6 Which of the following describes threshold frequency?

- ☒ **A** The frequency of light that causes photoelectrons to have maximum kinetic energy.
- ☒ **B** The frequency of light emitted when excited electrons fall to the ground state.
- ☒ **C** The minimum frequency of light that can cause an electron to leave a surface.
- ☒ **D** The maximum frequency of light which excites an electron in the ground state.

(Total for Question 6 = 1 mark)

10 The evidence for the wave nature of electrons came from experiments involving

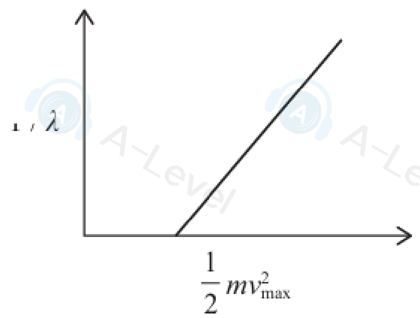
- ☒ **A** diffraction.
- ☒ **B** polarisation.
- ☒ **C** reflection.
- ☒ **D** refraction.

(Total for Question 10 = 1 mark)

10 Light of wavelength λ travelling at speed c is incident on a metal surface.

Photoelectrons are emitted from the surface with a maximum kinetic energy $\frac{1}{2}mv^2_{max}$.

The graph shows the relationship between $1/\lambda$ and $\frac{1}{2}mv^2_{max}$.



Which of the following shows how the gradient of the graph can be used to determine the Planck constant h?

- ☒ **A** $h = \frac{1}{\text{gradient}}$
- ☒ **B** $h = \frac{1}{\text{c} \times \text{gradient}}$
- ☒ **C** $h = \frac{\text{c}}{\text{gradient}}$
- ☒ **D** $h = \text{gradient}$

(Total for Question 10 = 1 mark)

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4 Electromagnetic radiation can be described in terms of a photon model.

Which of the following demonstrates the photon model of light?

- ☒ **A** diffraction patterns
- ☒ **B** Huygens' construction
- ☒ **C** photoelectric effect
- ☒ **D** plane polarisation

(Total for Question 4 = 1 mark)

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4 Which of the following has the largest de Broglie wavelength?

- ☒ **A** an electron travelling at $3.0 \times 10^5\ \text{m s}^{-1}$
- ☒ **B** an electron travelling at $4.0 \times 10^5\ \text{m s}^{-1}$
- ☒ **C** a neutron travelling at $3.0 \times 10^5\ \text{m s}^{-1}$
- ☒ **D** a neutron travelling at $4.0 \times 10^5\ \text{m s}^{-1}$

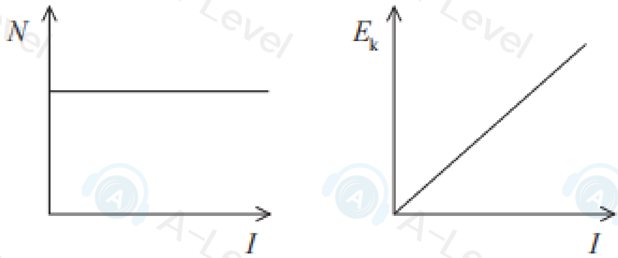
(Total for Question 4 = 1 mark)

4 Ultraviolet light is incident on a metal surface and photoelectrons are released.

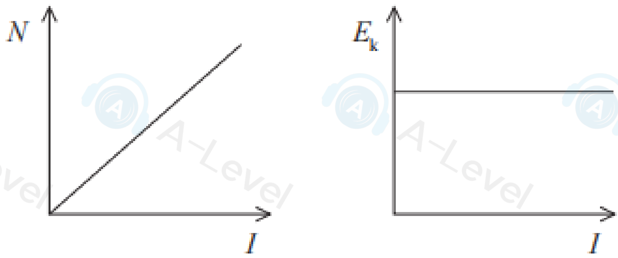
The number of photoelectrons released per second is N and the maximum kinetic energy of the released electrons is E_k.

Which of the following pairs of graphs shows how N and E_k vary with the intensity I of the incident light?

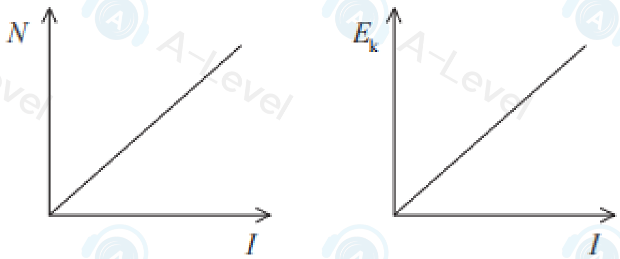
☒ **A**



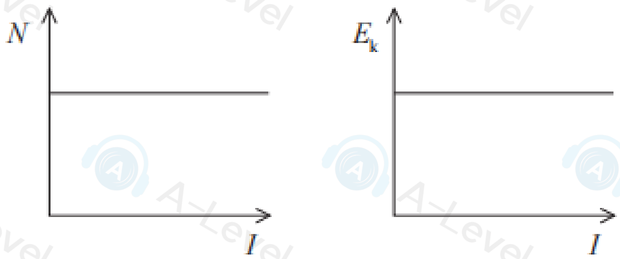
☒ **B**



☒ **C**



☒ **D**



(Total for Question 4 = 1 mark)

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4 Which of the following describes a change in energy of 1 eV?

☒ **A** A charge of 1 C is accelerated across a potential difference of 1 V.

☒ **B** A charge of 1 C passes a point in a time of 1 s.

☒ **C** An electron is accelerated across a potential difference of 1 V.

☒ **D** There is a current of 1 A for a time of 1 s.

(Total for Question 4 = 1 mark)

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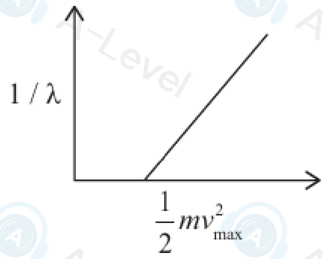

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A $h = \dfrac{1}{\text{gradient}}$

B $h = \dfrac{1}{\text{c} \times \text{gradient}}$

C $h = \dfrac{\text{c}}{\text{gradient}}$

D $h = \text{gradient}$

(Total for Question 10 = 1 mark)

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9 In 1924 de Broglie suggested that electrons have wave properties.
The de Broglie equation states:

$$\lambda = \frac{h}{p}$$

Which of the following is correct?

☒ **A** The de Broglie wavelength is independent of the mass of the particle.

☒ **B** The de Broglie equation can be used to calculate the momentum of a photon.

☒ **C** The term p represents the mass of an electron multiplied by the speed of light.

☒ **D** The value of h depends on the particle involved.

(Total for Question 9 = 1 mark)

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7 Particle X of mass m is moving with velocity v and has a de Broglie wavelength λ.

Particle Y has a de Broglie wavelength 0.25λ.

Which row of the table could give the mass and velocity of particle Y?

	Mass	Velocity
☒ **A**	$0.25m$	v
☒ **B**	$0.5m$	$8v$
☒ **C**	m	$2v$
☒ **D**	$2m$	$4v$

(Total for Question 7 = 1 mark)

7 A fluorescent lamp has a power input of 14 W.

The rate of transfer to thermal energy by the lamp is 9.8 W, the remainder of the energy becoming light.

Which of the following is the efficiency of the lamp?

☒ **A** 0.30

☒ **B** 0.43

☒ **C** 0.70

☒ **D** 1.43

(Total for Question 7 = 1 mark)

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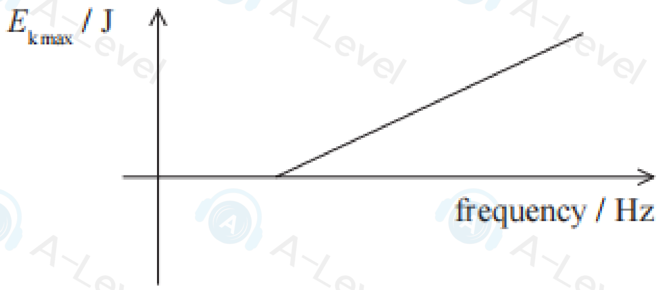
9 Light of varying frequency is incident on a metal electrode and the maximum kinetic energy of the electrons emitted is determined.

The maximum kinetic energy of the electrons varies with the frequency of the incident light as shown.



Which of the following is the numerical value of the gradient?

☒ **A** 6.63×10^{-34}

☒ **B** 9.11×10^{-31}

☒ **C** 1.60×10^{-19}

☒ **D** 3.00×10^{8}

(Total for Question 9 = 1 mark)

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9: When monochromatic light is incident on the surface of a metal, photoelectrons are emitted.

Which of the following statements is correct?

☒ **A** The maximum kinetic energy of the photoelectrons depends on the intensity of the incident light.

☒ **B** The number of photoelectrons emitted per second depends on the frequency of the incident light.

☒ **C** The maximum kinetic energy of the photoelectrons depends on the frequency of the incident light.

☒ **D** The number of photoelectrons emitted per second depends on the work function of the metal.

(Total for Question 9 = 1 mark)

6 When the photoelectric effect occurs, light incident on the surface of a metal releases electrons.

Which of the following is an experimental observation of the photoelectric effect?

- ☒ **A** Electrons are only released after light has been incident for a long time.
- ☒ **B** Increasing the frequency of the light increases the maximum kinetic energy of the released electrons.
- ☒ **C** Increasing the intensity of the light increases the maximum kinetic energy of the released electrons.
- ☒ **D** Only light with a wavelength above a threshold value releases electrons.

(Total for Question 6 = 1 mark)

4 Which of the following is evidence that electrons can behave like waves?

- ☒ **A** Electrons are attracted towards positively charged objects.
- ☒ **B** Electrons can absorb photons and move between energy levels in an atom.
- ☒ **C** Electrons can be diffracted when passing through a thin sheet of graphite.
- ☒ **D** Electrons can be released by photons in the photoelectric effect.

(Total for Question 4 = 1 mark)

19 A photomultiplier is a device that can detect very low intensity light.
In a photomultiplier, a metal plate called a photocathode is connected to the negative terminal of a power supply.

Electromagnetic radiation incident on the photocathode can cause the photoelectric effect.

(a) Describe the photoelectric effect.

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(b) The photomultiplier can only detect electromagnetic radiation that causes the photoelectric effect.

Explain why the photomultiplier cannot detect some frequencies of electromagnetic radiation.

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(c) Visible light has a range of wavelengths from 380 nm to 700 nm.

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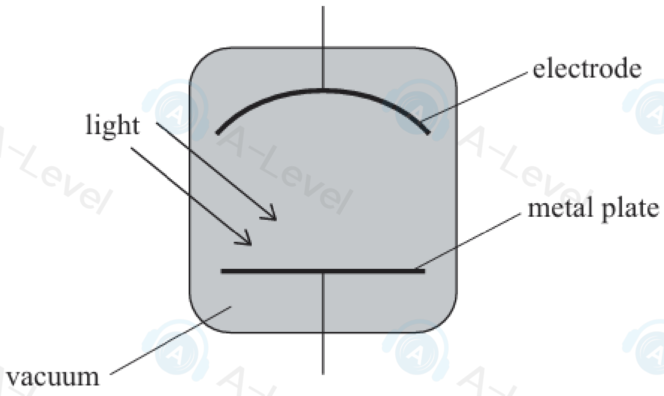
(c) Visible light has a range of wavelengths from 380 nm to 700 nm.

19 A scientist used a photocell to investigate the photoelectric effect.
A photocell consists of a metal plate and an electrode, as shown.



Light incident on the metal plate can cause the photoelectric effect.

(a) A beam of monochromatic light is directed onto the metal plate and causes the photoelectric effect. All photons in the beam have the same energy.

Explain why the beam produces photoelectrons with a range of kinetic energies.

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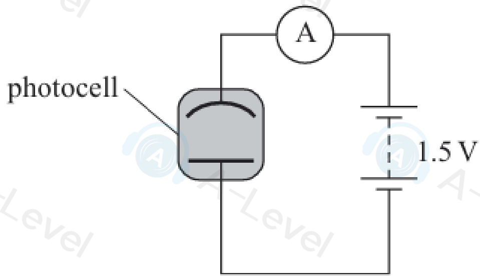
(b) The scientist connected the photocell to an ammeter and battery, as shown.



Photoelectrons are attracted to the electrode, causing a current in the circuit.

The scientist directed different frequencies and intensities of light onto the photocell.

She made the following observations:

- white light with a low intensity caused no current
- white light with a high intensity caused no current
- ultraviolet light with a low intensity caused a current.

Explain what these observations show about the nature of light.

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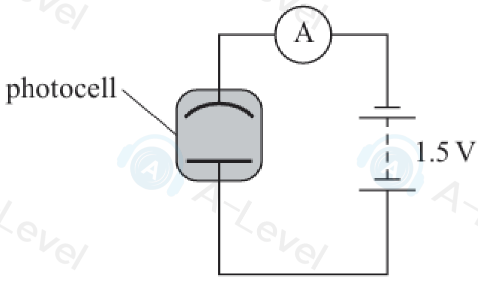
(c) The scientist reversed the connections to the battery, as shown.



The battery has negligible internal resistance.

When photoelectrons have enough kinetic energy to overcome the potential difference across the photocell, there is a current in the circuit.

Ultraviolet light of wavelength 250 nm is incident on the photocell.

Deduce whether there is a current in the circuit.

work function of metal plate in photocell = 6.9×10^{-19} J

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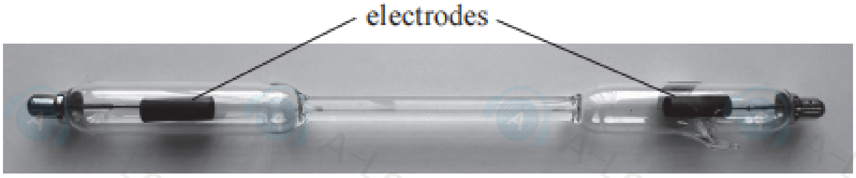
16 In 1857, Heinrich Geissler invented the first gas discharge tube. A sodium gas discharge tube is shown.



When a high potential difference is applied between the electrodes, electrons move through the sodium gas in the tube. The electrons collide with the sodium atoms. The tube then gives out visible light with a wavelength of 589 nm.

(a) Describe the process by which visible light is emitted from the sodium atoms.

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(b) Calculate the energy, in eV, of a photon of visible light with a wavelength of 589 nm.

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Photon energy = ... eV

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(c) Light from the tube was directed through a diffraction grating, labelled as having 300 lines per mm. The diffraction pattern produced was displayed on a flat screen. The student measured the distance s between the central maximum and the first-order maximum on the screen. He also measured the distance D from the diffraction grating to the screen.

Determine whether the labelling of the diffraction grating as having 300 lines per mm was correct.

$s = 0.234$ m
$D = 1.30$ m
$\lambda = 589$ nm

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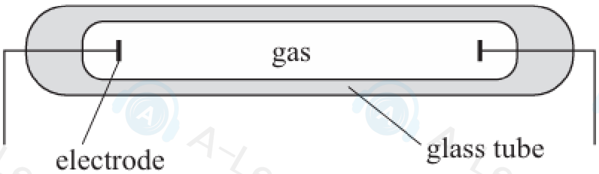
(Total for Question 16 = 9 marks)

17 In the second half of the 19th century, scientists began to investigate interactions between photons and electrons.

(a) A discharge tube is a glass tube containing gas, as shown.



When the discharge tube is connected into an electrical circuit, the gas atoms emit photons. The photons have specific frequencies.

(i) One of the emitted photons has an energy of 3.44×10^{-19} J.

Calculate the frequency of this photon.

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Frequency of photon = ...

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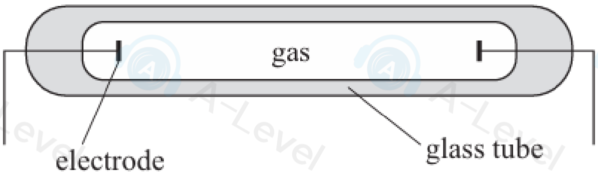
(a) A discharge tube is a glass tube containing gas, as shown.



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(i) One of the emitted photons has an energy of 3.44×10^{-19} J.

Calculate the frequency of this photon.

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Frequency of photon = ...

*(ii) The electrical circuit applies a large potential difference (p.d.) across the discharge tube.

Explain how the p.d. across the discharge tube causes photons to be emitted by the gas atoms.

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(b) Photons with energy 4.75 eV are incident on a metal surface. These photons cause electrons to be emitted from the metal surface.

(i) Show that the maximum speed of the emitted electrons is about $5.3 \times 10^{5}\,\mathrm{m\,s^{-1}}$.

work function of metal = 6.30×10^{-19} J

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work function of metal = $6.30 \times 10^{-19}\,\mathrm{J}$

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(ii) Calculate the de Broglie wavelength of electrons moving at $5.3 \times 10^5\,\mathrm{m\,s^{-1}}$.

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de Broglie wavelength = ...

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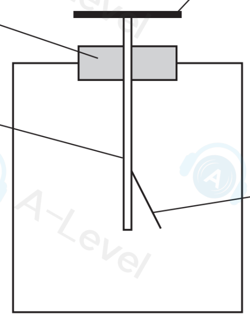
19 A gold leaf electroscope is a device that can be used to detect charge. The deflection of the gold leaf depends on the amount of charge on the zinc plate and the conducting rod.



In a demonstration of the photoelectric effect, a teacher charged the zinc plate with a negative charge and the gold leaf was deflected.

When ultraviolet radiation of frequency 2.0×10^{15} Hz was shone onto the zinc plate, the deflection of the gold leaf reduced.

(a) (i) Explain why the deflection of the gold leaf reduced. Your answer should include a calculation.

(4)

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

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(ii) Explain what would be observed with the gold leaf electroscope if ultraviolet radiation of the same frequency but with a lower intensity was used.

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(b) In the early 20th century, the wave model was generally accepted as an explanation of the nature of light.

Explain why the wave model cannot explain the photoelectric effect.

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(Total for Question 19 = 11 marks)

TOTAL FOR SECTION B = 70 MARKS
TOTAL FOR PAPER = 80 MARKS

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