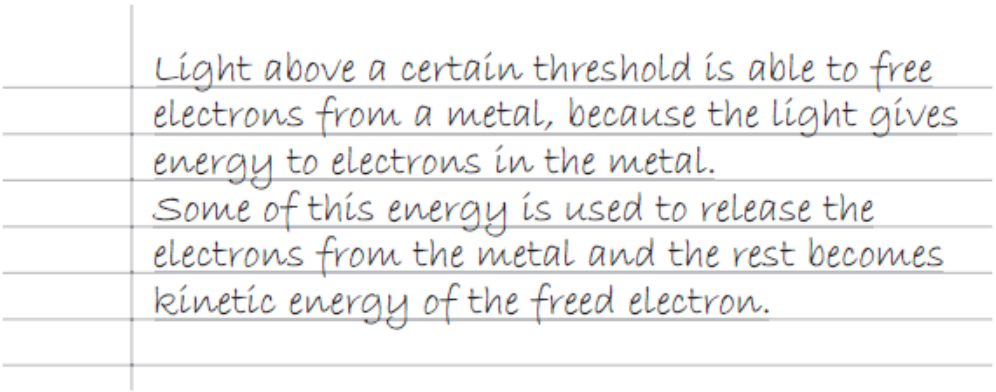
☒ **D** When the intensity of the incident light increases, photoelectrons are emitted at a greater rate.

(Total for question = 1 mark)

Q12.

A student has been learning about the photoelectric effect.

The student was asked by his teacher to explain the photoelectric effect. He gave the following explanation:



Discuss whether the student's answer fully explains the photoelectric effect.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

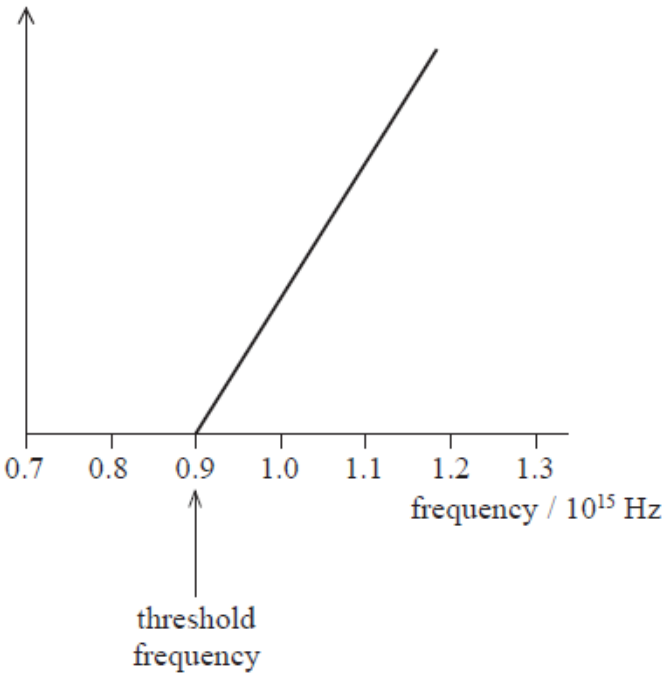
.....

.....

(Total for question = 4 marks)

Q13.

The graph shows the results for an experiment to demonstrate the photoelectric effect by illuminating a clean metal sheet with light of increasing frequency.



(a) State a quantity, and its unit, which could have been plotted on the Y-axis to produce this graph.

(2)

.....

.....

(b) The threshold frequency is shown on the graph.

Explain why there is a threshold frequency.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q14.

*****In 1905 Einstein published his equation for the photoelectric effect.

In 1916 Millikan demonstrated that the maximum kinetic energy of photoelectrons is consistent with Einstein's equation.

Discuss the extent to which our current understanding of observations of the photoelectric effect supports the idea that light behaves as photons rather than as waves.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q15.

A solar panel uses electromagnetic radiation from the Sun to generate electricity.
In one installation a sensor in the solar panel measures the intensity of radiation arriving from different directions. A motor rotates the solar panel so that it always faces the brightest part of the sky.

When light is incident on an LDR, electrons move to a higher energy level where they become conduction electrons. This causes the resistance of the LDR to decrease.

A student suggests that this is an example of the photoelectric effect. The student is not correct.

Compare and contrast the photoelectric effect with the effect of radiation incident on an LDR.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

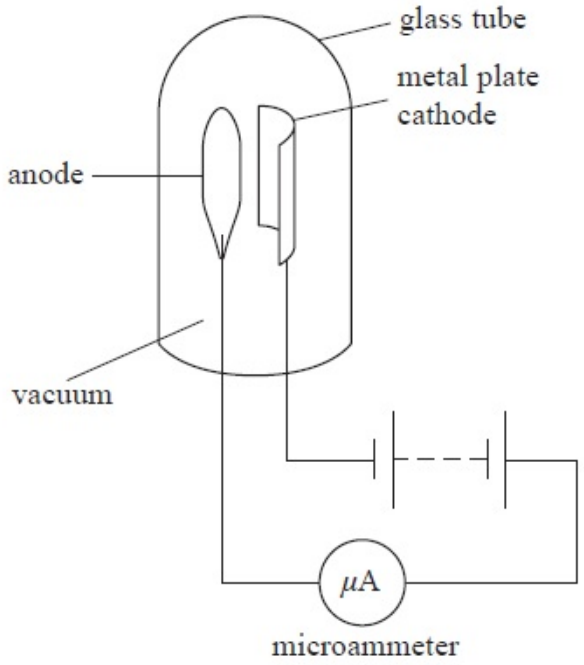
.....

.....

.....

(Total for question = 6 marks)

Q16. Phototubes are devices which make use of the photoelectric effect to detect light above a specific frequency.



(a) Explain why

- no current flows when the phototube is in darkness
- current flows in the circuit when the phototube is illuminated by light above a specific frequency.

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(b) Make an appropriate calculation to explain why caesium is used as the cathode for visible light but zinc is not.

work function of zinc = 3.63 eV

work function of caesium = 2.14 eV

(4)

.....

.....

.....

.....

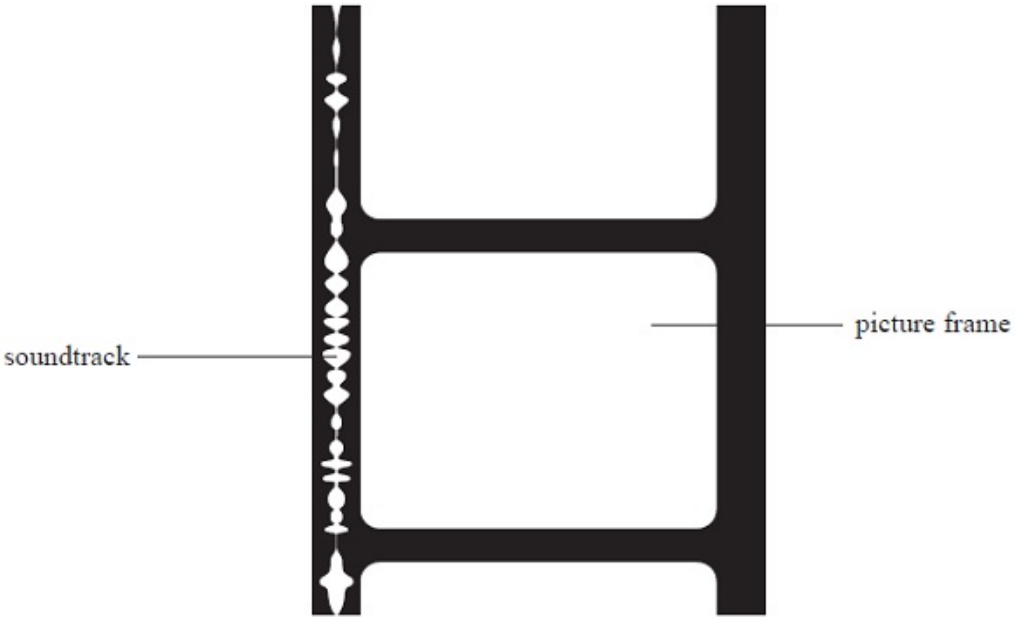
.....

.....

.....

.....

(c) Before digital technology was used, the films used at the cinema had an optical soundtrack next to the picture frames.



The film, including the soundtrack as shown, moves through a projector past a source of light. Light is detected by a phototube on the other side of the soundtrack. The changing current produced by the phototube circuit is converted to a sound signal with the same variation in amplitude and frequency as the original sound.

(i) State what is meant by amplitude.

(1)

.....

.....

(ii) Explain how the changing pattern of the soundtrack produces a changing current in the

phototube circuit.

(3)

.....

.....

.....

.....

.....

.....

.....

.....

(Total for Question = 13 marks)

Q17.

(a) Solar sails are a form of propulsion for spacecraft. The sail is made of a thin sheet of reflective material. When photons of light from the Sun reflect from the material a force is exerted on the sail. The photons reflect with a momentum equal to their initial momentum but in the opposite direction.

(i) Show that a single photon of frequency 1.5×10^{15} Hz has a momentum of about 3×10^{-27} N s.

(2)

.....

.....

.....

.....

(ii) Hence determine the momentum transferred to the solar sail by this photon.

(1)

.....

Momentum transferred = ...

(b) An alternative method of producing a momentum change is being investigated. Researchers have suggested that 'larger changes in momentum could be produced by directing laser light at graphene oxide'. Electrons are emitted from the graphene oxide surface, resulting in a force

being exerted on the graphene oxide in the opposite direction.

A researcher has suggested that one possible mechanism for the emission of the electrons is the photoelectric effect.

(i) Show that the maximum velocity for a photoelectron emitted after absorption of a photon of light of frequency 1.5×10^{15} Hz is about 8×10^{5} m s^{-1}.

work function of graphene oxide = 6.7×10^{-19} J

(3)

.....

.....

.....

.....

.....

.....

(ii) Hence calculate the momentum of the photoelectron.

(2)

.....

.....

.....

Momentum of photoelectron = ...

(c) Explain whether the suggestion in (b) that 'larger changes in momentum could be produced by directing laser light at graphene oxide' is true.

(2)

.....

.....

.....

.....

.....

.....

(Total for question = 10 marks)

Q18. When the photoelectric effect was first observed in the nineteenth century, scientists could not explain it using the wave theory of light.

In 1905 Albert Einstein published a paper, for which he won a Nobel Prize, explaining the photoelectric effect by using a photon model of light, rather than a wave model.

(a) Explain what is meant by a photon.

(2)

.....

.....

.....

.....

*(b) Explain why the following observations may be understood by using a photon model of light, rather than a wave model.

- Light above a certain frequency causes the emission of electrons from the surface of a metal. This emission occurs instantaneously.
- Light below a certain frequency will not result in the emission of electrons however long it illuminates the surface.

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(c) Zinc has a work function of 4.3 eV.

(i) Calculate the threshold frequency for zinc.

(3)

.....

.....

.....

.....

.....

Threshold frequency = ...

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

(1)

.....

(Total for Question = 11 marks)

Q19.

Read the following extract and then answer the questions that follow.

Powdery dust, the by-product of fearsome meteor storms that pounded the Moon, coats much of the lunar surface. A build-up of this dust could damage sensitive machinery.

Scientists theorise that lunar dust must be electrostatically charged by ultraviolet solar radiation from the Sun. When ultraviolet radiation hits the Moon's "day side", the half that faces the Sun, it knocks electrons out of atoms in the lunar soil.

(a) Describe the particle model of ultraviolet radiation that explains how it can "knock electrons out of atoms".

(3)

.....

.....

.....

.....

.....

.....

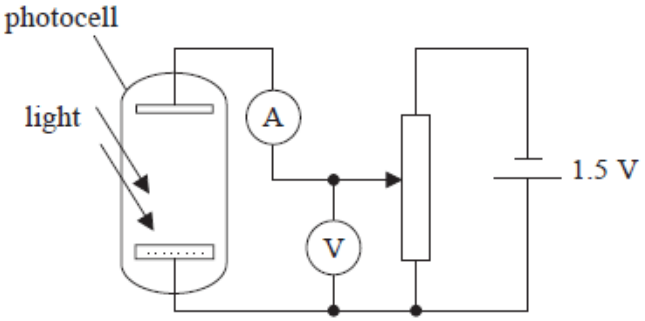
.....

.....

.....

(b) A teacher uses the arrangement below to demonstrate that electrons can be knocked out of a metal surface in a photocell by visible light.

The arrangement can also be used to measure the maximum kinetic energy of these electrons.



(i) Explain how the potential divider circuit can produce a range of values from 0 to 1.5 V on the voltmeter.

(3)

.....

.....

.....

.....

.....

.....

.....

.....

.....

(ii) The potential difference on the voltmeter is increased until the ammeter reading is zero.

The voltmeter reads 0.6 V at this instant.
State the maximum kinetic energy of the electrons in eV.

(1)

Maximum kinetic energy = ... eV

(c) Discuss whether the photocell arrangement in part (b) gives a valid demonstration of how dust particles become charged on the Moon.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 11 marks)

Q20.

* The behaviour of electromagnetic radiation can be described in terms of a photon model or a wave model.

In the photoelectric effect, electromagnetic radiation is incident on a metal plate and under certain conditions electrons are emitted.

It is observed that, for a given metal,

- no electrons are emitted if the frequency of the incident radiation is below a certain threshold frequency.
- electrons are emitted instantaneously if the frequency of the incident radiation is above a certain threshold frequency.
- the kinetic energy of the emitted electrons depends only on the frequency of the incident radiation.

Discuss how the photon model of electromagnetic radiation can explain these observations and why the wave model of electromagnetic radiation cannot.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

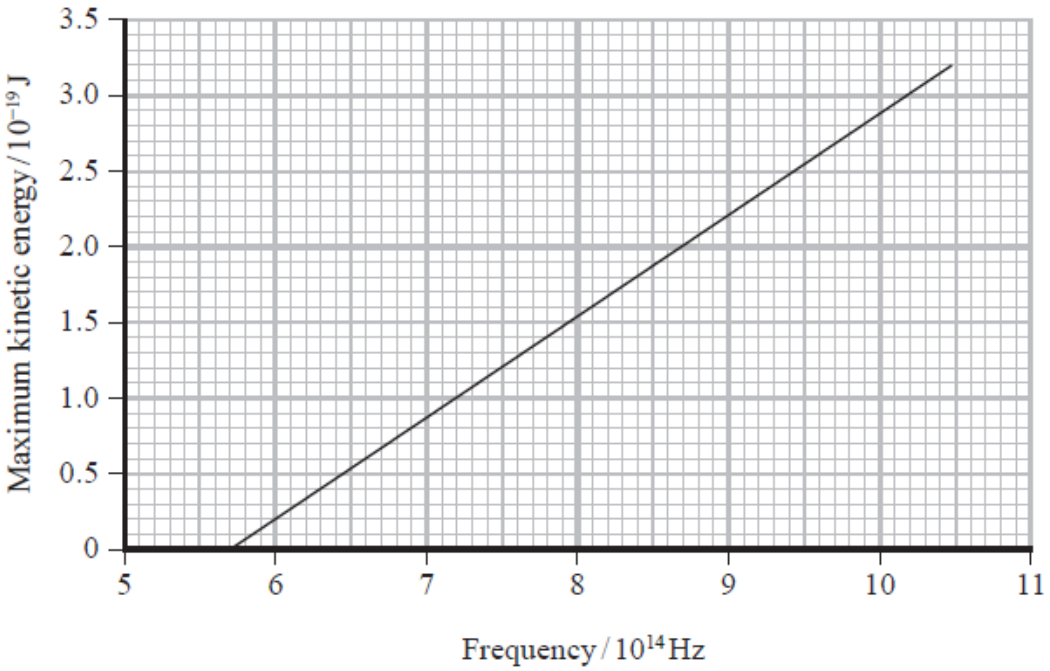
Q1.

In 1905 Einstein published his equation for the photoelectric effect.

In 1916 Millikan demonstrated that the maximum kinetic energy of photoelectrons is consistent with Einstein's equation.

Millikan used his data to obtain a value of the Planck constant.

The following graph of maximum kinetic energy of photoelectrons against frequency was produced from his data for the photoelectric effect using lithium.



Millikan suggested that the uncertainty from his results for lithium was as little as 1%.

Determine whether the value of the Planck constant obtained from this graph is within 1% of the value stated on the data sheet for this examination paper.

(3)

.....

.....

.....

.....

.....

.....

.....

.....

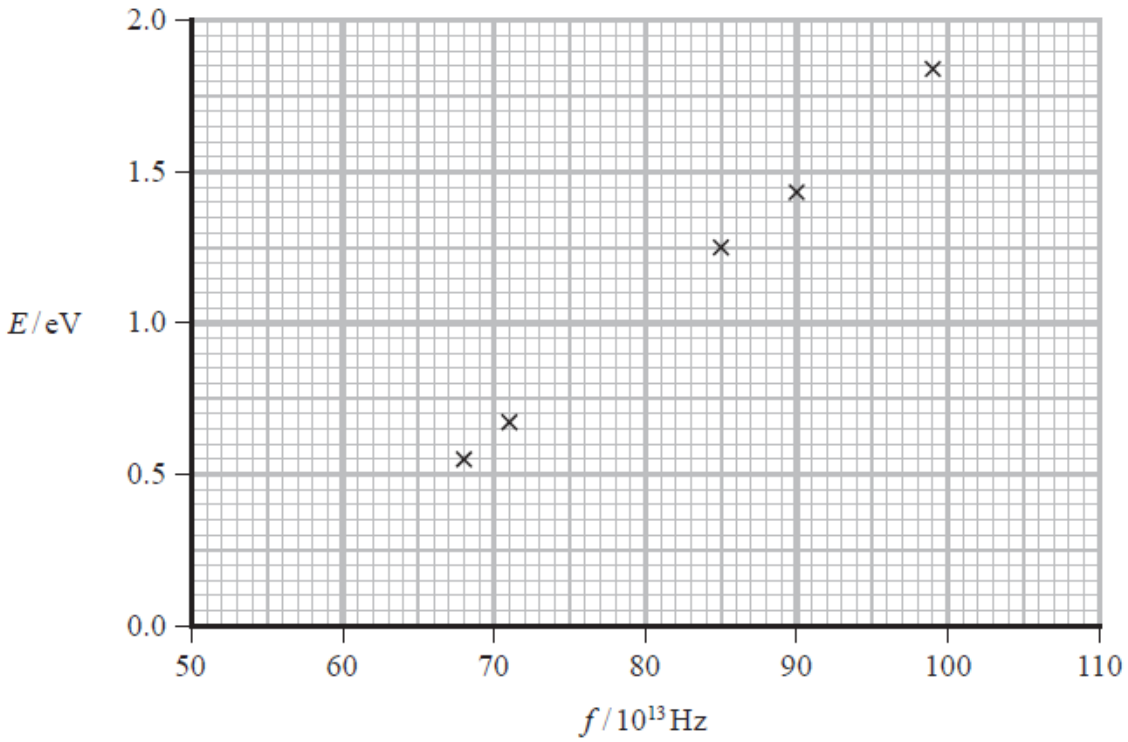
.....

(Total for question = 3 marks)

Q2.

In an investigation of the photoelectric effect, electromagnetic radiation of frequency *f* was directed onto a metal plate. The maximum kinetic energy *E* of the photoelectrons emitted from the metal plate was determined. The procedure was repeated for a range of frequencies.

The graph shows how *E* depended upon *f*.



Determine a value for the Planck constant, *h*, in J s.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

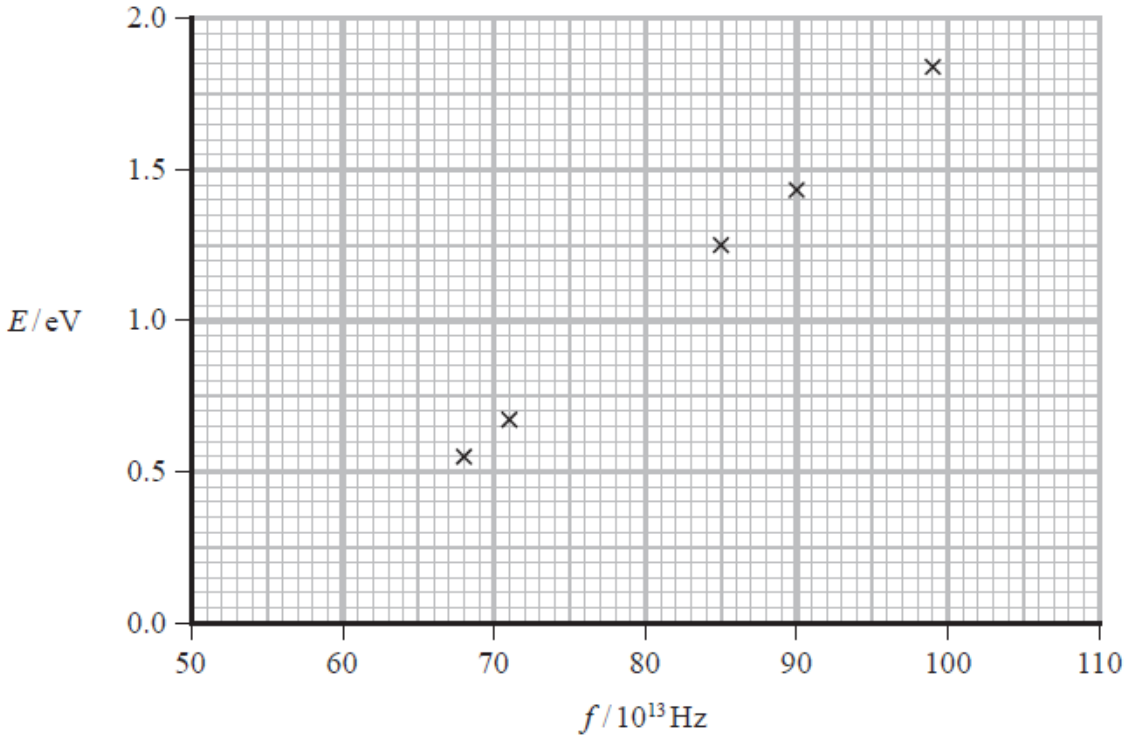
h = ... J s

(Total for question = 4 marks)

Q3.

In an investigation of the photoelectric effect, electromagnetic radiation of frequency f was directed onto a metal plate. The maximum kinetic energy E of the photoelectrons emitted from the metal plate was determined. The procedure was repeated for a range of frequencies.

The graph shows how E depended upon f.



The table gives data for different metal surfaces.

Metal surface	Work function / eV
Caesium	2.0
Calcium	2.9
Magnesium	3.7

Deduce which metal was being used in the investigation.

(3)

.....

.....

.....

.....

.....

.....

.....

(Total for question = 3 marks)

Q4.

A coulombmeter is used to measure charge.



In a laboratory demonstration of the photoelectric effect, a sheet of zinc was placed on top of a coulombmeter and the zinc was given a negative charge.

* The following observations were made:

- under normal lighting conditions the charge remained constant
- when the zinc was illuminated with ultraviolet light, the magnitude of the charge on the zinc decreased as time passed
- when a larger sheet of zinc was used the charge on the zinc decreased more rapidly.

In each case the initial charge on the zinc was the same.

Explain these observations.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q5.

When electromagnetic radiation is incident on a metal plate, electrons may be emitted.

(a) State what is meant by threshold frequency.

(1)

.....

.....

(b) Calculate the threshold frequency for a metal with a work function of 2.28 eV.

(3)

.....

.....

.....

.....

.....

.....

Threshold frequency = ...

(Total for question = 4 marks)

Q6.

The photoelectric effect was discovered by Hertz who investigated the effect of ultraviolet radiation incident upon the surface of zinc. The effect was found to depend on the frequency of the radiation.

(a) State what is meant by threshold frequency.

(1)

.....

.....

.....

(b) Light of frequency 8.9×10^{14} Hz is incident upon the surface of a different metal. The photoelectrons have a maximum speed of 6.7×10^{5} m s^{-1}.

Calculate the work function of the metal in eV.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

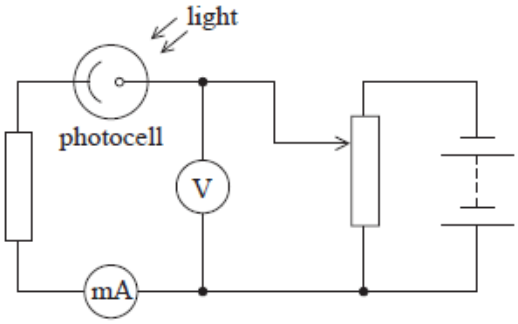
Work function = ... eV

(Total for question = 5 marks)

Q7.

A student has been learning about the photoelectric effect.

The student sets up a circuit to investigate the photoelectric effect.



The student illuminates the photocell with light of known frequency f. A current is produced in the circuit due to the emitted electrons. He adjusts the potential difference, using a potential divider, until the reading on the milliammeter is zero and records the corresponding reading V_s on the voltmeter. He repeats this procedure for other frequencies of light.

When the reading on the milliammeter is zero the maximum kinetic energy of the emitted electrons is given by eV_s.

Explain how the student can use his results to determine a value for the Planck constant h using a graphical method.

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 5 marks)

Q8.

Einstein's photoelectric equation states

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

The quantity denoted by ϕ is the minimum

☒ **A** amount of energy of a photon needed to release an electron.

☒ **B** amount of energy of an electron needed to release a photon.

☒ **C** frequency of a photon needed to release an electron.

☒ **D** frequency of an electron needed to release a photon.

(Total for question = 1 mark)

Q9.

In the late 1880s it was discovered that a negatively-charged zinc plate loses its charge when exposed to ultraviolet radiation.

Explain why this happens, but only with ultraviolet radiation and not white light. You are expected to complete a calculation to support your answer.

work function of zinc = 6.9×10^{-19} J

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

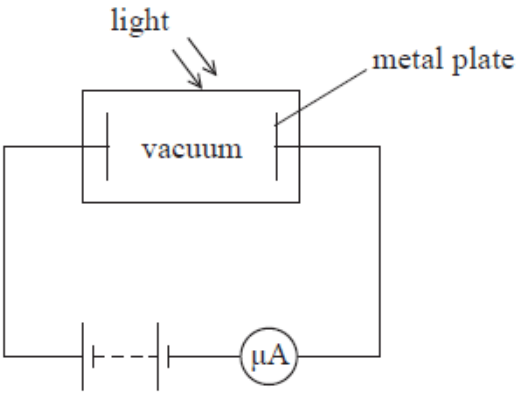
.....

.....

(Total for question = 6 marks)

Q10.

The diagram shows apparatus that can be used to investigate the photoelectric effect.



Light is shone onto the metal plate.

For a particular metal there will only be a current for frequencies of light greater than 8.17×10^{14} Hz.

* Explain how this observation supports the particle theory of light rather than the wave theory.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Q11. Dolphins use ultrasound when hunting prey. They emit short pulses of ultrasound, known as clicks, and detect the ultrasound reflected from their prey.

(a) Describe how ultrasound travels through water.

(2)

.....

.....

.....

.....

(b) Suggest why the dolphins emit a series of clicks rather than a continuous sound.

(1)

.....

.....

.....

.....

(c) When searching for prey the dolphins emit 16 clicks per second.

(i) Show that the time between clicks when searching for prey is about 0.06 s.

(1)

.....

.....

(ii) Calculate the maximum distance that can be determined by the dolphin when searching for prey.

speed of sound in seawater = 1530 m s^{-1}

(3)

.....

.....

.....

.....

.....

.....

Maximum distance = ...

(iii) The dolphin increases the number of clicks per second to 125 when near to capturing its prey.

Suggest why.

(1)

.....

.....

(d) Bats use ultrasound in air when hunting prey. The ultrasound frequency and the duration of the click is the same for both bats and dolphins.

Explain whether bats or dolphins would be able to locate their prey more precisely.

speed of sound in air = 330 m s^{-1}

(3)

.....

.....

.....

.....

.....

.....

(Total for Question = 11 marks)

Q12.

In 2010, Andre Geim and Konstantin Novoselov were awarded the Nobel Prize in Physics for producing, identifying and studying graphene.

Graphene is a form of carbon which exists only as a single atomic layer of graphite. It has a breaking stress of 130 GPa compared to 0.5 GPa for steel. Some scientists claim that graphene is the strongest material ever measured.

(a) Explain why graphene, despite its greater strength, is unlikely to replace steel in many applications.

(2)

.....

.....

.....

.....

.....

.....

.....

.....

(b) Graphite used in pencils consists of many layers of carbon. It can be assumed that a pencil deposits approximately 100 layers of carbon atoms when drawn across a piece of paper.

A student carried out an experiment to determine the resistivity of the graphite in a pencil.

A line of length 0.200m and width 0.50mm was drawn on a piece of paper. An ohmmeter was then used to measure the resistance of the graphite line.



Calculate the resistivity of graphite.

resistance = $1.029 \times 10^{6}\ \Omega$
diameter of carbon atom = 1.4×10^{-10} m

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Resistivity of graphite = ...

(c) Photocells traditionally use silicon to generate electricity using visible light. Research demonstrates that unlike silicon, graphene is able to respond at all wavelengths and releases multiple electrons as it absorbs one photon.

Deduce why it would be an advantage to use graphene in photocells to generate electricity.

(3)

.....

.....

.....

.....

.....

.....

.....

(Total for question = 9 marks)

Q13.

Answer the question with a cross in the box you think is correct (☒). If you change your mind about an answer, put a line through the box (☒) and then mark your new answer with a cross (☒).

When monochromatic light is incident on the surface of a metal, electrons are emitted by the photoelectric effect.

If other conditions are unchanged, the maximum kinetic energy of the electrons will be increased by

☒ **A** increasing the frequency of the incident light.

☒ **B** increasing the intensity of the incident light.

☒ **C** using a metal with a higher threshold frequency.

☒ **D** using a metal with a higher work function.

(Total for question = 1 mark)

Q14.

Read the extract and answer the question that follows.

In the 17th century there were two proposed theories to explain the refraction of light. Using a wave model, Huygens stated that light slows down when it passes from air to water. Using a particle model, Newton stated that light speeds up when it passes from air to water. Newton's theory was more readily accepted until the speed of light in water was measured in the 19th century.

In the early 20th century, Einstein used observations from the photoelectric effect to provide evidence for the particle model of light.

Nowadays, both the wave model of light and the particle model of light are accepted, as each can be used to explain different aspects of the behaviour of light.

In a demonstration of the photoelectric effect, electromagnetic radiation is shone onto a clean metal surface. It can be shown that the metal loses negative charge when the radiation has a frequency above a certain threshold frequency.

Explain how the particle model of light is consistent with this observation.

(3)

.....

.....

.....

.....

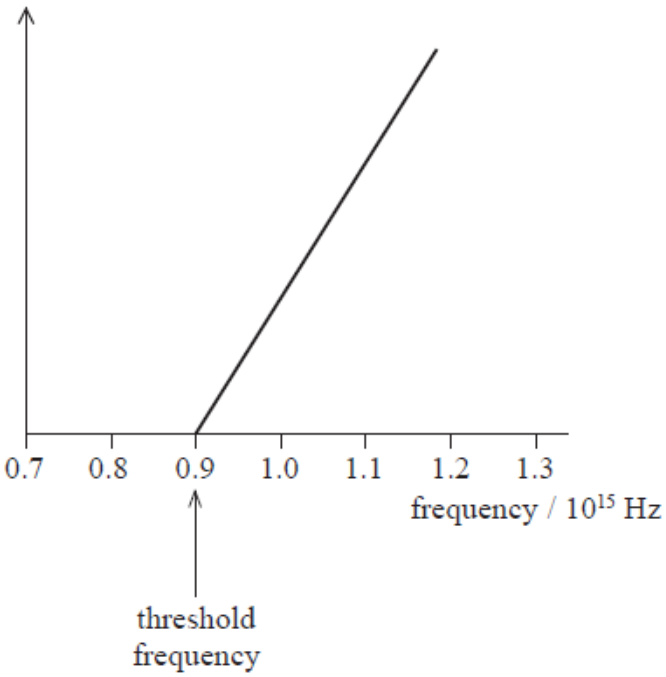
.....

.....

(Total for question = 3 marks)

Q15.

The graph shows the results for an experiment to demonstrate the photoelectric effect by illuminating a clean metal sheet with light of increasing frequency.



(a) State a quantity, and its unit, which could have been plotted on the Y-axis to produce this graph.

(2)

.....

.....

(b) The threshold frequency is shown on the graph.

Explain why there is a threshold frequency.

(4)

.....

.....

.....

.....

.....

.....

.....

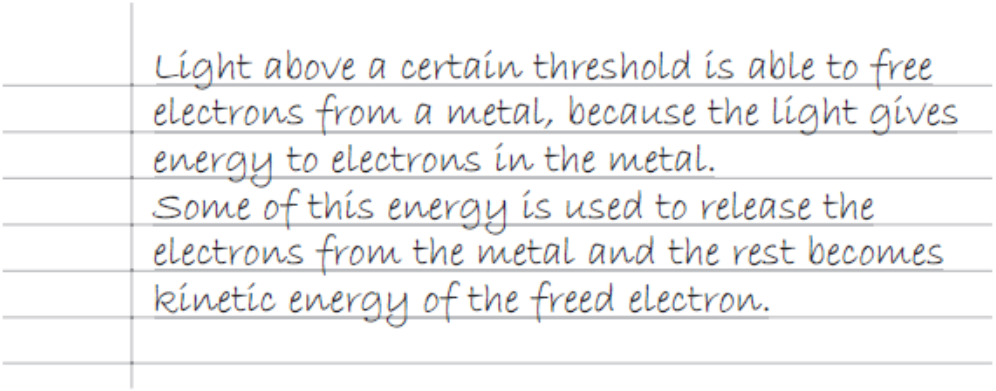
.....

(Total for question = 6 marks)

Q16.

A student has been learning about the photoelectric effect.

The student was asked by his teacher to explain the photoelectric effect. He gave the following explanation:



Discuss whether the student's answer fully explains the photoelectric effect.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

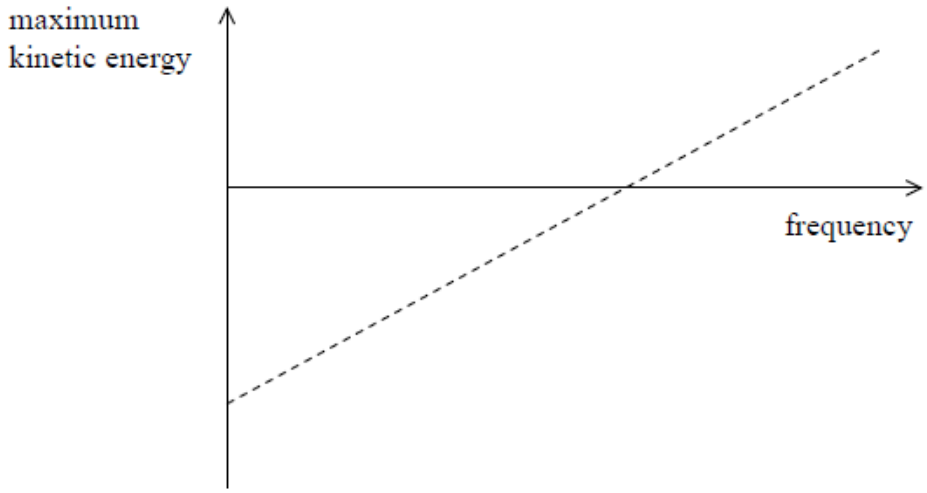
.....

(Total for question = 4 marks)

Q17.

In an investigation of the photoelectric effect, a metal plate is illuminated with light of different frequencies.

The graph shows the maximum kinetic energy of emitted electrons at different frequencies.



Which line of the table correctly shows the values given by the graph?

		***x* intercept**	**negative *y* intercept**
☒	**A**	Planck constant	work function
☒	**B**	threshold frequency	Planck constant
☒	**C**	threshold frequency	work function
☒	**D**	work function	threshold frequency

(Total for question = 1 mark)

Q18.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

The photoelectric effect provides evidence for the particle nature of electromagnetic radiation.

Which of the following observations of the photoelectric effect could also be explained using the wave nature of electromagnetic radiation?

☒ **A** The emission of photoelectrons is instantaneous.

☒ **B** The maximum kinetic energy of photoelectrons depends on frequency.

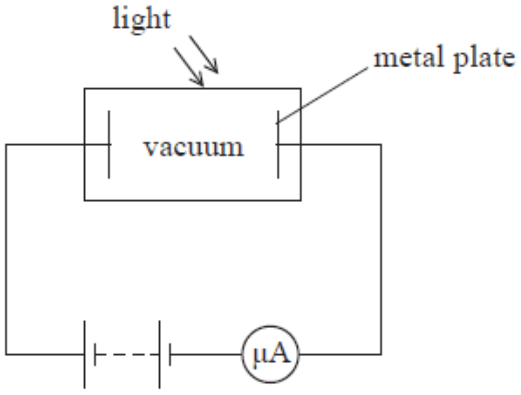
☒ **C** The rate of emission of photoelectrons depends on intensity.

☒ **D** There is a minimum frequency for emission of photoelectrons to occur.

(Total for question = 1 mark)

Q19.

The diagram shows apparatus that can be used to investigate the photoelectric effect.



Light is shone onto the metal plate.

For a particular metal there will only be a current for frequencies of light greater than 8.17×10^{14} Hz.

If the applied potential difference is reversed and increased, the current will decrease and at a certain value of potential difference the current will be zero.

Calculate this potential difference when the frequency of the incident light is 9.62×10^{14} Hz.

(4)

.....

.....

.....

.....

.....

.....

.....

Potential difference = ...

Q20.

*****In 1905 Einstein published his equation for the photoelectric effect.

In 1916 Millikan demonstrated that the maximum kinetic energy of photoelectrons is consistent with Einstein's equation.

Discuss the extent to which our current understanding of observations of the photoelectric effect supports the idea that light behaves as photons rather than as waves.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

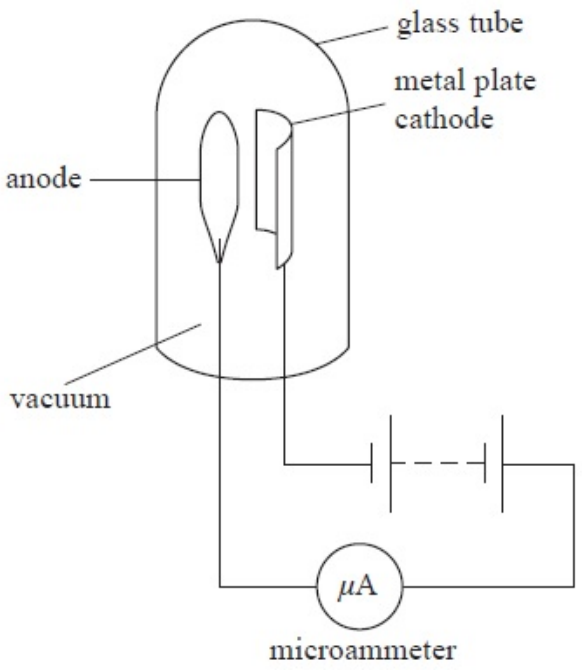
.....

.....

.....

(Total for question = 6 marks)

Q21. Phototubes are devices which make use of the photoelectric effect to detect light above a specific frequency.



(a) Explain why

- no current flows when the phototube is in darkness
- current flows in the circuit when the phototube is illuminated by light above a specific frequency.

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(b) Make an appropriate calculation to explain why caesium is used as the cathode for visible light but zinc is not.

work function of zinc = 3.63 eV

work function of caesium = 2.14 eV

(4)

.....

.....

.....

.....

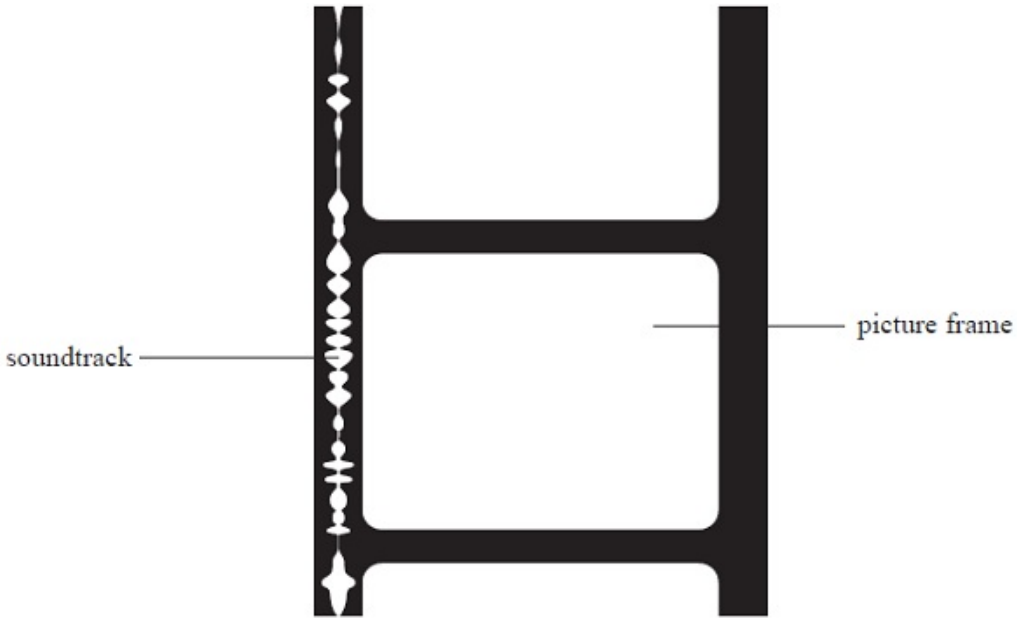
.....

.....

.....

.....

(c) Before digital technology was used, the films used at the cinema had an optical soundtrack next to the picture frames.



The film, including the soundtrack as shown, moves through a projector past a source of light. Light is detected by a phototube on the other side of the soundtrack. The changing current produced by the phototube circuit is converted to a sound signal with the same variation in amplitude and frequency as the original sound.

(i) State what is meant by amplitude.

(1)

.....

.....

(ii) Explain how the changing pattern of the soundtrack produces a changing current in the phototube circuit.

(3)

.....

.....

.....

.....

.....

.....

.....

.....

(Total for Question = 13 marks)

Q22.

(a) Solar sails are a form of propulsion for spacecraft. The sail is made of a thin sheet of reflective material. When photons of light from the Sun reflect from the material a force is exerted on the sail. The photons reflect with a momentum equal to their initial momentum but in the opposite direction.

(i) Show that a single photon of frequency 1.5×10^{15} Hz has a momentum of about 3×10^{-27} N s.

(2)

.....

.....

.....

.....

(ii) Hence determine the momentum transferred to the solar sail by this photon.

(1)

.....

Momentum transferred = ...

(b) An alternative method of producing a momentum change is being investigated. Researchers have suggested that 'larger changes in momentum could be produced by directing laser light at graphene oxide'. Electrons are emitted from the graphene oxide surface, resulting in a force being exerted on the graphene oxide in the opposite direction.

A researcher has suggested that one possible mechanism for the emission of the electrons is the photoelectric effect.

(i) Show that the maximum velocity for a photoelectron emitted after absorption of a photon of light of frequency 1.5×10^{15} Hz is about 8×10^{5} m s^{-1}.

work function of graphene oxide = 6.7×10^{-19} J

(3)

.....

.....

.....

.....

.....

.....

(ii) Hence calculate the momentum of the photoelectron.

(2)

.....

.....

.....

Momentum of photoelectron = ...

(c) Explain whether the suggestion in (b) that 'larger changes in momentum could be produced by directing laser light at graphene oxide' is true.

(2)

.....

.....

.....

.....

.....

.....

(Total for question = 10 marks)

Q23.

* The behaviour of electromagnetic radiation can be described in terms of a photon model or a wave model.

In the photoelectric effect, electromagnetic radiation is incident on a metal plate and under certain conditions electrons are emitted.

It is observed that, for a given metal,

- no electrons are emitted if the frequency of the incident radiation is below a certain threshold frequency.
- electrons are emitted instantaneously if the frequency of the incident radiation is above a certain threshold frequency.
- the kinetic energy of the emitted electrons depends only on the frequency of the incident radiation.

Discuss how the photon model of electromagnetic radiation can explain these observations and why the wave model of electromagnetic radiation cannot.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q24.

The idea of energy quantisation was used to explain the photoelectric effect, first observed by Heinrich Hertz.
When ultraviolet radiation is shone onto a metal surface, electrons may be released.
A cadmium surface is illuminated with light of wavelength 2.54×10^{-7} m.

Calculate the maximum kinetic energy of the photoelectrons released from the surface.

Work function of cadmium = 4.07 eV

(4)

.....

.....

.....

.....

.....

.....

.....

.....

Maximum kinetic energy = ... J

(Total for question = 4 marks)

Q25.

The Planck constant is an important universal constant used in the study of wave–particle duality.

In a demonstration of the photoelectric effect, ultraviolet radiation with a frequency of 2.8×10^{16} Hz is incident on the surface of clean zinc. Electrons are released from the surface of the zinc.

Calculate the maximum velocity of the released electrons.

work function of zinc = 6.9×10^{-19} J

(2)

.....

.....

.....

.....

.....

.....

Maximum velocity = ...

(Total for question = 2 marks)

Q1.

Our understanding of the atom has developed over time, from early models in which atoms were considered to be hard incompressible spheres, through to the nuclear model of the atom and the ladder model in which electrons exist in a discrete number of allowed energy states.

The nuclear model of the atom was established following a series of experiments in which alpha particles were directed at thin gold foil.

(i) An alpha particle approaching a gold nucleus, $^{197}_{79}Au$, head-on will be brought to rest and returned along its original path.

Calculate the minimum distance between the alpha particle and the nucleus for alpha particles of energy of 5.5 MeV.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

Minimum distance = ...

(ii) It is observed that electrons, with energy of 5.5 keV, are diffracted as they pass through the thin gold foil.

Explain a conclusion about the electrons that can be made from this observation.

(3)

.....

.....

.....

.....

.....

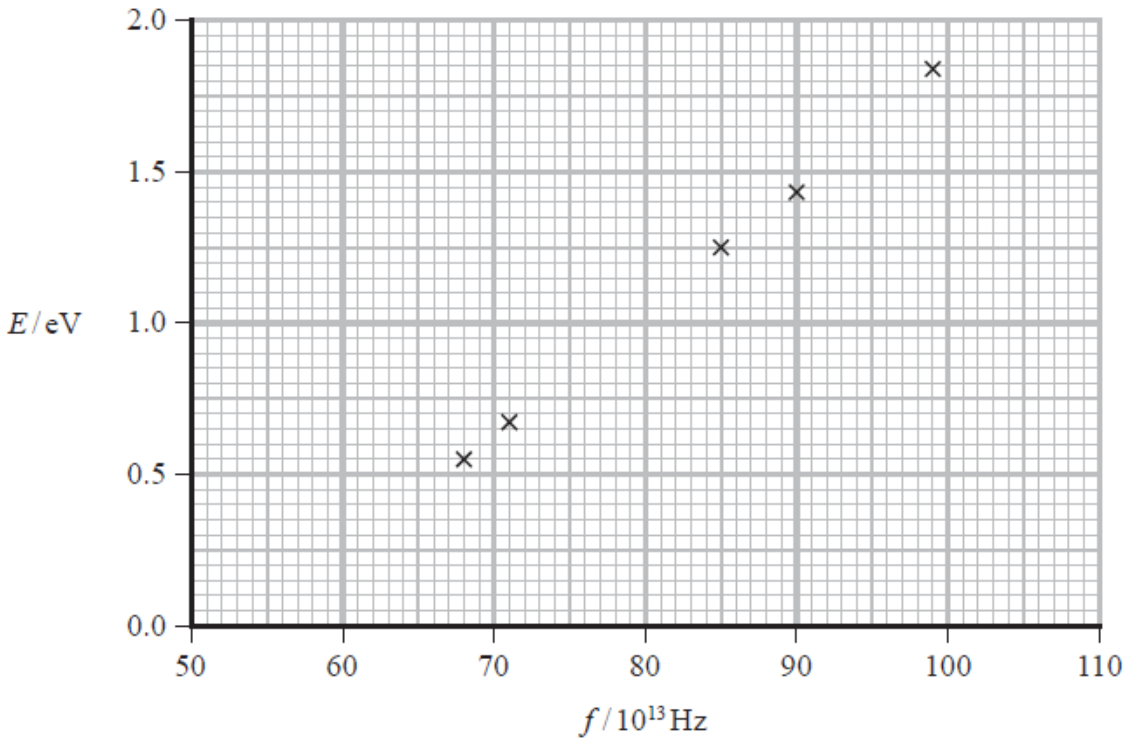
.....

(Total for question = 7 marks)

Q2.

In an investigation of the photoelectric effect, electromagnetic radiation of frequency *f* was directed onto a metal plate. The maximum kinetic energy *E* of the photoelectrons emitted from the metal plate was determined. The procedure was repeated for a range of frequencies.

The graph shows how *E* depended upon *f*.



Determine a value for the Planck constant, *h*, in J s.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

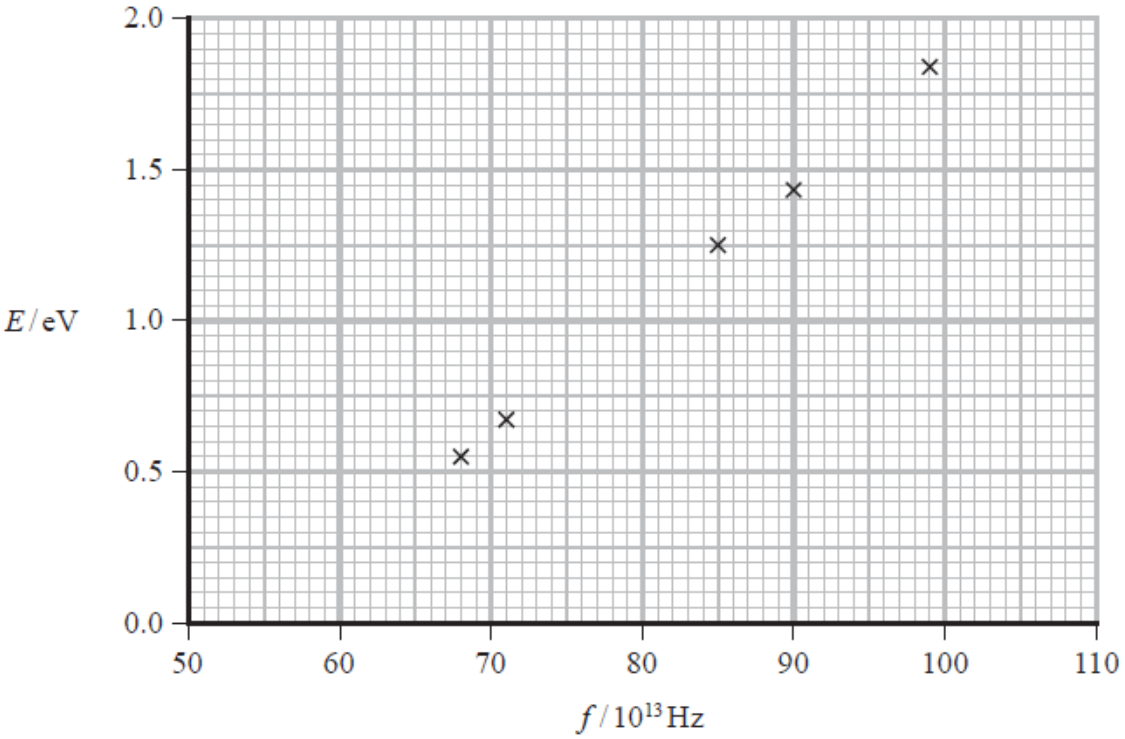
h = ... J s

(Total for question = 4 marks)

Q3.

In an investigation of the photoelectric effect, electromagnetic radiation of frequency f was directed onto a metal plate. The maximum kinetic energy E of the photoelectrons emitted from the metal plate was determined. The procedure was repeated for a range of frequencies.

The graph shows how E depended upon f.



The table gives data for different metal surfaces.

Metal surface	Work function / eV
Caesium	2.0
Calcium	2.9
Magnesium	3.7

Deduce which metal was being used in the investigation.

(3)

.....

.....

.....

.....

.....

.....

.....

(Total for question = 3 marks)

Q4.

Helium was first discovered because of dark lines observed in the continuous spectrum of light from the Sun. The lines were caused by a few specific frequencies of light in the spectrum being present at very much lower intensity than the rest.

Scientists deduced that this was due to an unknown element in the Sun's atmosphere.

(a) Explain how helium in the Sun's atmosphere caused this set of dark lines.

(5)

.....

.....

.....

.....

.....

.....

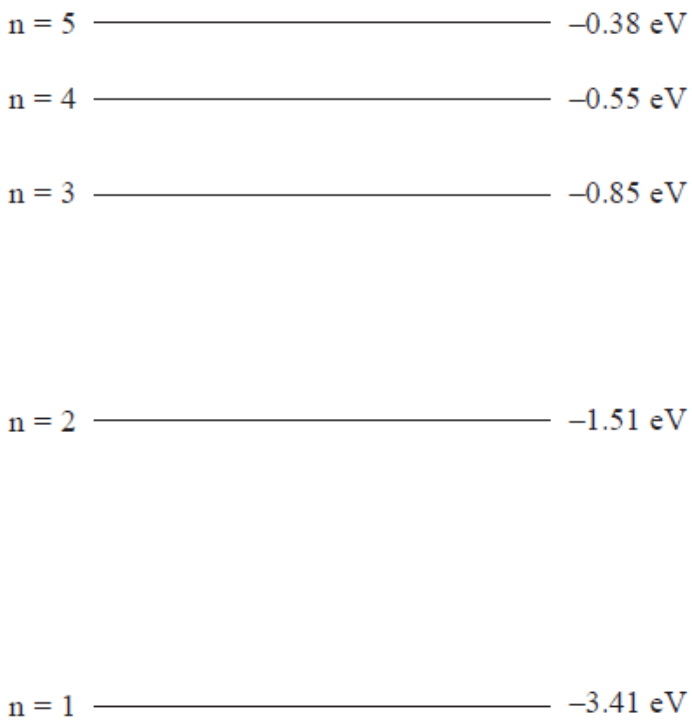
.....

.....

.....

.....

(b) The diagram shows some of the energy levels for an atom of another element.



(i) Determine which energy levels are associated with photons of frequency 4.6×10^{14} Hz.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

(ii) Suggest why the energy levels all have a negative value.

(2)

.....

.....

.....

.....

(c) Lines such as those described in (a) can be used to determine the motion of stars relative to

the Earth.

Suggest how these lines may be used to determine the motion of stars.

(3)

.....

.....

.....

.....

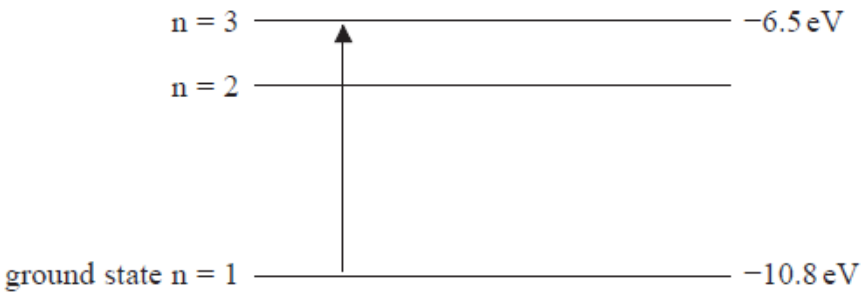
.....

.....

(Total for question = 14 marks)

Q5.

An electron in its ground state absorbs electromagnetic radiation of wavelength λ.
The energy level diagram represents the resulting energy transition of the electron.



Calculate the wavelength of radiation absorbed by the electron.

(3)

.....

.....

.....

.....

.....

.....

Wavelength = ...

(Total for question = 3 marks)

Q6.

(a) State what is meant by the de Broglie wavelength.

(2)

.....

.....

.....

.....

(b) An electron is accelerated from rest, in a vacuum, through a potential difference of 500 V.

(i) Show that the final momentum of the electron is about 1×10^{-23} N s.

(3)

.....

.....

.....

.....

.....

.....

(ii) Calculate the de Broglie wavelength for this electron.

(2)

.....

.....

.....

de Broglie wavelength = ...

(Total for question = 7 marks)

Q7.

When electromagnetic radiation is incident on a metal plate, electrons may be emitted.

(a) State what is meant by threshold frequency.

(1)

.....

.....

(b) Calculate the threshold frequency for a metal with a work function of 2.28 eV.

(3)

.....

.....

.....

.....

.....

.....

Threshold frequency = ...

(Total for question = 4 marks)

Q8.

The photoelectric effect was discovered by Hertz who investigated the effect of ultraviolet radiation incident upon the surface of zinc. The effect was found to depend on the frequency of the radiation.

(a) State what is meant by threshold frequency.

(1)

.....

.....

.....

(b) Light of frequency 8.9×10^{14} Hz is incident upon the surface of a different metal. The photoelectrons have a maximum speed of 6.7×10^{5} m s^{-1}.

Calculate the work function of the metal in eV.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

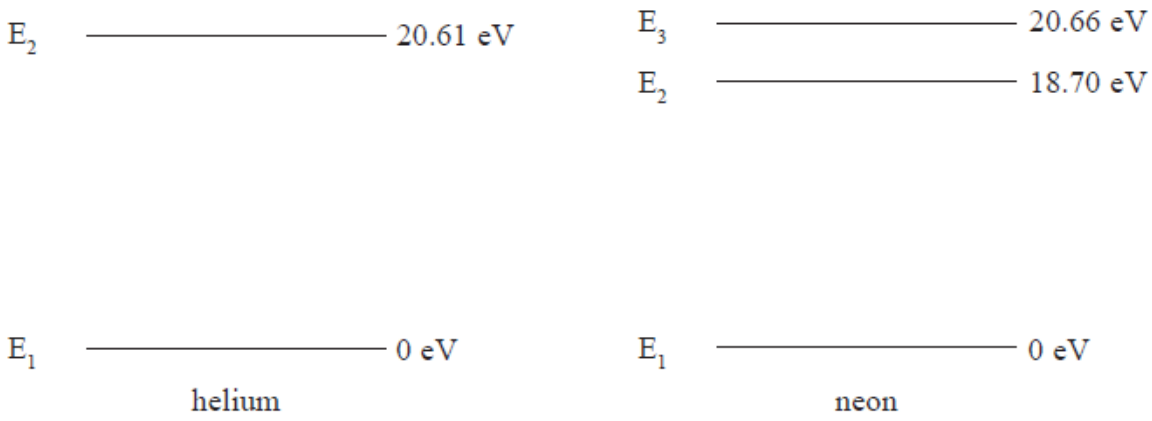
Work function = ... eV

(Total for question = 5 marks)

Q9.

A helium-neon gas laser is often used in the laboratory as a source of high intensity, coherent, monochromatic light.

The diagram shows some of the energy levels above the ground level E_3 for helium atoms and for neon atoms. The highest shown levels for helium atoms and neon atoms are almost identical.



Helium atoms in the gas are excited to level E_2 by the current passing through the laser. They collide at high speed with neon atoms. Because the energies are so similar, the energy is transferred from the helium atoms to the neon atoms. The neon atoms become excited in turn to level E_3. As the neon atoms subsequently drop to level E_2 they emit photons.

(a) Explain what is meant by a photon.

(2)

.....

.....

.....

(b) Calculate the frequency of the photons produced as the neon atoms drop from level E_3 to level E_2.

(3)

.....

.....

.....

.....

Frequency = ...

(c) An electron in level E_3 of neon has 0.05 eV more energy than an electron in level E_2 of helium.

Suggest the source of the energy to make up this difference.

(1)

.....

.....

(d) The photograph shows a device for making a vertical slit with variable width.



© THORLABS, Inc.

When the slit is fully open a laser beam is shone through it and a single point of light is seen on a screen.

As the slit is reduced in width the point of light becomes a horizontal line that gets longer as the slit gets narrower.

Explain this observation

(3)

.....

.....

.....

.....

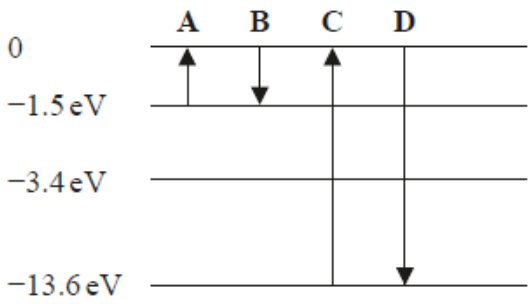
.....

.....

(Total for question = 9 marks)

Q10.

Some of the energy levels of an atom of a gas are shown.



During which transition, A, B, C or D, is electromagnetic radiation with the shortest wavelength emitted?

☒ **A**

☒ **B**

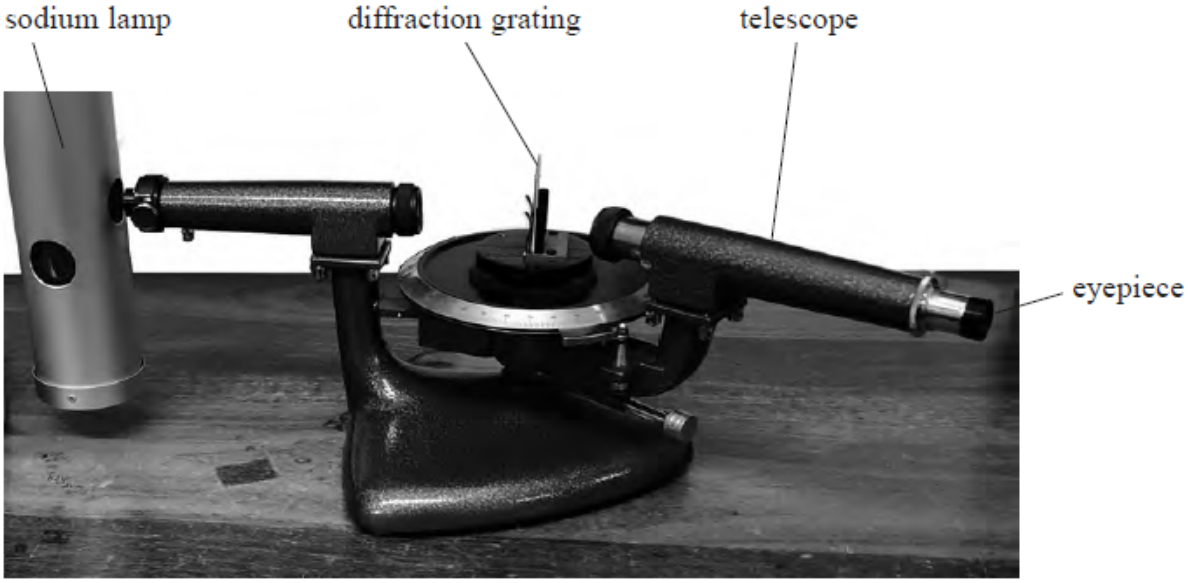
☒ **C**

☒ **D**

(Total for question = 1 mark)

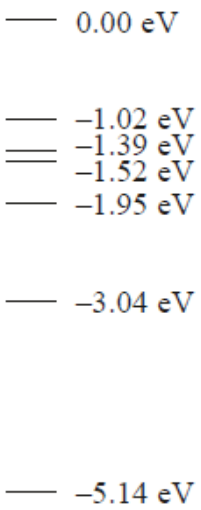
Q11.

The photograph shows a school spectrometer.



The spectrometer allows parallel rays of light to be passed through a diffraction grating and the resulting angles of diffraction to be measured.

The diagram shows some of the energy levels in a sodium atom.



Add an arrow to the diagram to show the transition involved in the emission of yellow light of wavelength 589 nm.

Show your working below.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

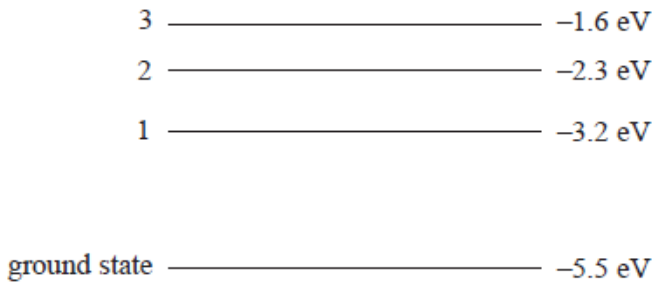
.....

.....

(Total for question = 4 marks)

Q12.

The diagram shows the lowest energy levels for a certain atom.



A photon with energy 3.2 eV is absorbed.

An electron could move from

(1)

☒ **A** ground state to level 1.

☒ **B** ground state to level 2.

☒ **C** level 1 to ground state.

☒ **D** level 2 to ground state.

(Total for question = 1 mark)

Q13.

Phosphogypsum is a by-product in the manufacture of fertiliser. It is slightly radioactive because of the presence of radium-226, a radioisotope with a half-life of 1600 years.

It must be stored securely as long as the activity of the radium-226 it contains is greater than 0.4 Bq per gram of phosphogypsum.

Radium-226 decays to radon-222 by alpha emission.

Determine the energy released in MeV in the decay of a single nucleus of radium-226.

(5)

mass of radium-226 nucleus = 225.97713 u
mass of radon-222 nucleus = 221.97040 u
mass of α particle = 4.00151 u

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Energy released = ... MeV

(Total for question = 5 marks)

Q14.

In the late 1880s it was discovered that a negatively-charged zinc plate loses its charge when exposed to ultraviolet radiation.

Explain why this happens, but only with ultraviolet radiation and not white light. You are expected to complete a calculation to support your answer.

work function of zinc = 6.9×10^{-19} J

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q15.

A simple model of the hydrogen atom consists of an electron moving in a circular path around a proton.

(i) In this simple model it is the electrostatic force, rather than the gravitational force, that is responsible for keeping the electron in a circular path.

By means of calculations justify this statement.

radius r of the hydrogen atom = 5.3×10^{-11} m

(4)

.....

.....

.....

.....

.....

(ii) Ignoring the gravitational force, calculate the velocity of the electron in this simple model of the hydrogen atom.

(3)

.....

.....

.....

.....

.....

Velocity = ...

(Total for question = 7 marks)

Q16.

An electron is accelerated from rest through a potential difference of 5.0 kV.

The kinetic energy gained by the electron is

☒ **A** 8.0×10^{-16} J

☒ **B** 8.0×10^{-19} J

☒ **C** 3.2×10^{-20} J

☒ **D** 3.2×10^{-23} J

(Total for question = 1 marks)

Q17. Dolphins use ultrasound when hunting prey. They emit short pulses of ultrasound, known as clicks, and detect the ultrasound reflected from their prey.

(a) Describe how ultrasound travels through water.

(2)

.....

.....

.....

.....

(b) Suggest why the dolphins emit a series of clicks rather than a continuous sound.

(1)

.....

.....

.....

.....

(c) When searching for prey the dolphins emit 16 clicks per second.

(i) Show that the time between clicks when searching for prey is about 0.06 s.

(1)

.....

.....

(ii) Calculate the maximum distance that can be determined by the dolphin when searching for prey.

speed of sound in seawater = 1530 m s^{-1}

(3)

.....

.....

.....

.....

.....

.....

Maximum distance = ...

(iii) The dolphin increases the number of clicks per second to 125 when near to capturing its prey.

Suggest why.

(1)

.....

.....

(d) Bats use ultrasound in air when hunting prey. The ultrasound frequency and the duration of the click is the same for both bats and dolphins.

Explain whether bats or dolphins would be able to locate their prey more precisely.

speed of sound in air = 330 m s^{-1}

(3)

.....

.....

.....

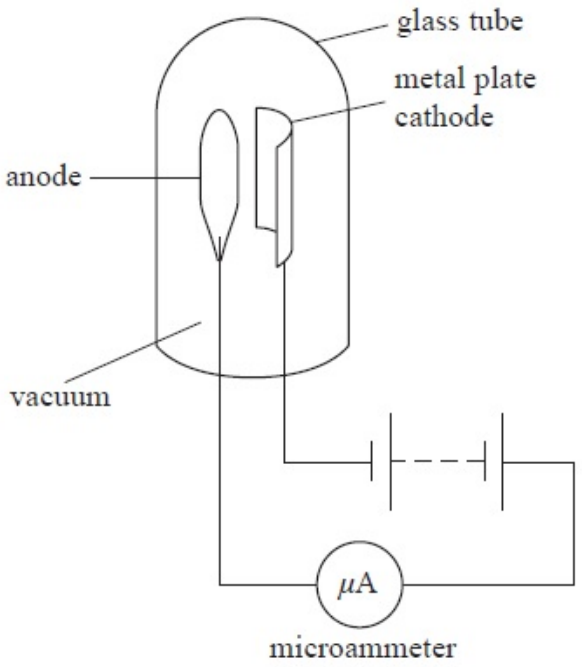
.....

.....

.....

(Total for Question = 11 marks)

Q18. Phototubes are devices which make use of the photoelectric effect to detect light above a specific frequency.



(a) Explain why

- no current flows when the phototube is in darkness
- current flows in the circuit when the phototube is illuminated by light above a specific frequency.

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(b) Make an appropriate calculation to explain why caesium is used as the cathode for visible light but zinc is not.

work function of zinc = 3.63 eV

work function of caesium = 2.14 eV

(4)

.....

.....

.....

.....

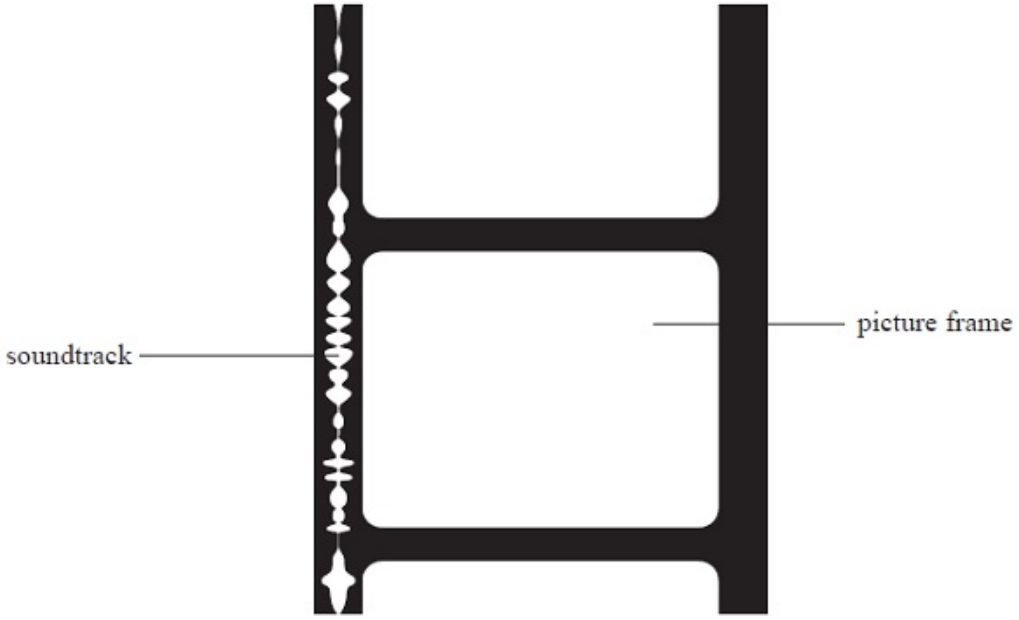
.....

.....

.....

.....

(c) Before digital technology was used, the films used at the cinema had an optical soundtrack next to the picture frames.



The film, including the soundtrack as shown, moves through a projector past a source of light. Light is detected by a phototube on the other side of the soundtrack. The changing current produced by the phototube circuit is converted to a sound signal with the same variation in amplitude and frequency as the original sound.

(i) State what is meant by amplitude.

(1)

.....

.....

(ii) Explain how the changing pattern of the soundtrack produces a changing current in the phototube circuit.

(3)

.....

.....

.....

.....

.....

.....

.....

.....

(Total for Question = 13 marks)

Q19. When the photoelectric effect was first observed in the nineteenth century, scientists could not explain it using the wave theory of light.

In 1905 Albert Einstein published a paper, for which he won a Nobel Prize, explaining the photoelectric effect by using a photon model of light, rather than a wave model.

(a) Explain what is meant by a photon.

(2)

.....

.....

.....

.....

*(b) Explain why the following observations may be understood by using a photon model of light, rather than a wave model.

- Light above a certain frequency causes the emission of electrons from the surface of a metal. This emission occurs instantaneously.
- Light below a certain frequency will not result in the emission of electrons however long it illuminates the surface.

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(c) Zinc has a work function of 4.3 eV.

(i) Calculate the threshold frequency for zinc.

(3)

.....

.....

.....

.....

.....

Threshold frequency = ...

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

(1)

.....

(Total for Question = 11 marks)

Q20.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

In a particular radioactive decay, there is a mass decrease equivalent to 0.05 u.

Which of the following expressions gives the energy released in MeV?

☐ **A** $\frac{0.05 \times 1.66 \times 10^{-27} \times (3 \times 10^{8})^{2}}{1.6 \times 10^{-19}}$

☐ **B** $\frac{0.05 \times 1.67 \times 10^{-27} \times (3 \times 10^{8})^{2}}{1.6 \times 10^{-19}}$

☐ **C** $\frac{0.05 \times 1.66 \times 10^{-27} \times (3 \times 10^{8})^{2}}{1.6 \times 10^{-13}}$

☐ **D** $\frac{0.05 \times 1.67 \times 10^{-27} \times (3 \times 10^{8})^{2}}{1.6 \times 10^{-13}}$

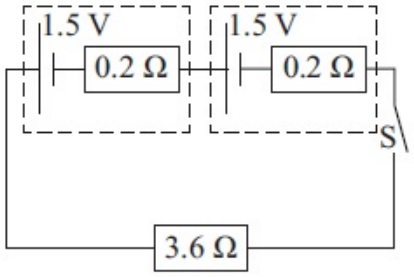
(Total for question = 1 mark)

Q21.

Electrically heated gloves are used by skiers and climbers to provide extra warmth for their hands.



Each glove has a heating element of resistance 3.6 Ω. Two cells each of e.m.f. 1.5 V and internal resistance 0.2 Ω are used to operate each heating element.



(a) When the switch is closed:

(i) Calculate the total resistance in the circuit

(1)

.....

Total resistance = ...

(ii) Calculate the current in the heating element

(2)

.....

.....

Current = ...

(iii) Calculate the power output from the heating element.

(2)

.....

.....

Power output = ...

(b) When in use the internal resistance of each cell gradually increases.

State and explain the effect this will have on the power output of the heating element.

(3)

.....

.....

.....

.....

.....

.....

(Total for question = 8 marks)

Q22.

Read the passage and answer the question that follows.

Atoms can be promoted into an excited state when they absorb energy. This results in the release of radiation at a random time. When several atoms are close together a quantum effect can occur. When one atom emits radiation this affects all the other nearby excited atoms. The excess energy of many of the atoms is released simultaneously and an intense flash of light is produced. This effect is called superradiance and can be used to produce lasers that emit a narrower range of frequencies than conventional lasers.

Superradiance occurs when the distance between atoms is less than the wavelength of the emitted radiation.

An atom is in the ground state. The atom absorbs 6.2 eV of energy. The distance between neighbouring atoms is 140 nm.

Deduce whether superradiance can occur.

(3)

.....

.....

.....

.....

.....

(Total for question = 3 marks)

Q23.

Read the following extract and then answer the questions that follow.

Powdery dust, the by-product of fearsome meteor storms that pounded the Moon, coats much of the lunar surface. A build-up of this dust could damage sensitive machinery.

Scientists theorise that lunar dust must be electrostatically charged by ultraviolet solar radiation from the Sun. When ultraviolet radiation hits the Moon's "day side", the half that faces the Sun, it knocks electrons out of atoms in the lunar soil.

(a) Describe the particle model of ultraviolet radiation that explains how it can "knock electrons out of atoms".

(3)

.....

.....

.....

.....

.....

.....

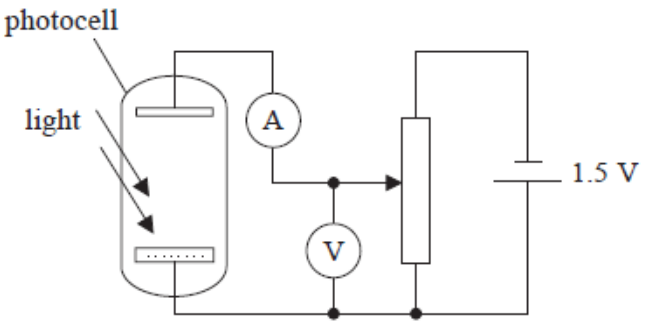
.....

.....

.....

(b) A teacher uses the arrangement below to demonstrate that electrons can be knocked out of a metal surface in a photocell by visible light.

The arrangement can also be used to measure the maximum kinetic energy of these electrons.



(i) Explain how the potential divider circuit can produce a range of values from 0 to 1.5 V on the voltmeter.

(3)

.....

.....

.....

.....

.....

.....

.....

.....

.....

(ii) The potential difference on the voltmeter is increased until the ammeter reading is zero.

The voltmeter reads 0.6 V at this instant.
State the maximum kinetic energy of the electrons in eV.

(1)

Maximum kinetic energy = ... eV

(c) Discuss whether the photocell arrangement in part (b) gives a valid demonstration of how dust particles become charged on the Moon.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 11 marks)

Q24.

An electron gun uses a potential difference V to accelerate electrons of mass m and charge e from rest to a speed v.
The potential difference V can be expressed as

☐ **A** $\frac{mv^2}{2e}$

☐ **B** $\frac{2ev^2}{m}$

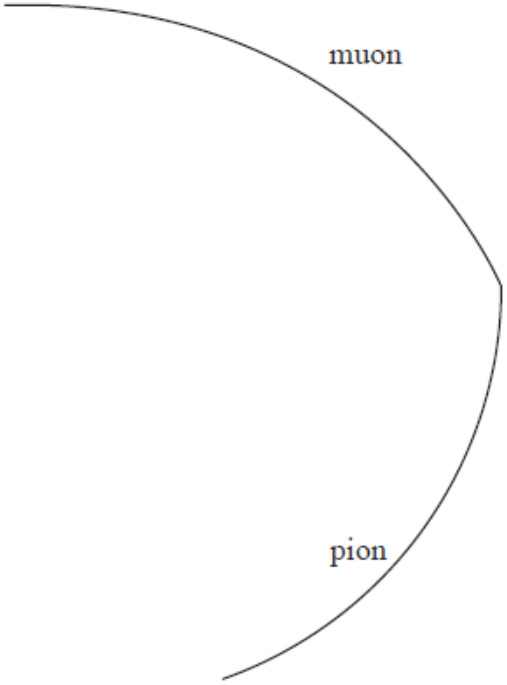
☐ **C** $\sqrt{\frac{2ev}{m}}$

☐ **D** $\sqrt{\frac{mv}{2e}}$

(Total for question = 1 mark)

Q25.

A negatively charged pion decays into a muon and an antineutrino. The diagram shows tracks in a particle detector formed in such an event.



Use a vector diagram to determine the momentum of the antineutrino.

The initial momentum of the muon is 1.59×10^{-19} N s.

(5)

Momentum of antineutrino = ...

Direction of antineutrino = ...

(Total for question = 5 marks)

Q1. Analysing the light from a star allows elements present in its outer atmosphere to be identified because each element produces a distinctive set of spectral lines.

*(a) Describe how a spectral line is produced by a hot gas, explaining why a particular element can only give rise to particular frequencies.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

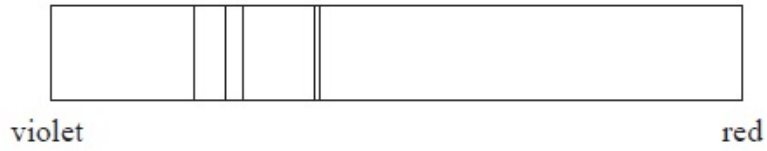
.....

.....

.....

.....

(b) The diagram shows the spectral lines produced by a particular element when observed in a laboratory.



The diagram below shows the spectral lines obtained by analysing the light from a star. This shows the same pattern of lines, but in a different part of the spectrum.



Name this effect and explain what may be deduced about the motion of this star relative to the Earth.

(3)

.....

.....

.....

.....

.....

.....

(c) Suggest what the phenomena in parts (a) and (b) imply about the nature of light.

(1)

.....

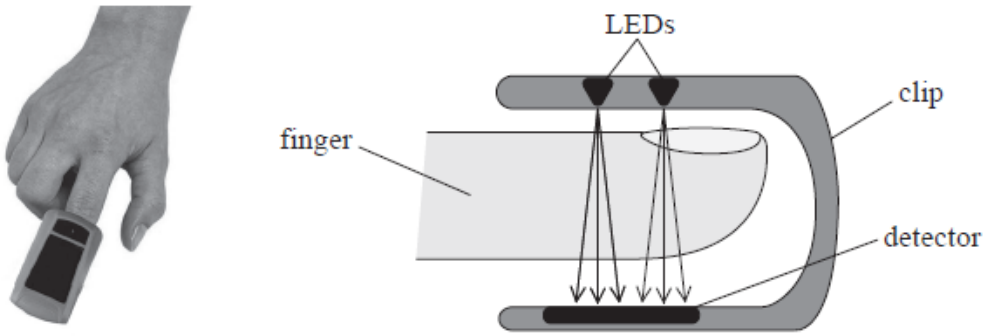
.....

(Total for Question = 10 marks)

Q2.

An oximeter is a device used in hospitals to monitor the oxygen level in a patient's blood.

In an oximeter, two light-emitting diodes (LEDs) are mounted opposite light sensors in a clip and attached to the patient's finger. One of the LEDs produces red light and the other produces infrared.



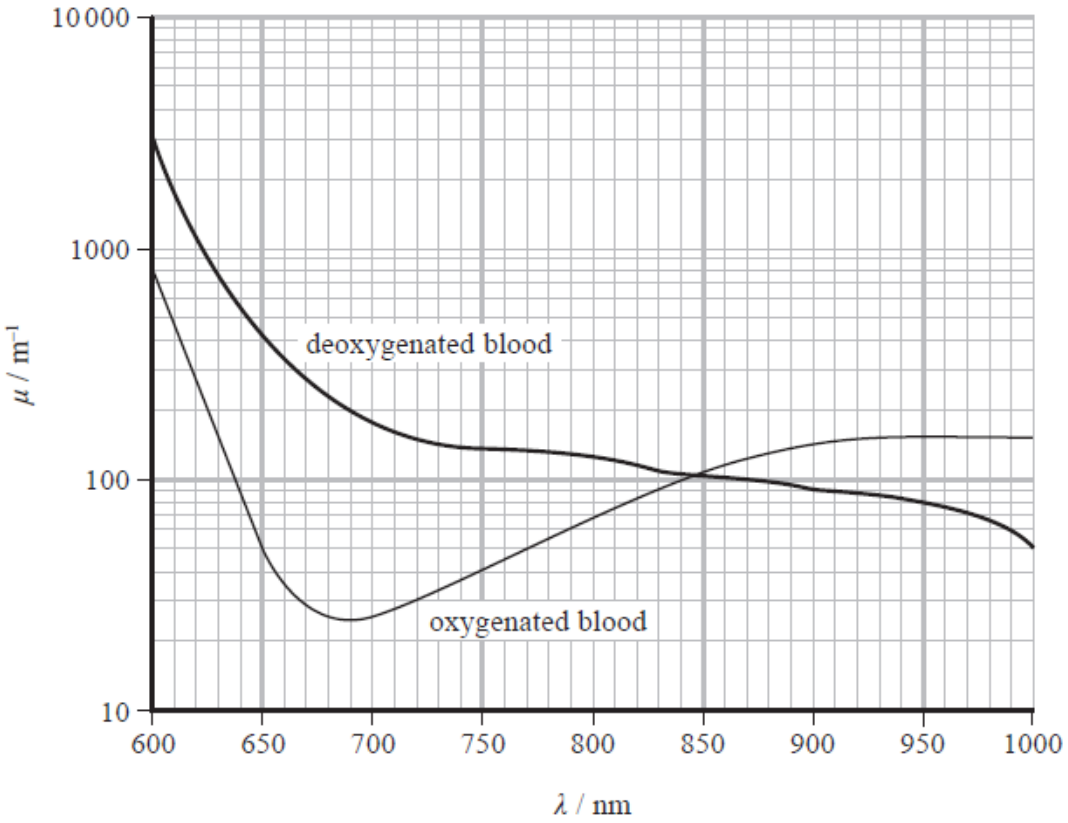
The intensity I of electromagnetic radiation received by the detector, after passing through a thickness x of blood, is given by

$$I = I_0^{e-\mu x}$$

where I_0 is the intensity that would have been received if the blood were not present and μ is the attenuation coefficient of blood.

The red LED emits visible light of wavelength 650 nm and the infrared LED emits infrared of wavelength 950 nm.

The graph shows how μ varies with wavelength λ for oxygenated blood and deoxygenated blood.



The oximeter determines I / I_0 the fraction of radiation transmitted at each wavelength.

Deduce whether I / I_0 will be smaller for the red or the infrared radiation if the blood is deoxygenated.

(3)

.....

.....

.....

.....

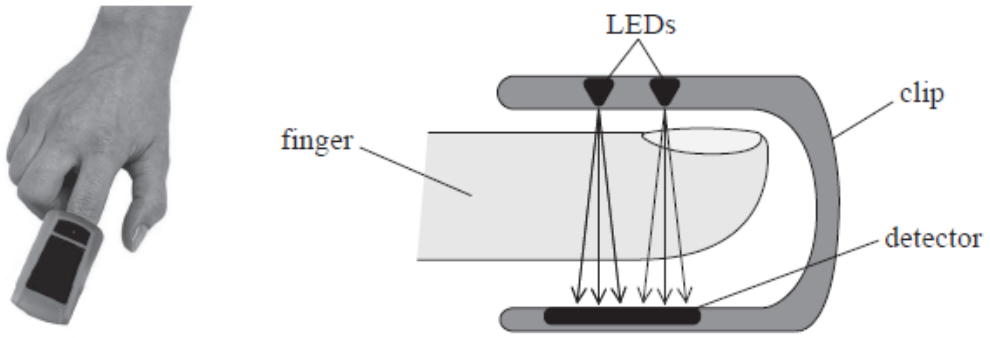
.....

(Total for question = 3 marks)

Q3.

An oximeter is a device used in hospitals to monitor the oxygen level in a patient's blood.

In an oximeter, two light-emitting diodes (LEDs) are mounted opposite light sensors in a clip and attached to the patient's finger. One of the LEDs produces red light and the other produces infrared.



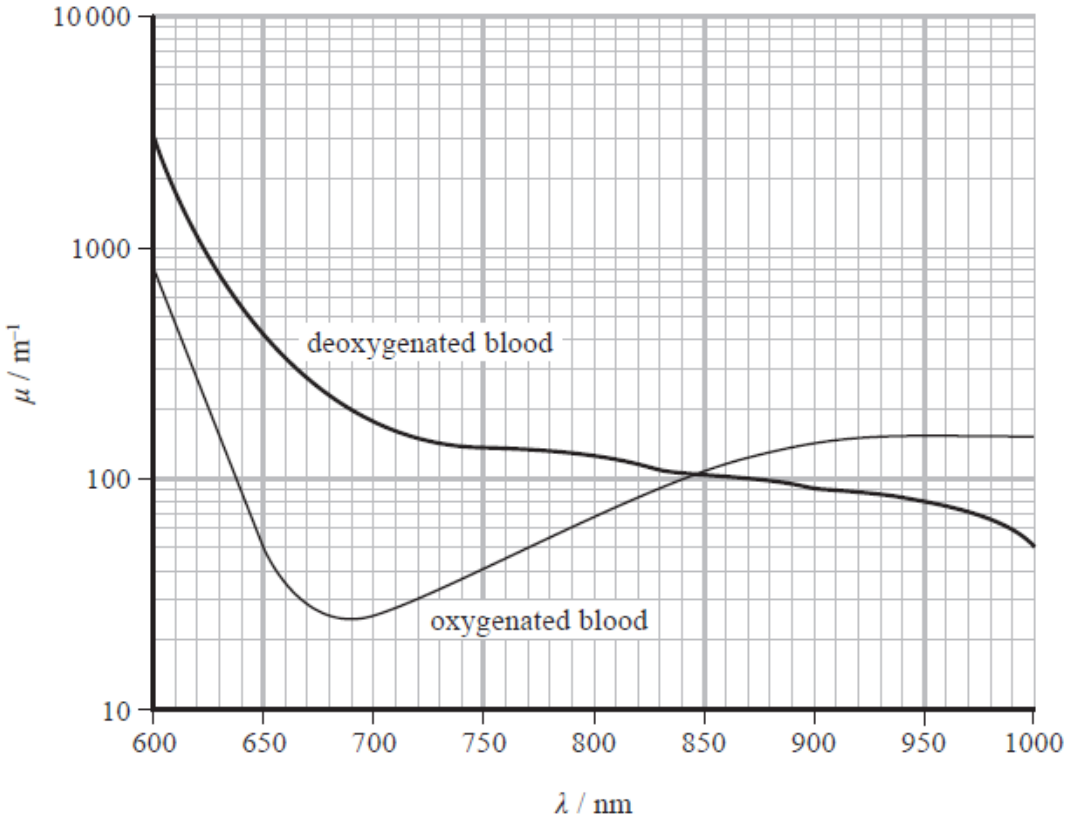
The intensity I of electromagnetic radiation received by the detector, after passing through a thickness x of blood, is given by

$$I = I_0^{e-\mu x}$$

where I_0 is the intensity that would have been received if the blood were not present and μ is the attenuation coefficient of blood.

The red LED emits visible light of wavelength 650 nm and the infrared LED emits infrared of wavelength 950 nm.

The graph shows how μ varies with wavelength λ for oxygenated blood and deoxygenated blood.



I_0 for the infrared LED is 1.8 W m^{-2}.

Calculate I for the infrared after passing through 1.4 mm of oxygenated blood.

(3)

.....

.....

.....

.....

.....

.....

.....

I = ...

(Total for question = 3 marks)

Q4.

In the late 1880s it was discovered that a negatively-charged zinc plate loses its charge when exposed to ultraviolet radiation.

Explain why this happens, but only with ultraviolet radiation and not white light. You are expected to complete a calculation to support your answer.

work function of zinc = 6.9×10^{-19} J

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

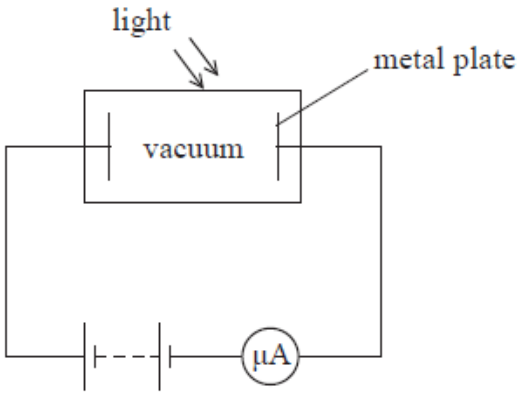
.....

.....

(Total for question = 6 marks)

Q5.

The diagram shows apparatus that can be used to investigate the photoelectric effect.



Light is shone onto the metal plate.

For a particular metal there will only be a current for frequencies of light greater than 8.17×10^{14} Hz.

* Explain how this observation supports the particle theory of light rather than the wave theory.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Q6.

Read the extract and answer the question that follows.

In the 17th century there were two proposed theories to explain the refraction of light. Using a wave model, Huygens stated that light slows down when it passes from air to water. Using a particle model, Newton stated that light speeds up when it passes from air to water. Newton's theory was more readily accepted until the speed of light in water was measured in the 19th century.

In the early 20th century, Einstein used observations from the photoelectric effect to provide evidence for the particle model of light.

Nowadays, both the wave model of light and the particle model of light are accepted, as each can be used to explain different aspects of the behaviour of light.

In a demonstration of the photoelectric effect, electromagnetic radiation is shone onto a clean metal surface. It can be shown that the metal loses negative charge when the radiation has a frequency above a certain threshold frequency.

Explain how the particle model of light is consistent with this observation.

(3)

.....

.....

.....

.....

.....

.....

(Total for question = 3 marks)

Q7.

When light is incident on the surface of a metal, electrons may be emitted by the photoelectric effect. Observations of the photoelectric effect helped to establish that light can exhibit particle behaviour.

Which of the following observations of the photoelectric effect could also be explained by light behaving as a wave?

☒ **A** Emission of photoelectrons occurs immediately the surface is illuminated.

☒ **B** Photoelectrons are only emitted when the frequency of the light is more than a certain minimum value.

☒ **C** The maximum kinetic energy of the photoelectrons is independent of the intensity of the incident light.

☒ **D** When the intensity of the incident light increases, photoelectrons are emitted at a greater rate.

(Total for question = 1 mark)

Q8.

*****In 1905 Einstein published his equation for the photoelectric effect.

In 1916 Millikan demonstrated that the maximum kinetic energy of photoelectrons is consistent with Einstein's equation.

Discuss the extent to which our current understanding of observations of the photoelectric effect supports the idea that light behaves as photons rather than as waves.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q9. When the photoelectric effect was first observed in the nineteenth century, scientists could not explain it using the wave theory of light.

In 1905 Albert Einstein published a paper, for which he won a Nobel Prize, explaining the photoelectric effect by using a photon model of light, rather than a wave model.

(a) Explain what is meant by a photon.

(2)

.....

.....

.....

.....

*(b) Explain why the following observations may be understood by using a photon model of light, rather than a wave model.

- Light above a certain frequency causes the emission of electrons from the surface of a metal. This emission occurs instantaneously.
- Light below a certain frequency will not result in the emission of electrons however long it illuminates the surface.

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(c) Zinc has a work function of 4.3 eV.

(i) Calculate the threshold frequency for zinc.

(3)

.....

.....

.....

.....

.....

Threshold frequency = ...

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

(1)

.....

(Total for Question = 11 marks)

Q10.

Read the following extract and then answer the questions that follow.

Powdery dust, the by-product of fearsome meteor storms that pounded the Moon, coats much of the lunar surface. A build-up of this dust could damage sensitive machinery.

Scientists theorise that lunar dust must be electrostatically charged by ultraviolet solar radiation from the Sun. When ultraviolet radiation hits the Moon's "day side", the half that faces the Sun, it knocks electrons out of atoms in the lunar soil.

(a) Describe the particle model of ultraviolet radiation that explains how it can "knock electrons out of atoms".

(3)

.....

.....

.....

.....

.....

.....

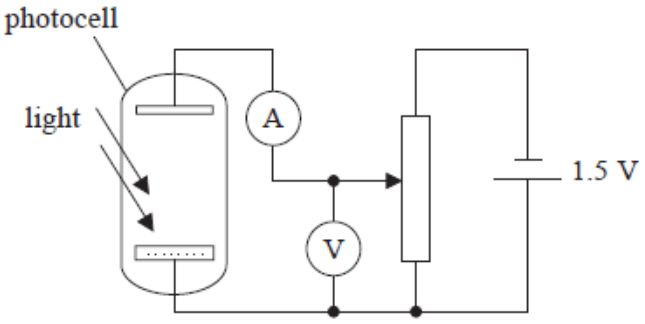
.....

.....

.....

(b) A teacher uses the arrangement below to demonstrate that electrons can be knocked out of a metal surface in a photocell by visible light.

The arrangement can also be used to measure the maximum kinetic energy of these electrons.



(i) Explain how the potential divider circuit can produce a range of values from 0 to 1.5 V on the voltmeter.

(3)

.....

.....

.....

.....

.....

.....

.....

.....

.....

(ii) The potential difference on the voltmeter is increased until the ammeter reading is zero.

The voltmeter reads 0.6 V at this instant.
State the maximum kinetic energy of the electrons in eV.

(1)

Maximum kinetic energy = ... eV

(c) Discuss whether the photocell arrangement in part (b) gives a valid demonstration of how dust particles become charged on the Moon.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 11 marks)

Q1.

Helium was first discovered because of dark lines observed in the continuous spectrum of light from the Sun. The lines were caused by a few specific frequencies of light in the spectrum being present at very much lower intensity than the rest.

Scientists deduced that this was due to an unknown element in the Sun's atmosphere.

(a) Explain how helium in the Sun's atmosphere caused this set of dark lines.

(5)

.....

.....

.....

.....

.....

.....

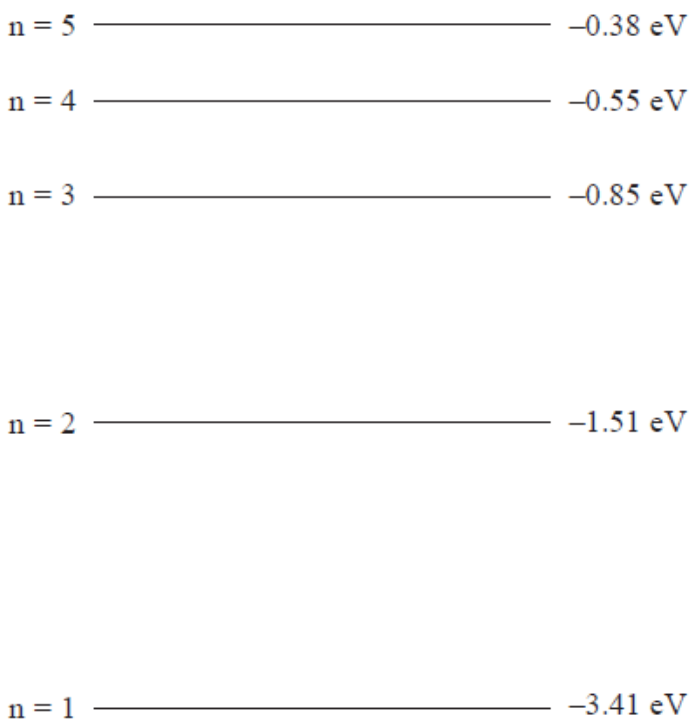
.....

.....

.....

.....

(b) The diagram shows some of the energy levels for an atom of another element.



(i) Determine which energy levels are associated with photons of frequency 4.6×10^{14} Hz.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

(ii) Suggest why the energy levels all have a negative value.

(2)

.....

.....

.....

.....

(c) Lines such as those described in (a) can be used to determine the motion of stars relative to the Earth.

Suggest how these lines may be used to determine the motion of stars.

(3)

.....

.....

.....

.....

.....

.....

(Total for question = 14 marks)

Q2. Analysing the light from a star allows elements present in its outer atmosphere to be identified because each element produces a distinctive set of spectral lines.

*(a) Describe how a spectral line is produced by a hot gas, explaining why a particular element can only give rise to particular frequencies.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(b) The diagram shows the spectral lines produced by a particular element when observed in a laboratory.



The diagram below shows the spectral lines obtained by analysing the light from a star. This shows the same pattern of lines, but in a different part of the spectrum.



Name this effect and explain what may be deduced about the motion of this star relative to the Earth.

(3)

.....

.....

.....

.....

.....

.....

(c) Suggest what the phenomena in parts (a) and (b) imply about the nature of light.

(1)

.....

.....

(Total for Question = 10 marks)

Q3.

In 1925 Franck and Hertz were awarded the Nobel Prize in Physics "for their discovery of the laws governing the impact of an electron upon an atom".
In one of their experiments, a beam of high-speed electrons is fired through mercury vapour.

An electron in the beam collides with a mercury atom, which becomes excited. The atom returns to its initial state by emitting electromagnetic radiation of a single frequency.

Explain why excited atoms only emit certain frequencies of radiation.

(5)

.....

.....

.....

.....

.....

.....

.....

.....

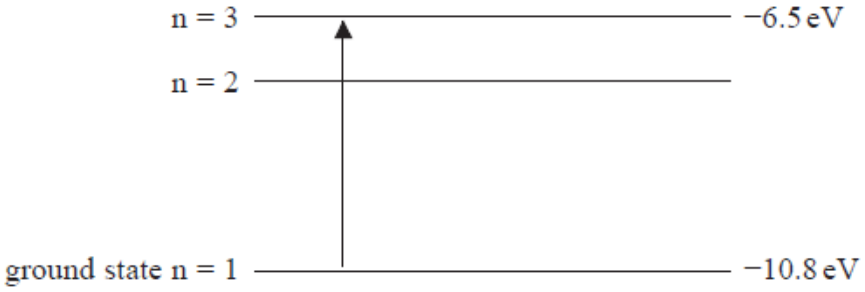
.....

.....

(Total for question = 5 marks)

Q4.

An electron in its ground state absorbs electromagnetic radiation of wavelength λ.
The energy level diagram represents the resulting energy transition of the electron.



Calculate the wavelength of radiation absorbed by the electron.

(3)

.....

.....

.....

.....

.....

.....

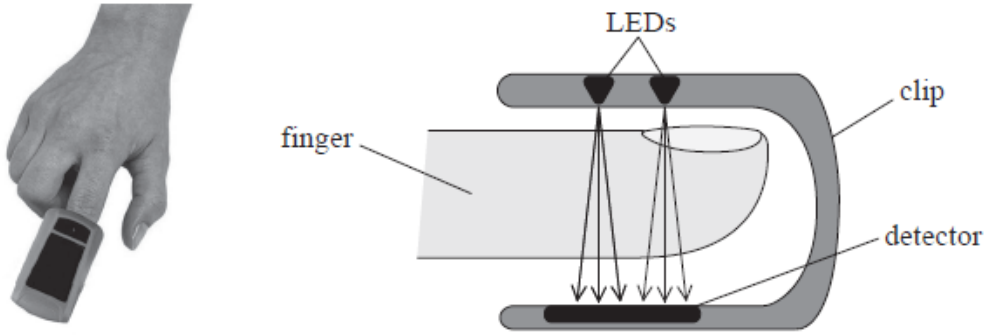
Wavelength = ...

(Total for question = 3 marks)

Q5.

An oximeter is a device used in hospitals to monitor the oxygen level in a patient's blood.

In an oximeter, two light-emitting diodes (LEDs) are mounted opposite light sensors in a clip and attached to the patient's finger. One of the LEDs produces red light and the other produces infrared.



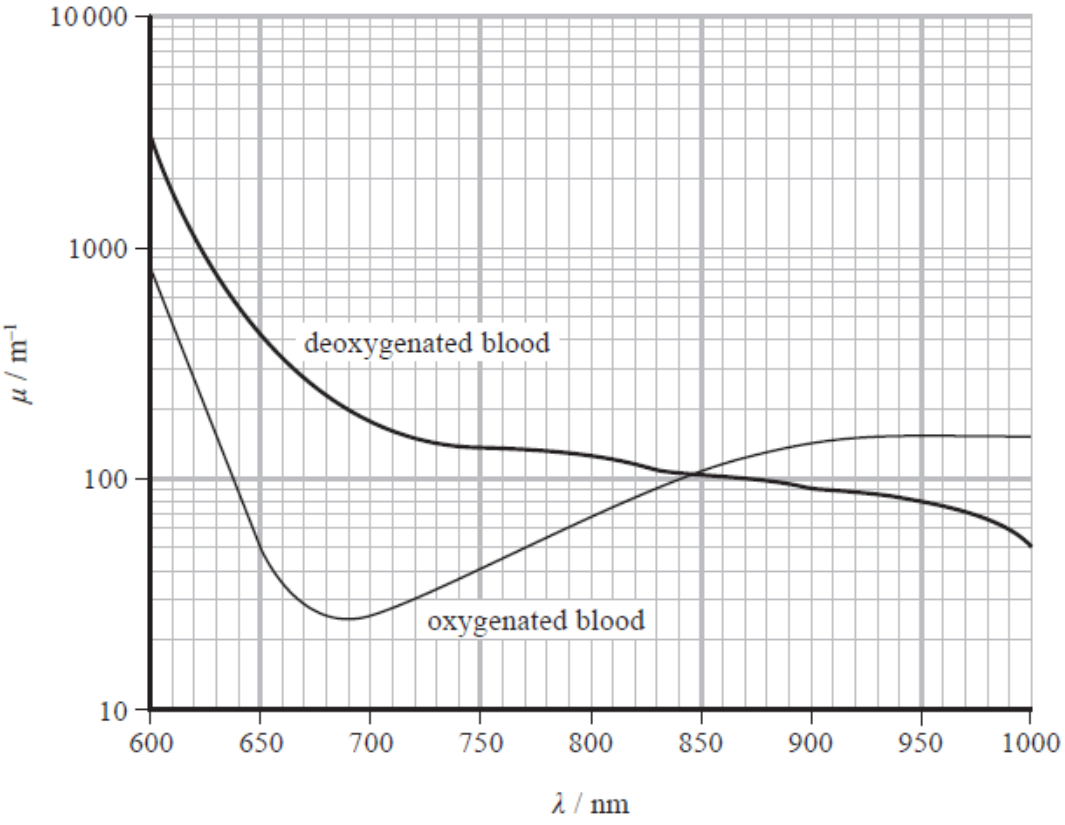
The intensity I of electromagnetic radiation received by the detector, after passing through a thickness x of blood, is given by

$$I = I_0^{e-\mu x}$$

where I_0 is the intensity that would have been received if the blood were not present and μ is the attenuation coefficient of blood.

The red LED emits visible light of wavelength 650 nm and the infrared LED emits infrared of wavelength 950 nm.

The graph shows how μ varies with wavelength λ for oxygenated blood and deoxygenated blood.



The oximeter determines I / I_0 the fraction of radiation transmitted at each wavelength.

Deduce whether I / I_0 will be smaller for the red or the infrared radiation if the blood is deoxygenated.

(3)

.....

.....

.....

.....

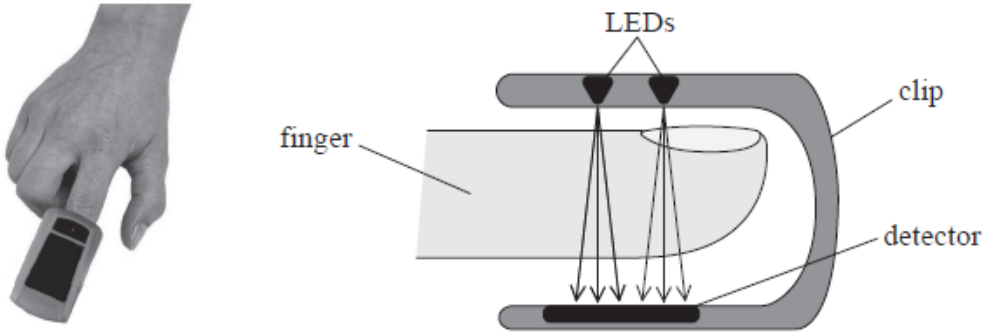
.....

(Total for question = 3 marks)

Q6.

An oximeter is a device used in hospitals to monitor the oxygen level in a patient's blood.

In an oximeter, two light-emitting diodes (LEDs) are mounted opposite light sensors in a clip and attached to the patient's finger. One of the LEDs produces red light and the other produces infrared.



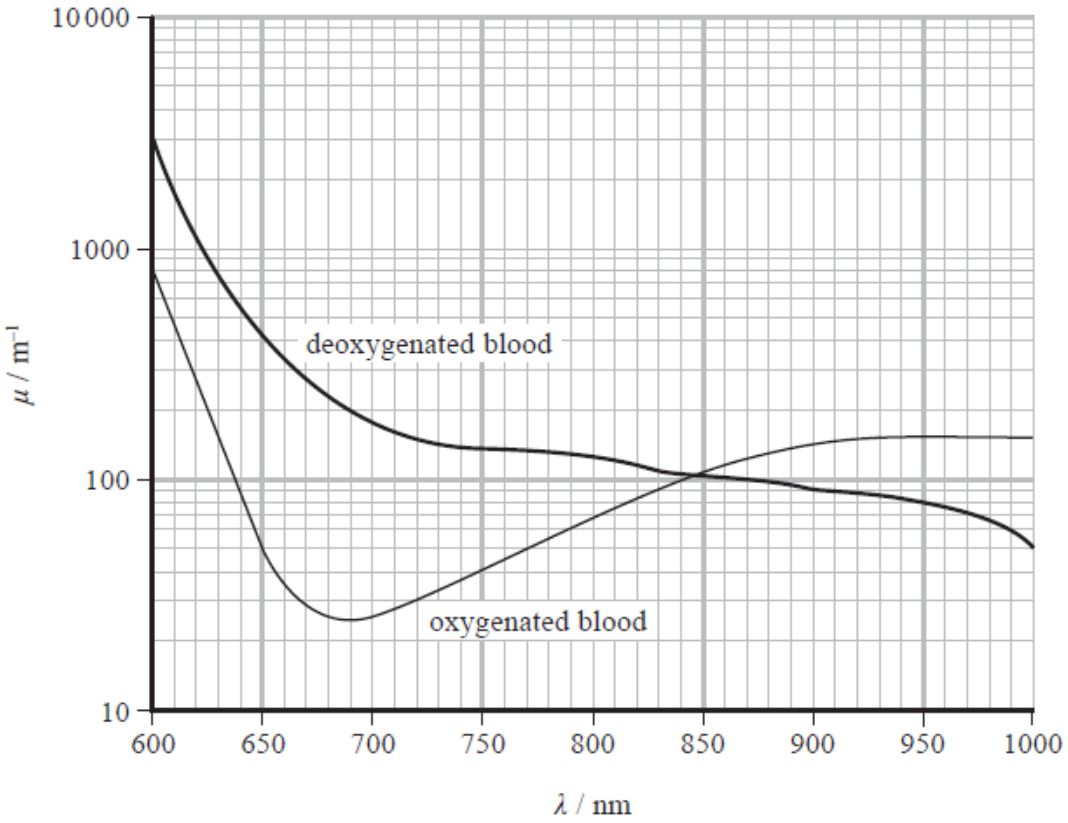
The intensity I of electromagnetic radiation received by the detector, after passing through a thickness x of blood, is given by

$$I = I_0^{e-\mu x}$$

where I_0 is the intensity that would have been received if the blood were not present and μ is the attenuation coefficient of blood.

The red LED emits visible light of wavelength 650 nm and the infrared LED emits infrared of wavelength 950 nm.

The graph shows how μ varies with wavelength λ for oxygenated blood and deoxygenated blood.



I_0 for the infrared LED is 1.8 W m^{-2}.

Calculate I for the infrared after passing through 1.4 mm of oxygenated blood.

(3)

.....

.....

.....

.....

.....

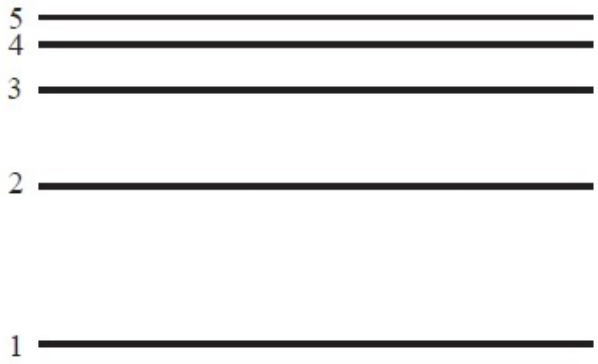
.....

.....

I = ...

(Total for question = 3 marks)

Q7. The diagram shows five energy levels in an atom.



Electromagnetic radiation is incident on the atom.

Which transition would be caused by the absorption of the lowest frequency of radiation?

☒ **A** 1 to 5

☒ **B** 1 to 2

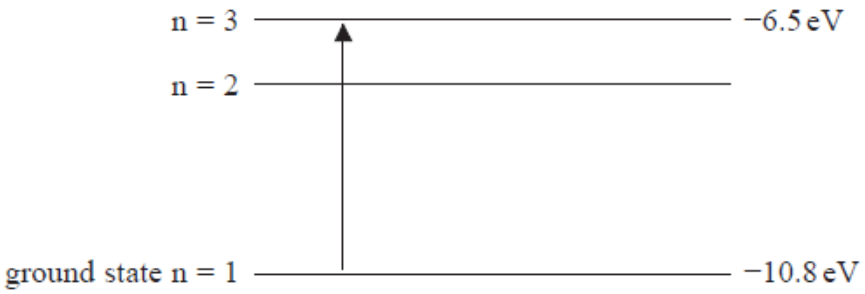
☒ **C** 4 to 5

☒ **D** 5 to 4

(Total for Question = 1 mark)

Q8.

An electron in its ground state absorbs electromagnetic radiation of wavelength λ.
The energy level diagram represents the resulting energy transition of the electron.



The electron eventually returns to its ground state.

Explain, with reference to the energy level diagram, how this may result in the emission of radiation with a longer wavelength than λ.

(3)

.....

.....

.....

.....

.....

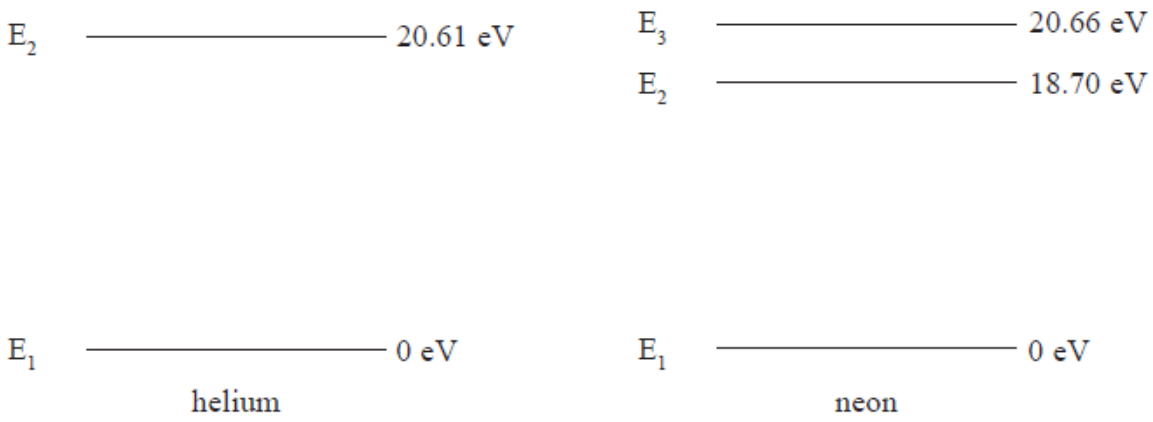
.....

(Total for question = 3 marks)

Q9.

A helium-neon gas laser is often used in the laboratory as a source of high intensity, coherent, monochromatic light.

The diagram shows some of the energy levels above the ground level E_3 for helium atoms and for neon atoms. The highest shown levels for helium atoms and neon atoms are almost identical.



Helium atoms in the gas are excited to level E_2 by the current passing through the laser. They collide at high speed with neon atoms. Because the energies are so similar, the energy is transferred from the helium atoms to the neon atoms. The neon atoms become excited in turn to level E_3. As the neon atoms subsequently drop to level E_2 they emit photons.

(a) Explain what is meant by a photon.

(2)

.....

.....

.....

(b) Calculate the frequency of the photons produced as the neon atoms drop from level E_3 to level E_2.

(3)

.....

.....

.....

.....

Frequency = ...

(c) An electron in level E_3 of neon has 0.05 eV more energy than an electron in level E_2 of helium.

Suggest the source of the energy to make up this difference.

(1)

.....

.....

(d) The photograph shows a device for making a vertical slit with variable width.



© THORLABS, Inc.

When the slit is fully open a laser beam is shone through it and a single point of light is seen on a screen.

As the slit is reduced in width the point of light becomes a horizontal line that gets longer as the slit gets narrower.

Explain this observation

(3)

.....

.....

.....

.....

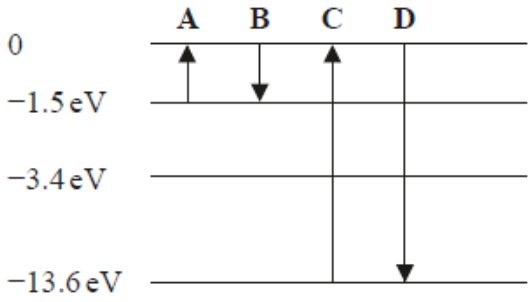
.....

.....

(Total for question = 9 marks)

Q10.

Some of the energy levels of an atom of a gas are shown.



During which transition, A, B, C or D, is electromagnetic radiation with the shortest wavelength emitted?

☒ **A**

☒ **B**

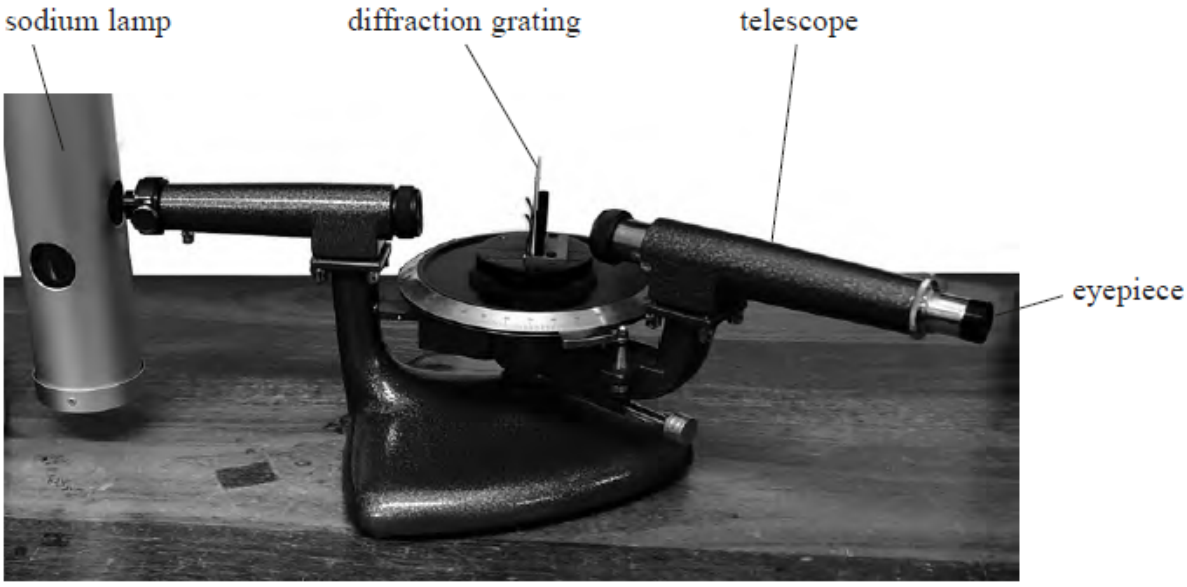
☒ **C**

☒ **D**

(Total for question = 1 mark)

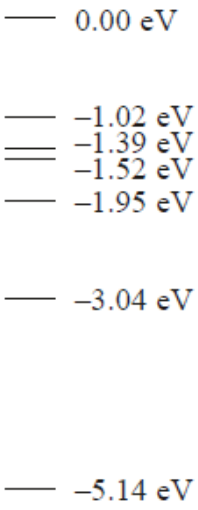
Q11.

The photograph shows a school spectrometer.



The spectrometer allows parallel rays of light to be passed through a diffraction grating and the resulting angles of diffraction to be measured.

The diagram shows some of the energy levels in a sodium atom.



Add an arrow to the diagram to show the transition involved in the emission of yellow light of wavelength 589 nm.

Show your working below.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

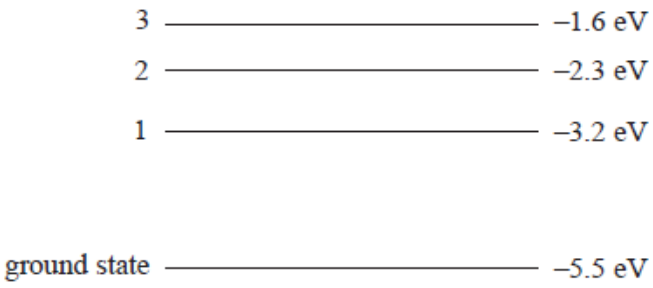
.....

.....

(Total for question = 4 marks)

Q12.

The diagram shows the lowest energy levels for a certain atom.



A photon with energy 3.2 eV is absorbed.

An electron could move from

(1)

☒ **A** ground state to level 1.

☒ **B** ground state to level 2.

☒ **C** level 1 to ground state.

☒ **D** level 2 to ground state.

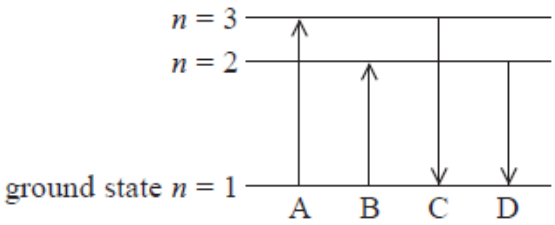
(Total for question = 1 mark)

Q13.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer

with a cross ☒.

The energy level diagram shows four possible energy transitions for an electron in an atom.



Which arrow shows the transition made by the electron when the atom emits radiation with the longest wavelength?

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(Total for question = 1 mark)

Q14.

When a large potential difference is applied to a discharge tube, the gas in the discharge tube emits coloured light. When this light is passed through a diffraction grating, an emission spectrum which is made up of a series of lines of different wavelengths may be seen.

The photographs show the spectra produced from a tube containing hydrogen and a tube containing helium.

Hydrogen:



Helium:



* Explain why different elements produce spectra containing different specific wavelengths of

light.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

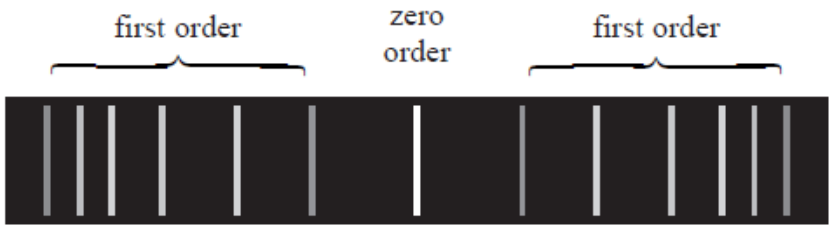
.....

.....

Q15.

In a spectrometer, light from a tube of hot gas is passed through a diffraction grating.

The diagram shows the zero order and the first order maxima for the line spectrum produced.



Explain why lines of different wavelengths are produced by the gas.

(4)

.....

.....

.....

.....

.....

.....

.....

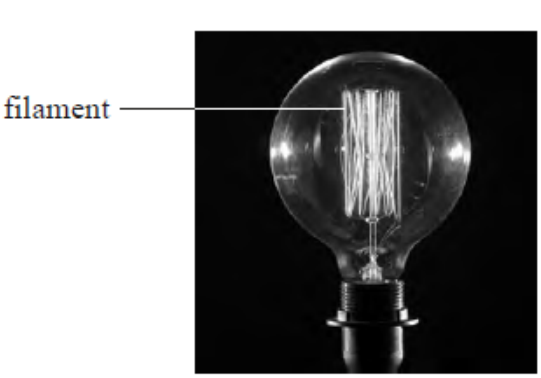
.....

Q16.

Filament and fluorescent are two types of light bulb.

Filament light bulbs contain a tightly coiled wire filament, surrounded by an inert gas and encased in a thin glass bulb. When the potential difference (p.d.) across the bulb is sufficient, the filament heats up, emitting visible light.

Fluorescent light bulbs use a long tube of glass containing a small amount of mercury. When a sufficient p.d. is applied across the ends of the tube, electrons moving through the tube cause the mercury to become a vapour and emit photons in the ultraviolet part of the electromagnetic spectrum. The collisions of these photons with the phosphor coating of the tube result in the emission of photons of visible light.



Filament bulb



Fluorescent bulb

(i) Explain how the wire in the filament lamp gets hot when a p.d. is applied.

(2)

.....

.....

.....

.....

.....

(ii) Explain how the fluorescent bulb emits photons when sufficient p.d is applied.

(2)

.....

.....

.....

.....

.....

.....

(Total for question = 4 marks)

Q17.

Our understanding of the atom has developed over time, from early models in which atoms were considered to be hard incompressible spheres, through to the nuclear model of the atom and the ladder model in which electrons exist in a discrete number of allowed energy states.

In the energy ladder model of the atom, electrons exist in a discrete number of allowed energy states. The collision of electrons with gold atoms may lead to the production of high frequency electromagnetic radiation.

Explain how high frequency electromagnetic radiation may be produced when electrons collide with atoms in a metal.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

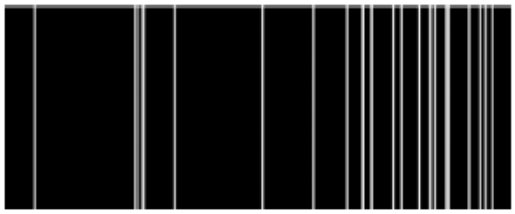
(Total for question = 4 marks)

Q18.

A fine-beam tube is used for investigating properties of electrons.

An electron beam is produced inside a spherical glass bulb. The bulb contains neon gas at a very low pressure.

* Interactions between electrons and the neon atoms in the tube make the beam visible. Part of the spectrum of visible light produced by these interactions is shown.



(Source: © MoFarouk/Shutterstock)

Explain the process that results in the emission of this spectrum. Your answer should include reference to
energy levels in atoms.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q19.

Barnard's star is a red dwarf star in the vicinity of the Sun. The wavelength of a line in the spectrum of light emitted from Barnard's star is measured to be 656.0 nm. The same light produced by a source in a laboratory has a wavelength of 656.2 nm.

Visible light from the star originates from the photosphere. In the photosphere of Barnard's star, hydrogen and helium atoms are at a temperature of 3100 K.

(i) Calculate the mean kinetic energy of an atom in the photosphere at a temperature of 3100 K.

(2)

.....

.....

.....

.....

Mean kinetic energy = ...

(ii) Describe how these atoms emit visible light.

(2)

.....

.....

.....

.....

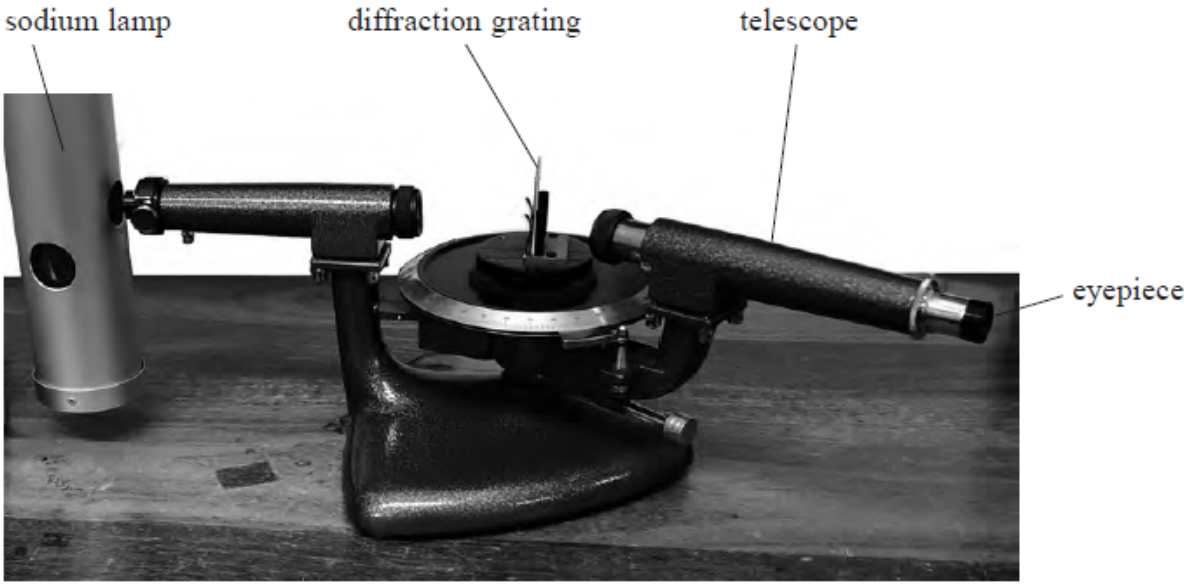
.....

.....

(Total for question = 4 marks)

Q20.

The photograph shows a school spectrometer.



The spectrometer allows parallel rays of light to be passed through a diffraction grating and the resulting angles of diffraction to be measured.

The spectrometer and diffraction grating are used to analyse the light from a sodium lamp. In the sodium lamp, sodium is heated until it becomes a vapour and an electric current is passed through it. The vapour then emits light.

After the light passes through the diffraction grating a line spectrum is observed.

(i) Explain why only certain wavelengths are observed.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(ii) Diffraction gratings with the following spacings are available:

$d / 10^{-6}$ m	1.0	1.7	2.0	3.3

Explain which would be the best spacing to use to measure the diffraction angle for the third order maximum for yellow light of wavelength 589 nm.

(3)

.....

.....

.....

.....

.....

.....

(Total for question = 9 marks)

Q21.

In 2016 the Breakthrough Starshot initiative was announced. This project intends to send a fleet of small probes to Proxima Centauri, the nearest star to the Sun. This journey would take about twenty years.

The composition of a star can be determined by analysis of its absorption spectrum.

Explain why there are certain specific frequencies missing from the spectrum.

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 5 marks)

Q22.

A solar panel uses electromagnetic radiation from the Sun to generate electricity.
In one installation a sensor in the solar panel measures the intensity of radiation arriving from different directions. A motor rotates the solar panel so that it always faces the brightest part of the sky.

When light is incident on an LDR, electrons move to a higher energy level where they become conduction electrons. This causes the resistance of the LDR to decrease.

A student suggests that this is an example of the photoelectric effect. The student is not correct.

Compare and contrast the photoelectric effect with the effect of radiation incident on an LDR.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for question = 6 marks)

Q23. When the photoelectric effect was first observed in the nineteenth century, scientists could not explain it using the wave theory of light.

In 1905 Albert Einstein published a paper, for which he won a Nobel Prize, explaining the photoelectric effect by using a photon model of light, rather than a wave model.

(a) Explain what is meant by a photon.

(2)

.....

.....

.....

.....

*(b) Explain why the following observations may be understood by using a photon model of light, rather than a wave model.

- Light above a certain frequency causes the emission of electrons from the surface of a metal. This emission occurs instantaneously.
- Light below a certain frequency will not result in the emission of electrons however long it illuminates the surface.

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(c) Zinc has a work function of 4.3 eV.

(i) Calculate the threshold frequency for zinc.

(3)

.....

.....

.....

.....

.....

Threshold frequency = ...

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

(1)

.....

(Total for Question = 11 marks)

Q24.

In 1925 Franck and Hertz were awarded the Nobel Prize in Physics "for their discovery of the laws governing the impact of an electron upon an atom".
In one of their experiments, a beam of high-speed electrons is fired through mercury vapour.

An electron in the beam collides with a mercury atom, which becomes excited. The atom returns to its initial state by emitting electromagnetic radiation of a single frequency.

An electron travelling with a speed of 2.5×10^6 m s^{-1} collides with a stationary mercury atom and continues at a speed of 2.1×10^6 m s^{-1}.

The table gives a range of wavelengths for ultraviolet, visible and infrared radiation.

Type of radiation	Typical range of wavelengths / m
ultraviolet	2.0×10^{-7} to 4.0×10^{-7}
visible	4.0×10^{-7} to 7.8×10^{-7}
infrared	7.8×10^{-7} to 1.0×10^{-3}

Deduce the type of radiation that is emitted by the stationary mercury atom.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

Type of radiation .....

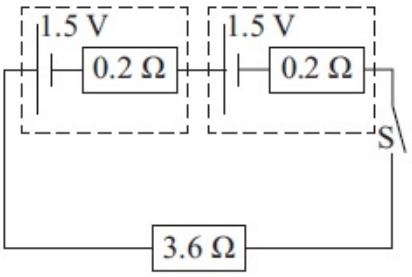
(Total for question = 4 marks)

Q25.

Electrically heated gloves are used by skiers and climbers to provide extra warmth for their hands.



Each glove has a heating element of resistance 3.6 Ω. Two cells each of e.m.f. 1.5 V and internal resistance 0.2 Ω are used to operate each heating element.



(a) When the switch is closed:

(i) Calculate the total resistance in the circuit

(1)

.....

Total resistance = ...

(ii) Calculate the current in the heating element

(2)

.....

.....

Current = ...

(iii) Calculate the power output from the heating element.

(2)

.....

.....

Power output = ...

(b) When in use the internal resistance of each cell gradually increases.

State and explain the effect this will have on the power output of the heating element.

(3)

.....

.....

.....

.....

.....

.....

(Total for question = 8 marks)