12.1 The Interaction of Matter with Radiation

Question Paper

Course	DP IB Physics
Section	12. Quantum & Nuclear Physics (HL only)
Topic	12.1 The Interaction of Matter with Radiation
Difficulty	Easy

Time allowed: 70

Score: /58

Percentage: /100

Question 1a

In an experiment to investigate the photoelectric effect, a constant number of photons is incident on a photo-surface.

(a)
State what is meant by the term photon.

[2]

[1 mark]

Question 1b

The photoelectric equation is given by:

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

(b)
Explain the meaning of each term in the photoelectric equation:

(i)
hf

[1]

(ii)
ϕ

[1]

(iii)
$\frac{1}{2}mv^2_{max}$

[1]

[3 marks]

Question 1c

(c)

(i)
Identify **one** feature of the photoelectric effect that cannot be explained by the wave theory of light.

[1]

(ii)
Describe how this feature can be explained by the photon theory of light.

[2]

[3 marks]

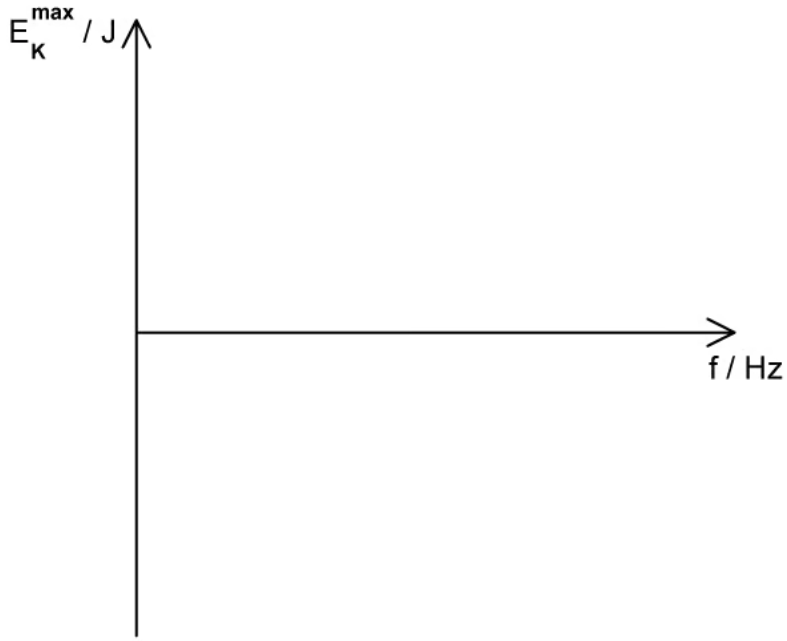
Question 1d

(d)

(i)

Sketch a graph of $E_{K(max)}$ against f on the axes provided.

[2]



(ii)

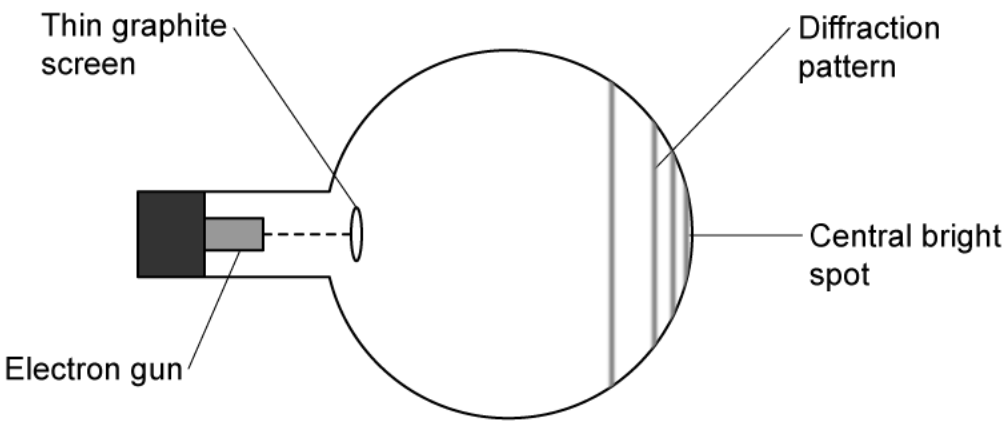
State the quantity represented by the gradient of the graph.

[1]

[3 marks]

Question 2a

The diagram shows the end of an electron diffraction tube.



A pattern forms when diffracted electrons are incident on a fluorescent layer at the end of the tube.

(a)
Explain how the pattern demonstrates that electrons have wave properties.

[3]

[3 marks]

Question 2b

The de Broglie wavelength λ of a particle accelerated close to the speed of light is approximately

$$\lambda \approx \frac{hc}{E}$$

Where E is the energy of the particle.

A beam of electrons is produced in a particle accelerator with energy 3.1×10^{8} eV.

(b)
Calculate the wavelength of an electron in the beam.

[3]

[3 marks]

Question 2c

(c)
State what can be deduced about an electron from the amplitude of its associated wavefunction.

[2]

[2 marks]

Question 2d

Heisenberg's uncertainty principle can be expressed as:

$$\Delta x \Delta p \geq \frac{nh}{2\pi}$$

An electron reaching the central bright spot on the fluorescent screen has a small uncertainty in its position.

(d)

(i)
Outline the meaning of each quantity in Heisenberg's uncertainty principle.

[2]

(ii)
Describe what the Heisenberg uncertainty principle is able to predict about another property of this electron.

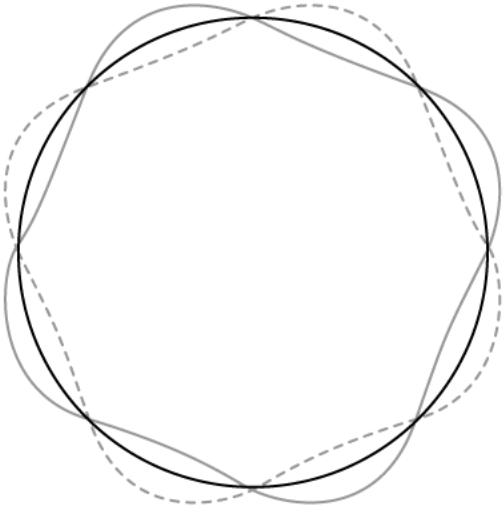
[1]

[3 marks]

Question 3a

In a hydrogen atom, an electron of mass *m* orbits the proton with speed *v* in a circular orbit of radius *r*.

The diagram shows an electron wave in hydrogen.



(a)

(i)
State the meaning of the term electron wave.

[1]

(ii)
Identify the number of allowed electron orbits shown in the diagram.

[1]

[2 marks]

Question 3b

(b)
By equating the centripetal and electric forces acting on the electron, show that the speed *v* of an electron in the hydrogen atom is related to the radius *r* of its orbit by the expression

$$v = \sqrt{\frac{ke^2}{m_e r}}$$

[3]

[3 marks]

Question 3c

(c)

Using your answer to (b) and the Bohr condition, deduce that the radius *r* of the electron's orbit in the n level of hydrogen is given by the following expression:

$$r = \frac{n^2 h^2}{4\pi^2 k m_e e^2}$$

[3]

[3 marks]

Question 3d

(d)

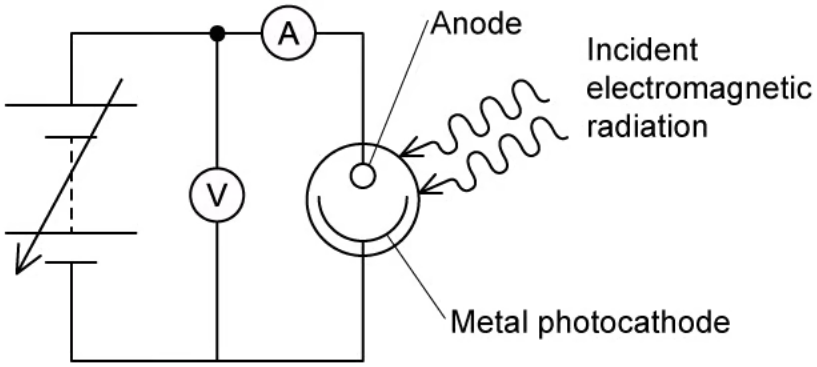
Calculate the electron's maximum orbital radius, *r*.

[3]

[3 marks]

Question 4a

Hydrogen atoms in an ultraviolet (UV) lamp make transitions from the first excited state to the ground state. Photons are emitted and are incident on a metal photocathode as shown.



(a)

(i)
Outline what happens at the metal photocathode when the photons are incident on its surface.

[1]

(ii)
Calculate the energy, in eV, of photons emitted from the UV lamp.

[3]

[4 marks]

Question 4b

No photoelectron emission is observed from the metal surface when the incident light is below a certain frequency.

(b)
Outline why the wave theory for light cannot explain this observation.

[2]

[2 marks]

Question 4c

The work function of the metal in the photocathode is 2.4 eV.

(c)
Outline the meaning of the terms:

(i)
Work function

[2]

(ii)
Threshold frequency

[2]

[4 marks]

Question 4d

(d)
Calculate:

(i)
The threshold frequency of the metal.

[2]

(ii)
The maximum kinetic energy, in J, of the emitted electrons.

[2]

[4 marks]

Question 5a

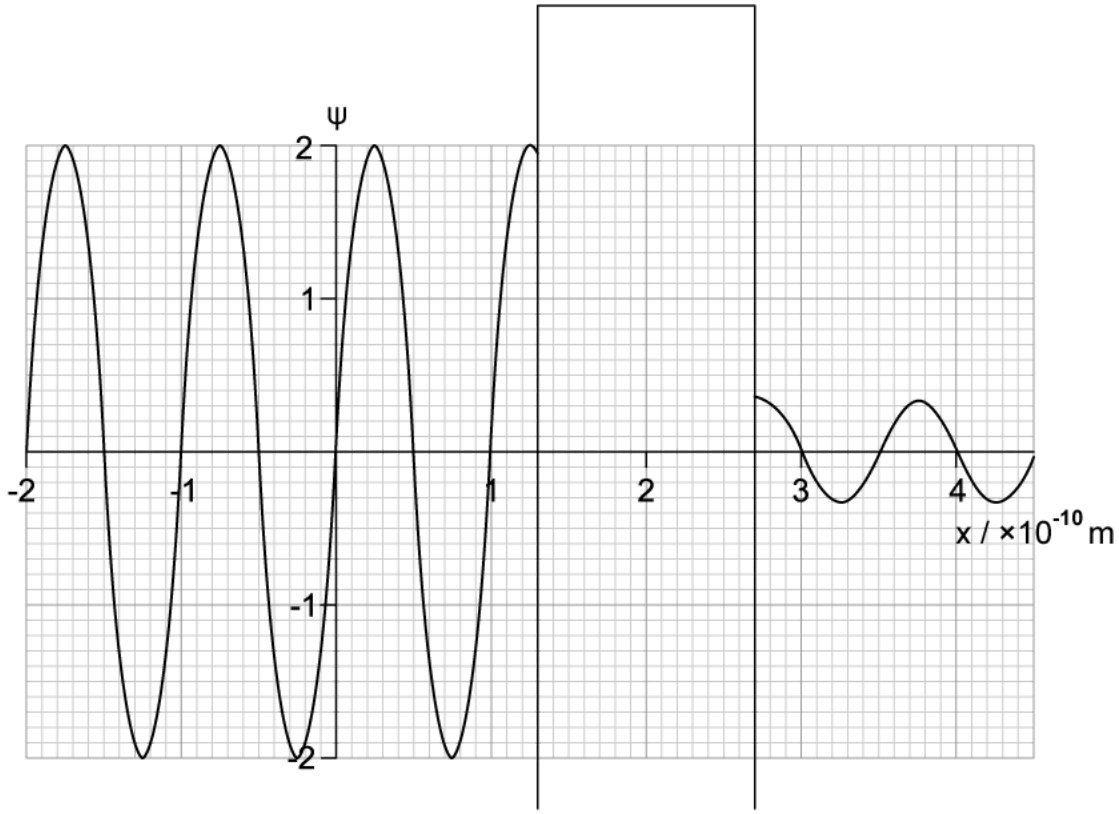
(a)
State what is meant by quantum tunnelling, and give an example of its application or natural occurrence.

[3]

[3 marks]

Question 5b

The graph shows the wavefunction, Ψ, of electrons that undergo tunnelling through a potential barrier.



(b)

Complete the graph by showing how the wavefunction propagates through the barrier.

[2]

[2 marks]

Question 5c

(c)
Use the graph in (b) to determine:

(i)
The width of the barrier, in m.

[1]

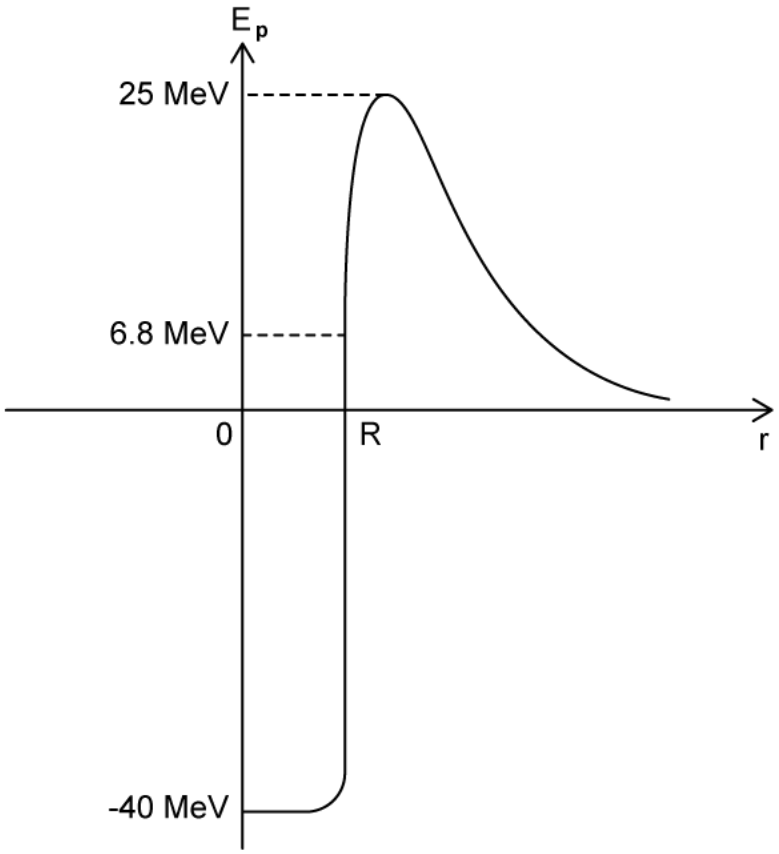
(ii)
If the kinetic energy of the electrons changes after tunnelling.

[2]

[3 marks]

Question 5d

The diagram shows the variation of the potential energy of an alpha particle with distance from the nuclear centre. The nuclear radius is R. The total energy of an alpha particle within the nucleus is 6.8 MeV.



(d)

(i)
State the significance of the value 25 MeV.

[1]

(ii)
On the graph, draw a line to show the path of the alpha particle when the nucleus decays, and indicate the "classically forbidden region" on the path.

[2]

(iii)
The probability of an alpha decay occurring can vary from 10^{-7} s to 10^{10} years depending on the nucleus. State the quantity used in nuclear physics that this time represents.

[1]

[4 marks]