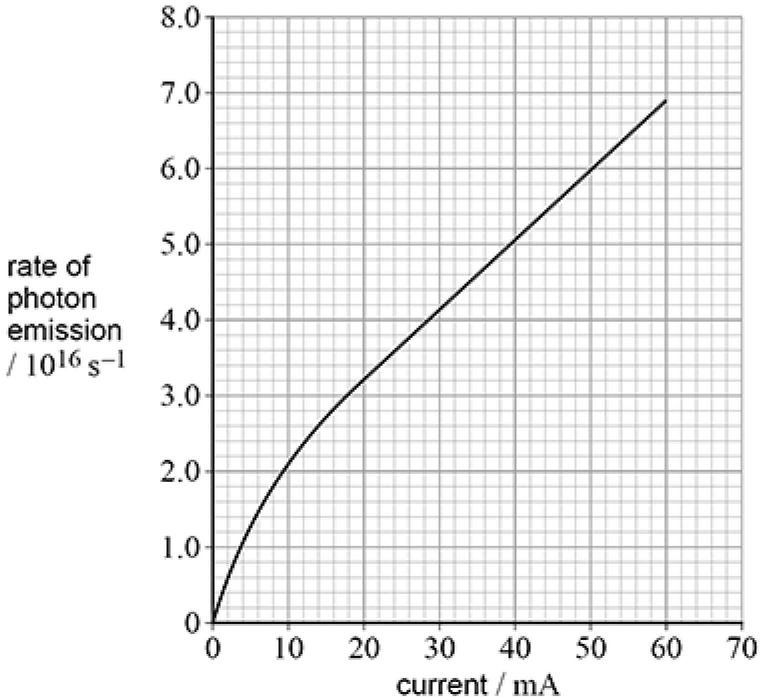
1. (a) A light emitting diode (LED) emits blue light with a wavelength of 440 nm. The rate of photon emission is $3.0 \times 10^{16}\ s^{-1}$.

Show that the power output of the LED is approximately 0.014 W.

(2)

(b) A different LED emits red light with a wavelength of 660 nm.
The graph below shows how the rate of photon emission varies with current up to the maximum operating current of this LED.



A student claims that the red LED can have twice the power output of the blue LED.

Deduce whether the student's claim is correct.

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(3)

(c) The student has paint that fluoresces when light of any wavelength is incident on it. She coats the blue LED and the red LED with the paint.

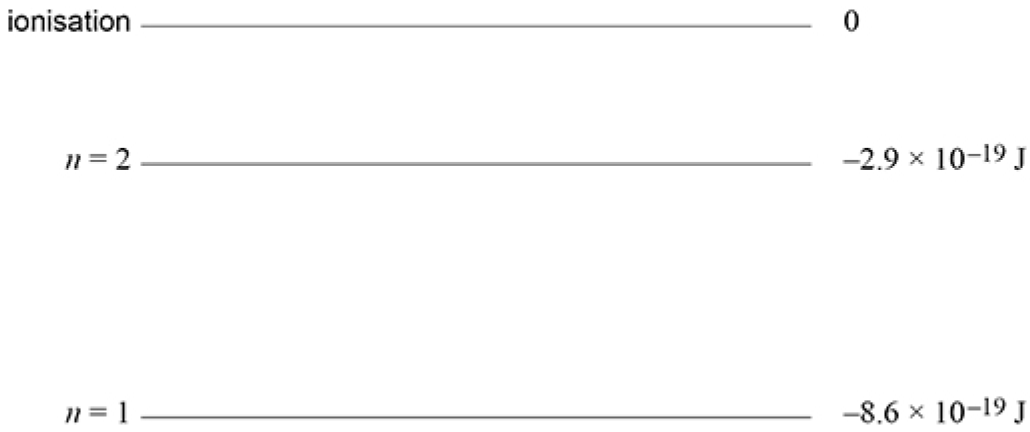
Compare the wavelengths of light emitted by the paint on each LED.

In your answer you should also explain the processes that cause the paint to fluoresce.

(6)

(Total 11 marks)

2. Some energy levels of a lithium atom are shown below.



A free electron with kinetic energy 6.0×10^{-19} J collides with a stationary lithium atom in its $n = 1$ energy level. The lithium atom is excited to the $n = 2$ energy level.

What is the kinetic energy of the free electron after the collision?

A 0.3×10^{-19} J

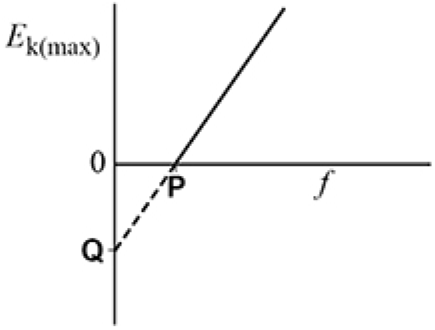
B 2.6×10^{-19} J

C 3.1×10^{-19} J

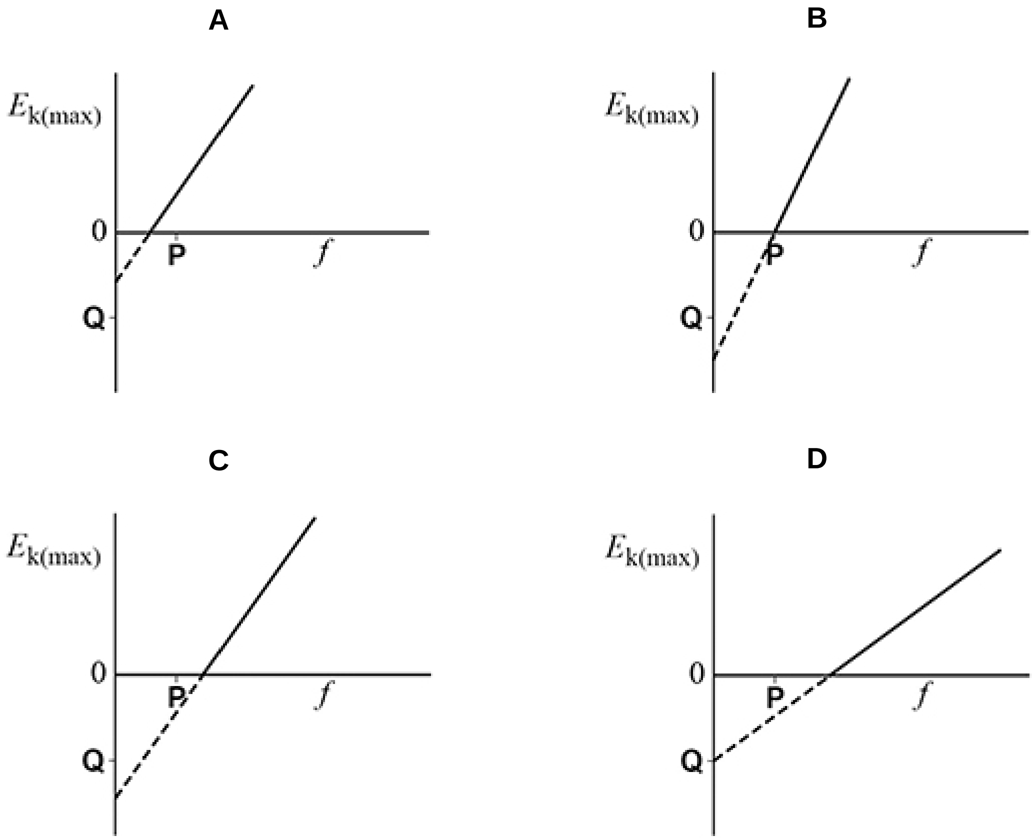
D 5.7×10^{-19} J

(Total 1 mark)

3. The graph shows how the maximum kinetic energy $E_{k(max)}$ of photoelectrons emitted from a metal surface varies with the frequency f of the incident radiation.
P is the intercept on the f axis. **Q** is the intercept on the $E_{k(max)}$ axis.



Which graph shows the variation of $E_{k(max)}$ with f for a metal with a greater work function?



A ⬭

B ⬭

C ⬭

D ⬭

(Total 1 mark)

4. Monochromatic light with a photon energy of 4.1×10^{-19} J is incident on a metal surface. The maximum speed of the photoelectrons released is 4.2×10^{5} m s^{-1}.

What is the work function of the metal?

A 2.5×10^{-19} J ⬭

B 3.3×10^{-19} J ⬭

C 4.1×10^{-19} J ⬭

D 4.9×10^{-19} J ⬭

(Total 1 mark)

5. What is the role of the mercury vapour in a fluorescent tube?

A It absorbs photons of UV light and emits visible light. ⬭

B It absorbs photons of visible light and emits UV light. ⬭

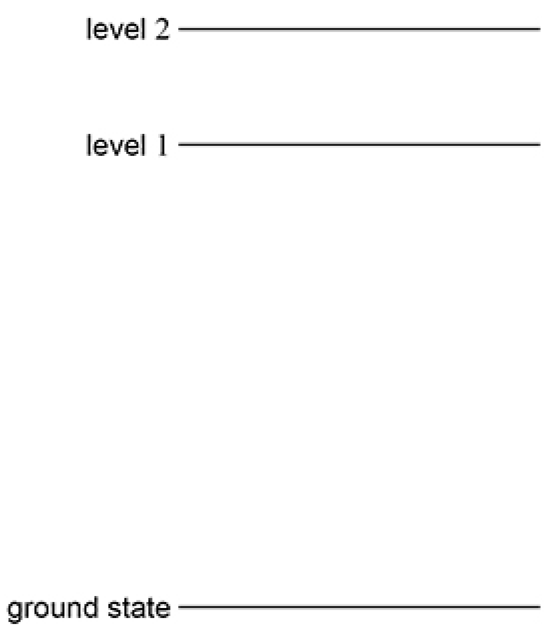
C It emits photons of visible light following ionisation or excitation. ⬭

D It emits photons of UV light following ionisation or excitation. ⬭

(Total 1 mark)

6. The diagram shows the three lowest energy levels for an atom.

The energy levels have been drawn to scale.



Transitions of electrons between these energy levels produce photons of the following frequencies:

4.56×10^{14} Hz
2.46×10^{15} Hz
2.92×10^{15} Hz.

What is the difference in energy between the ground state and energy level 1?

A 0.3×10^{-18} J

B 1.3×10^{-18} J

C 1.6×10^{-18} J

D 1.9×10^{-18} J

(Total 1 mark)

7. A muon and an electron are travelling at the same speed.

Which row gives the particle with the greater kinetic energy and the particle with the longer de Broglie wavelength?

	Greater kinetic energy	**Longer de Broglie wavelength**
A	muon	muon
B	muon	electron
C	electron	muon
D	electron	electron

(Total 1 mark)

8. Scintillation counters are used to detect beta particles. A scintillation counter consists of a scintillation material and a photomultiplier tube (PMT).

(a) Beta particles collide with atoms in the scintillation material, which emits photons of light as a result.

Explain how photons are produced by collisions between beta particles and atoms.

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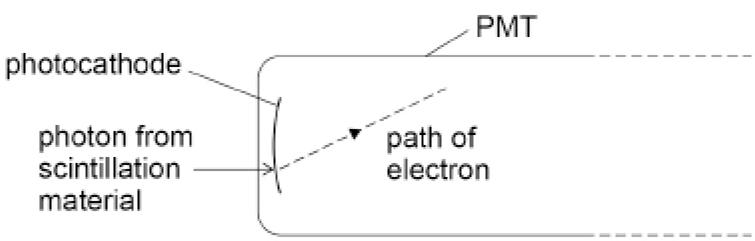
(2)

(b) A photon of light from the scintillation material enters the PMT, as shown in **Figure 1**. The front of the PMT contains a thin photocathode. The photon strikes the photocathode to release an electron.

Figure 1



The longest wavelength of light that releases an electron from this photocathode is 630 nm.

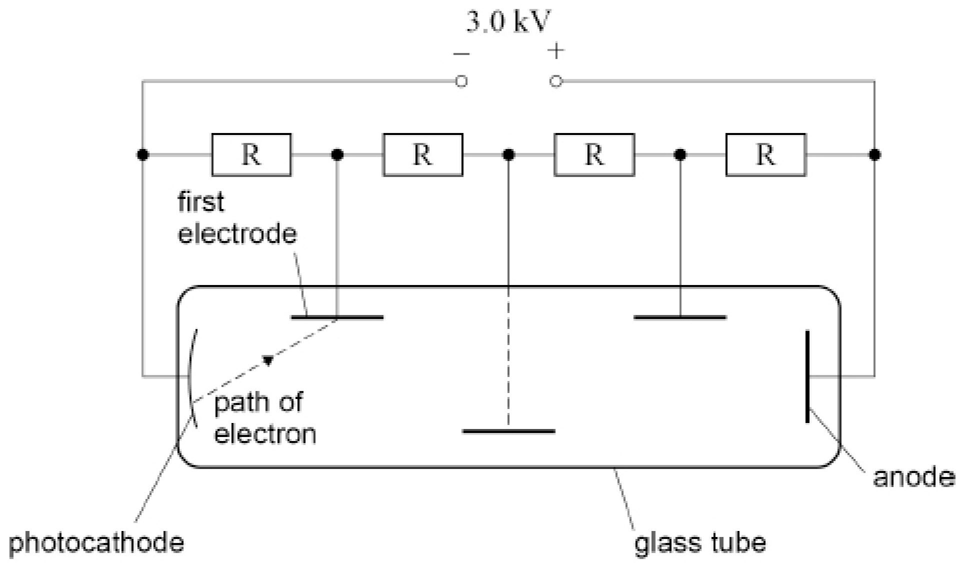
Calculate the minimum photon energy required to remove an electron from the photocathode.

minimum photon energy = ______________ J

(2)

(c) The PMT consists of an evacuated glass tube containing the photocathode, an anode and three metal electrodes, as shown in **Figure 2**.

Figure 2



The electrodes, anode and photocathode are connected to a potential divider consisting of four identical resistors R. The emf of the electrical supply is 3.0 kV.

The potential difference between the photocathode and the first electrode accelerates the electron along the path shown in **Figure 2**.

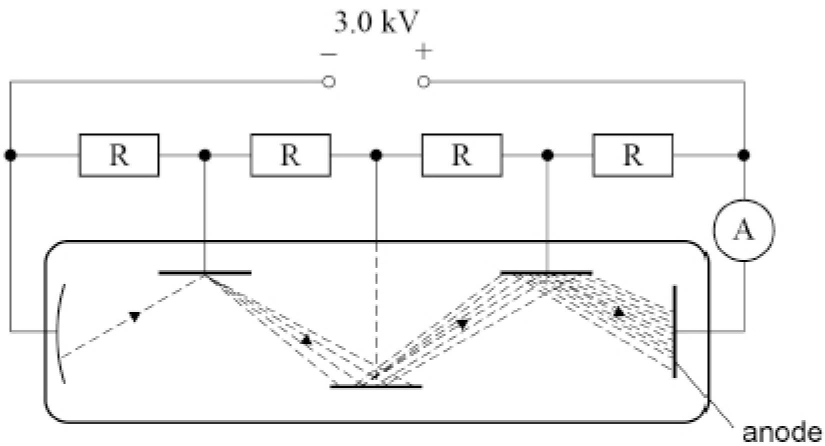
Calculate, in J, the maximum kinetic energy transferred to the electron when it accelerates from the photocathode to the first electrode.

maximum kinetic energy = _______________ J

(2)

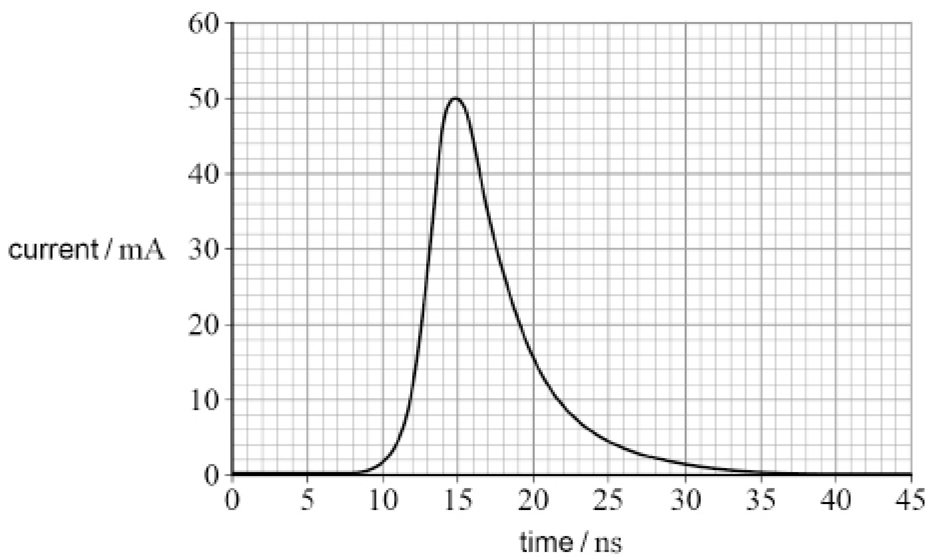
(d) The electron hits the first electrode and causes the release of several electrons. **Figure 3** shows how a series of accelerations and collisions produces a large number of electrons. These electrons hit the anode and produce a pulse of current in an ammeter.

Figure 3



The **Figure 4** shows the variation of current in the ammeter with time due to this pulse.

Figure 4



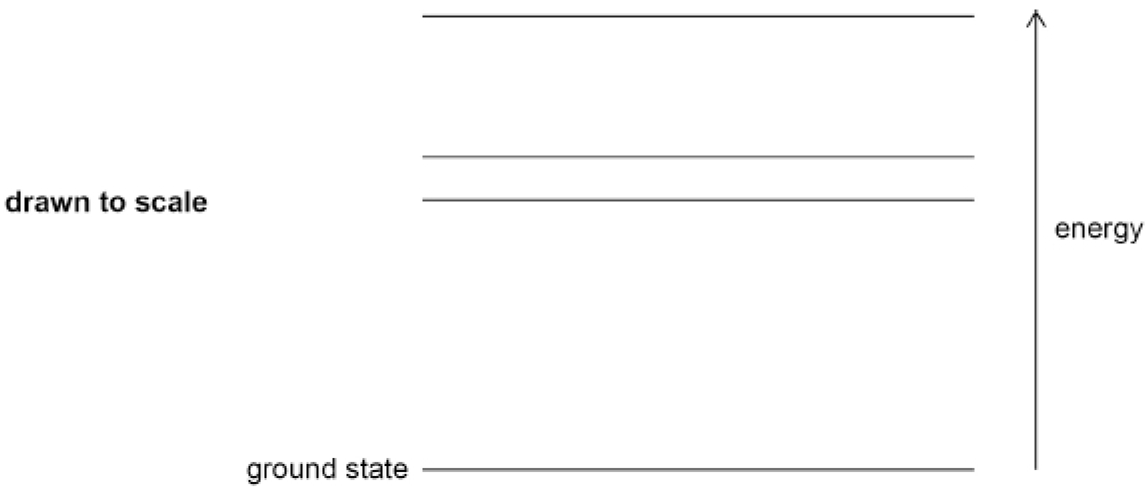
Determine the number of electrons that flow through the ammeter.

number of electrons = _______________

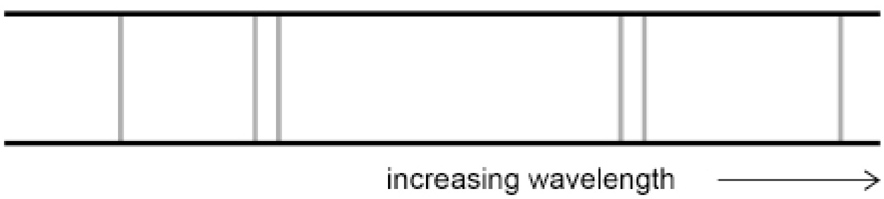
(4)

(Total 10 marks)

9. The diagram shows four energy levels of an atom drawn to scale. These energy levels give rise to part of an emission spectrum.

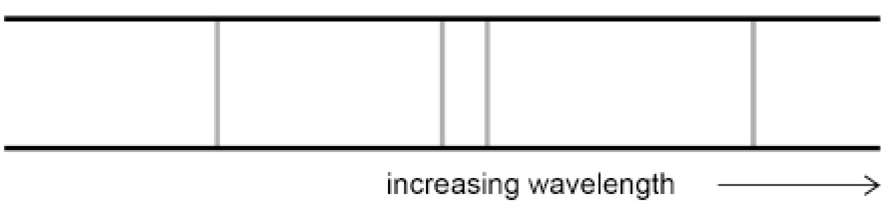


Which pattern of lines will be observed from these energy levels?

A


B


C


D


(Total 1 mark)

10. A particle has a kinetic energy of E_k and a de Broglie wavelength of λ.

What is the de Broglie wavelength when the particle has a kinetic energy of $4E_k$?

A $\frac{\lambda}{2}$ ⬭

B $\frac{\lambda}{\sqrt{2}}$ ⬭

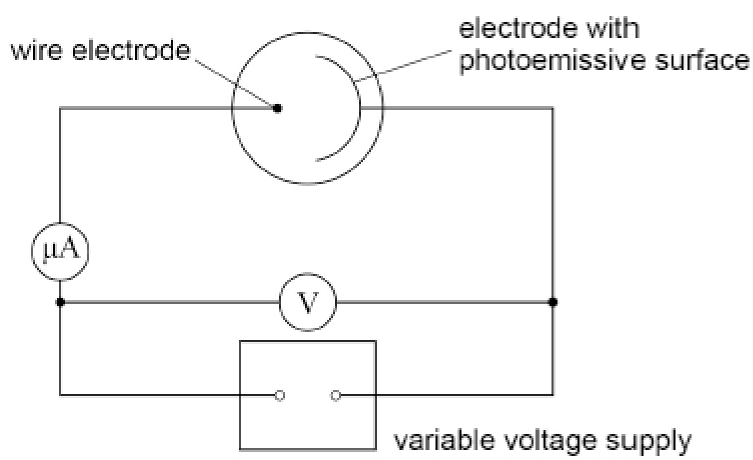
C $\sqrt{2}\lambda$ ⬭

D 2λ ⬭

(Total 1 mark)

11. **Figure 1** shows an arrangement used to investigate the photoelectric effect.

Figure 1



A current is measured on the microammeter only when electromagnetic radiation with a frequency greater than a certain value is incident on the photoemissive surface.

(a) Explain why the frequency of the electromagnetic radiation must be greater than a certain value.

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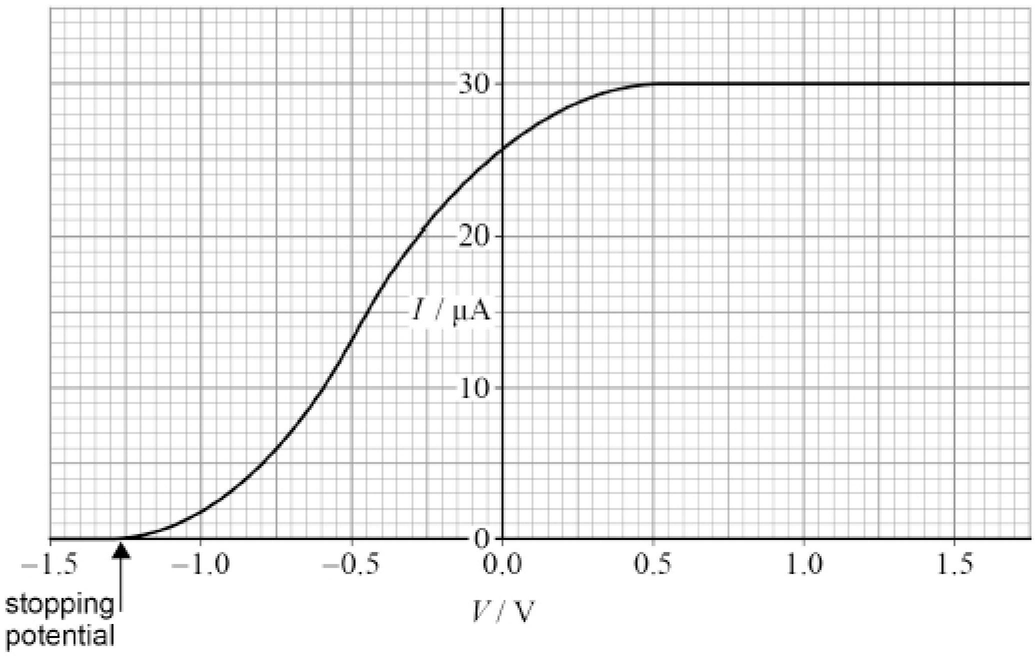
(2)

The apparatus in **Figure 1** is used with a monochromatic light source of constant intensity. Measurements are made to investigate how the current I in the microammeter varies with positive and negative values of the potential difference V of the variable voltage supply.

The **Figure 2** shows how the results of the investigation can be used to find the stopping potential.

Figure 2



(b) Determine the number of photoelectrons per second leaving the photoemissive surface when the current is a maximum.

number of photoelectrons per second = _______________

(2)

(c) Explain why I reaches a constant value for positive values of V.

(2)

(d) Explain why I decreases as the value of V becomes more negative.

(3)

(e) The investigation is repeated with a different photoemissive surface that has a smaller value of the work function. The source of electromagnetic radiation is unchanged.

Discuss the effect that this change in surface has on the value of the stopping potential.

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(3)

(Total 12 marks)

12. A photon has energy of 1×10^{18} eV.
An object of mass 0.03 kg has kinetic energy equal to the energy of the photon.

What is the speed of the object?

A 1 m s^{-1} ○

B 3 m s^{-1} ○

C 10 m s^{-1} ○

D 30 m s^{-1} ○

(Total 1 mark)

13. An electron collides with an isolated atom and raises an atomic electron to a higher energy level.

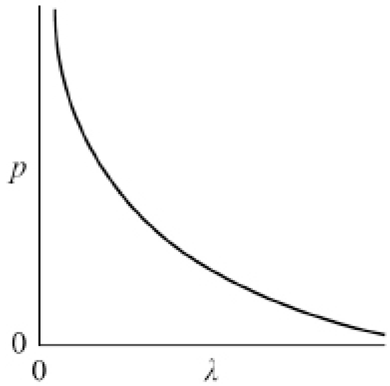
Which statement is correct?

A	The colliding electron is captured by the nucleus of the atom.	⬭
B	A photon is emitted when the electron rises to the higher energy level.	⬭
C	An electron is emitted when the excited electron returns to the ground state.	⬭
D	The colliding electron transfers energy to the atomic electron.	⬭

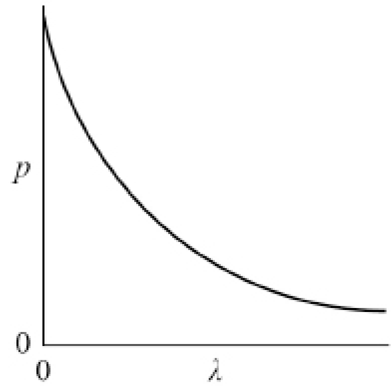
(Total 1 mark)

14. Which graph shows the variation of momentum p with wavelength λ of a photon?

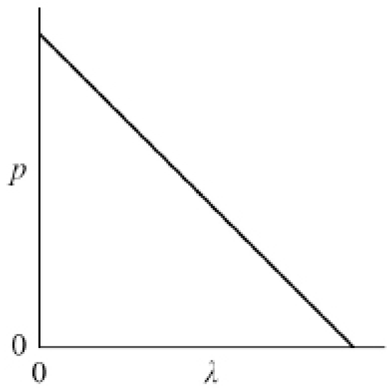
A



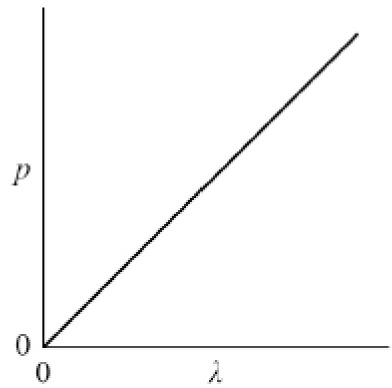
B



C



D



A ⬭

B ⬭

C ⬭

D ⬭

(Total 1 mark)

15. Scientists at CERN have produced atoms of antihydrogen.
An atom of antihydrogen contains the antiparticle of the proton and the antiparticle of the electron.

(a) State what is meant by an antiparticle.

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(2)

(b) Complete the table with the names of the antiparticles in an atom of antihydrogen.

Name of particle	**Name of antiparticle**
proton	
electron	

(2)

(c) The particles in antihydrogen can be made by pair production.

Calculate the total minimum energy, in J, needed to produce the particles in one atom of antihydrogen.

energy = ______________________ J

(3)

(d) Line emission spectra of hydrogen and antihydrogen have been compared.

Explain in terms of energy changes how line emission spectra are produced.

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(3)

(Total 10 marks)

16. Photons of energy 1.0×10^{-18} J are incident on a metal surface and cause the emission of electrons from the metal surface.

Which statement about the emitted electrons is correct?

A They each have a kinetic energy of 1.0×10^{-18} J. ☐

B They each have a kinetic energy that is a multiple of 1.0×10^{-18} J. ☐

C Their mean kinetic energy is 1.0×10^{-18} J. ☐

D The kinetic energy of each must be less than 1.0×10^{-18} J. ☐

(Total 1 mark)

17. Evidence of the wave-like properties of electrons is

A the emission of electrons when short-wavelength light falls on a metal surface. ☐

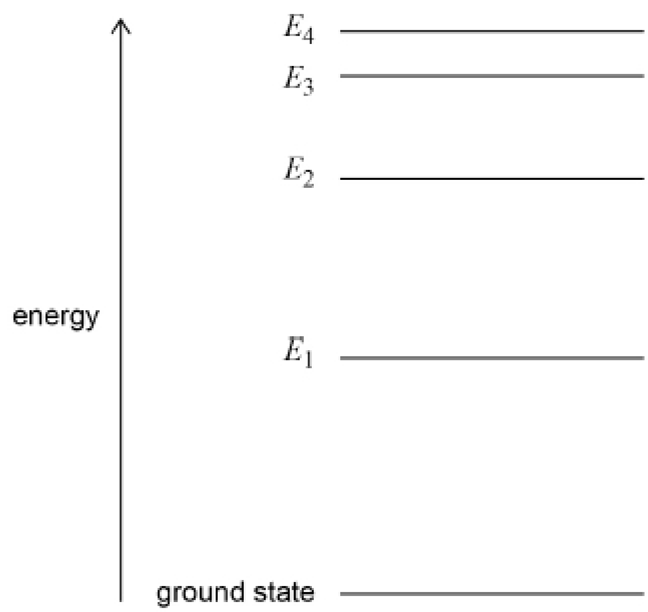
B the movement of electrons in an electric current. ☐

C the diffraction of electrons by a metal crystal. ☐

D the annihilation of an electron with a positron. ☐

(Total 1 mark)

18. The diagram shows the energy levels in an atom drawn to scale. A transition from E_4 to E_2 causes the emission of a photon of green light.



Which transition could cause the emission of a photon of red light?

A E_2 to E_1 ☐

B E_3 to E_1 ☐

C E_3 to E_2 ☐

D E_4 to E_1 ☐

(Total 1 mark)

19. An electron collides with an isolated atom and raises an orbiting electron to a higher energy level.

Which statement is correct?

A The colliding electron is captured by the nucleus of the atom. ☐

B A photon is emitted when the electron rises to the higher energy level. ☐

C An electron is emitted when the excited electron returns to the ground state. ☐

D Energy is transferred from the colliding electron to the orbiting electron. ☐

(Total 1 mark)

20. The table shows results of an experiment to investigate how the de Broglie wavelength λ of an electron varies with its velocity v.

v / 10^7 m s^{-1}	λ / 10^{-11} m
1.5	4.9
2.5	2.9
3.5	2.1

(a) Show that the data in the table are consistent with the relationship $\lambda \propto \frac{1}{v}$

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(2)

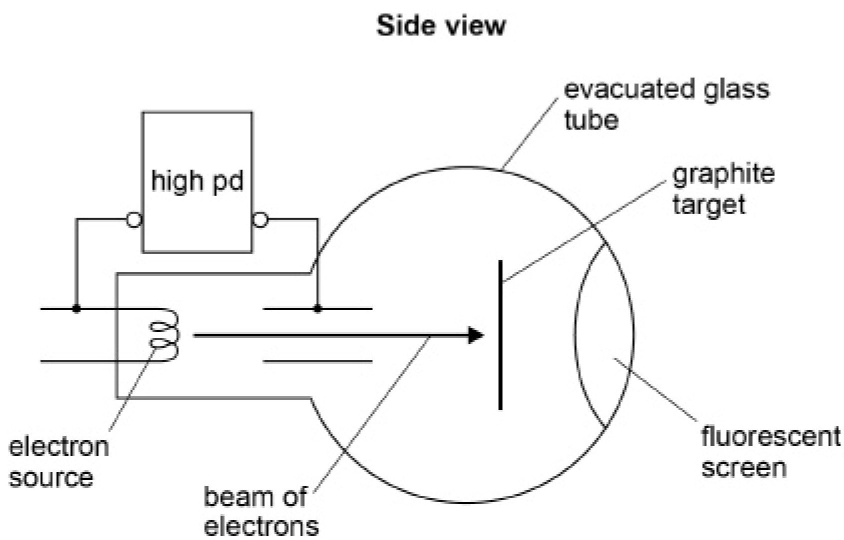
(b) Calculate a value for the Planck constant suggested by the data in the table.

Planck constant = ____________________ J s

(2)

(c) **Figure 1** shows the side view of an electron diffraction tube used to demonstrate the wave properties of an electron.

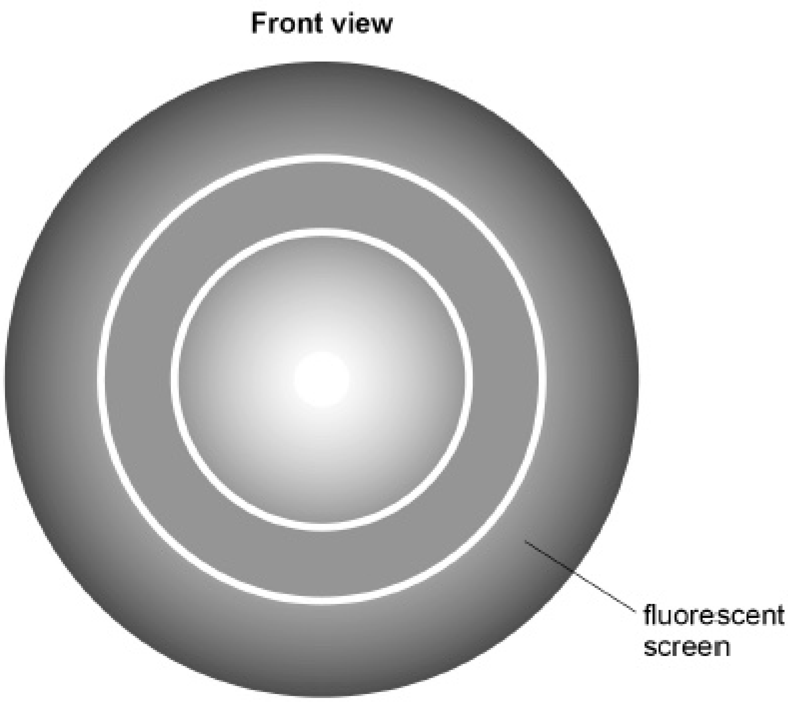
Figure 1



An electron beam is incident on a thin graphite target that behaves like the slits in a diffraction grating experiment. After passing through the graphite target the electrons strike a fluorescent screen.

Figure 2 shows the appearance of the fluorescent screen when the electrons are incident on it.

Figure 2



Explain how the pattern produced on the screen supports the idea that the electron beam is behaving as a wave rather than as a stream of particles.

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(3)

(d) Explain how the emission of light from the fluorescent screen shows that the electrons incident on it are behaving as particles.

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(3)

(Total 10 marks)

21. Photons of wavelength 290 nm are incident on a metal plate. The work function of the metal is 4.1 eV

What is the maximum kinetic energy of the emitted electrons?

A 0.19 eV ○

B 4.3 eV ○

C 6.9 eV ○

D 8.4 eV ○

(Total 1 mark)

22. In a discharge tube a high potential difference is applied across hydrogen gas contained in the tube. This causes the hydrogen gas to emit light that can be used to produce the visible line spectrum shown in **Figure 1**.

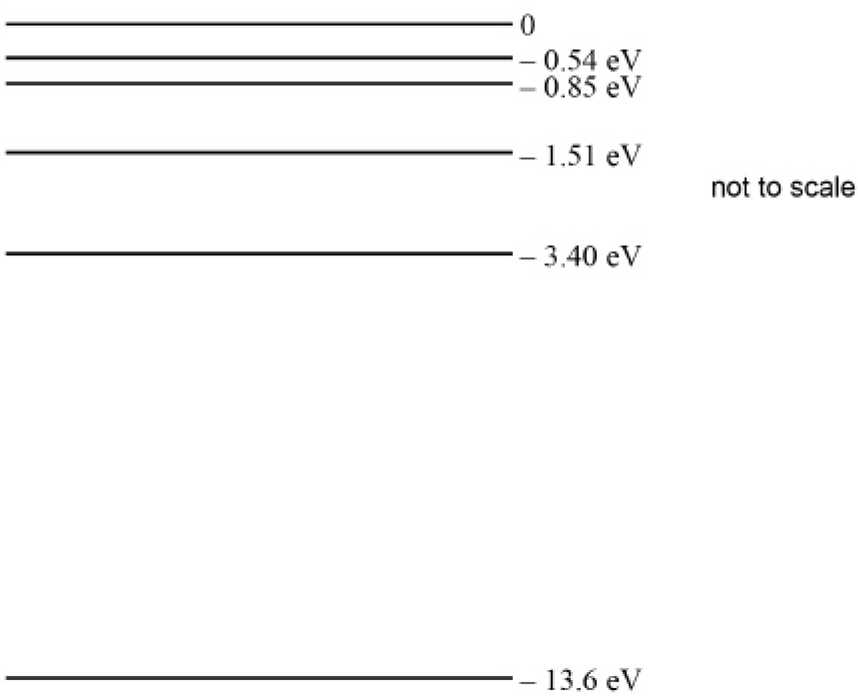
Figure 1

The visible line spectrum in **Figure 1** has been used to predict some of the electron energy levels in a hydrogen atom.

The energy levels predicted from the visible line spectrum are those between 0 and −3.40 eV in the energy level diagram.

Some of the predicted energy levels are shown in **Figure 2**.

Figure 2



(a) Calculate the energy, in eV, of a photon of light that has the lowest frequency in the visible hydrogen spectrum shown in **Figure 1**.

energy of photon = ____________________________ eV

(3)

(b) Identify the state of an electron in the energy level labelled 0.

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(1)

(c) Identify the state of an electron that is in the energy level labelled –13.6 eV.

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(1)

(d) Explain why the energy levels are negative.

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(1)

(e) Discuss how the discharge tube is made to emit electromagnetic radiation of specific frequencies.

In your answer you should:

- explain why there must be a high potential difference across the tube
- discuss how the energy level diagram in **Figure 2** predicts the spectrum shown in **Figure 1**
- show how one of the wavelengths of light is related to two of the energy levels in the energy level diagram.

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(6)

(Total 12 marks)

23. When light of a certain frequency greater than the threshold frequency of a metal is directed at the metal, photoelectrons are emitted from the surface.
The power of the light incident on the metal surface is doubled.

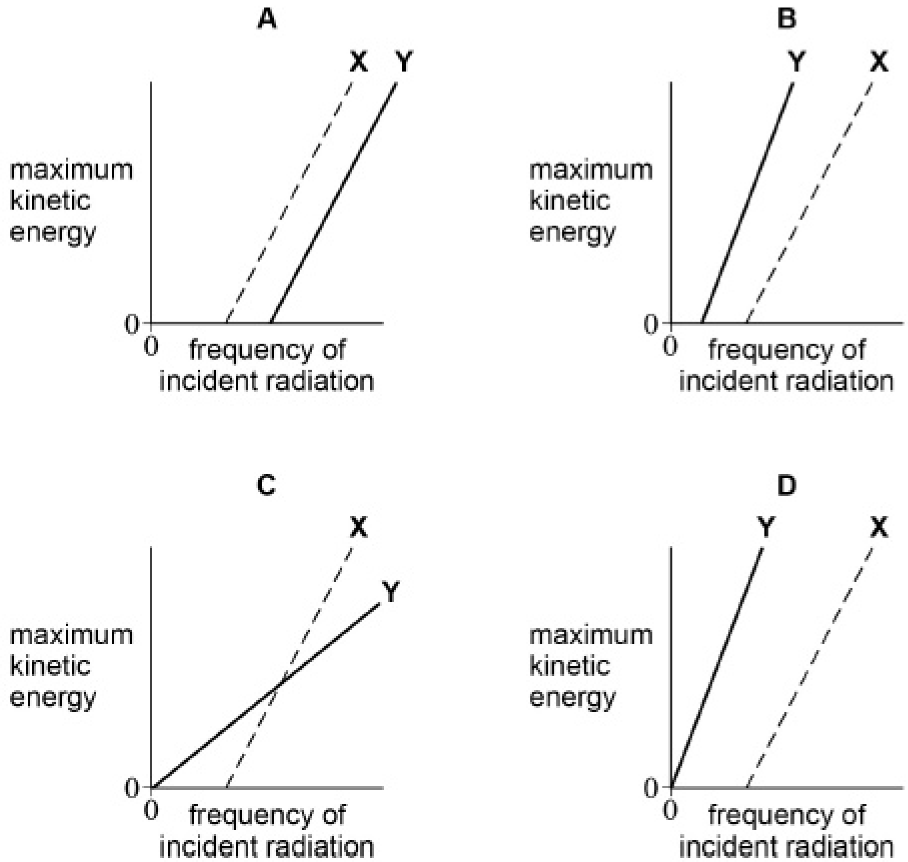
Which row shows the effect on the maximum kinetic energy and the number of photoelectrons emitted per second?

	Maximum kinetic energy	**Number of photoelectrons emitted per second**	
A	remains unchanged	remains unchanged	⬭
B	doubles	remains unchanged	⬭
C	remains unchanged	doubles	⬭
D	doubles	doubles	⬭

(Total 1 mark)

24. Line **X** on the graphs below shows how the maximum kinetic energy of emitted photoelectrons varies with the frequency of incident radiation for a particular metal.

Which graph shows the results for a metal **Y** that has a higher work function than **X**?



A ⬭

B ⬭

C ⬭

D ⬭

(Total 1 mark)

25. (a) The mercury atoms in a fluorescent tube are excited and then emit photons in the ultraviolet region of the electromagnetic spectrum.

(i) Explain how the mercury atoms become excited.

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(3)

(ii) Explain how the excited mercury atoms emit photons.

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(2)

(b) Explain how the ultraviolet photons in the tube are converted into photons in the visible part of the electromagnetic spectrum.

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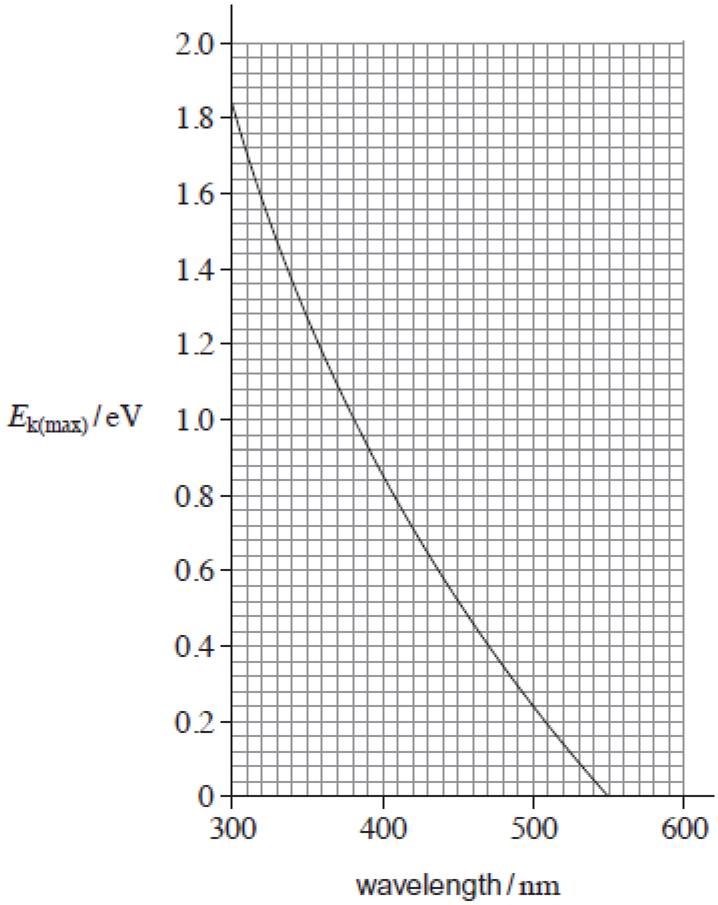
(2)

(Total 7 marks)

26. The maximum kinetic energy, $E_{k(max)}$, of photoelectrons varies with the wavelength of electromagnetic radiation incident on a metal surface.
This variation is shown in the graph.



(a) (i) Define the term work function.

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(2)

(ii) Show that the work function of the metal is approximately 4×10^{-19} J.

Use data from the graph in your calculation.

(3)

(b) Monochromatic radiation is incident on the metal surface.
Photoelectrons are ejected with a maximum speed of 4.6×10^5 m s^{-1}.

Determine the wavelength of the incident radiation.

wavelength ____________________ m

(3)

(Total 8 marks)