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	Medium

Time allowed: 70

Score: /51

Percentage: /100

Question 1a

(a)
Describe what is meant by the wave function of an electron.

[2]

[2 marks]

Question 1b

An electron is confined in a finite region of length 6.8×10^{-14} m.

(b)
Determine the uncertainty in the momentum of the electron.

[2]

[2 marks]

Question 1c

(c)
Determine the associated de Broglie wavelength of the electron if it was accelerated into its confinement through a potential difference of 5.5 GV.

[2]

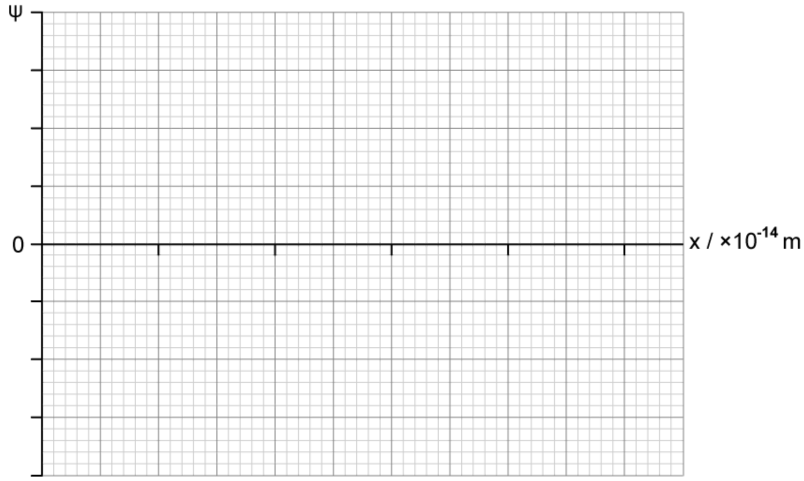
[2 marks]

Question 1d

(d)

On the axes provided, sketch the wave function Ψ of the electron described in part (b) and (c) with distance x.

You may assume that $\Psi = 0$ when $x = 0$.



[4]

[4 marks]

Question 2a

When monochromatic light is incident on a clean metal surface, photoelectrons may be emitted through the photoelectric effect.

(a)
Outline how Einstein's model is used to explain the photoelectric effect.

[3]

[3 marks]

Question 2b

(b)
Explain why, although the incident light is monochromatic, the kinetic energies of emitted photoelectrons vary up to some maximum.

[2]

[2 marks]

Question 2c

(c)
Explain why no photoelectrons are emitted if the frequency of the incident light is less than a certain value, no matter how intense the light.

[2]

[2 marks]

Question 2d

For monochromatic light of wavelength 570 nm a stopping potential of 1.80 V is required for this particular metal surface.

(d)
Determine the minimum energy required to emit a photoelectron from the metal surface.

[2]

[2 marks]

Question 3a

(a)
Outline the de Broglie hypothesis.

[2]

[2 marks]

Question 3b

(b)
Explain why a precise knowledge of the de Broglie wavelength of an electron implies that its position cannot be measured.

[3]

[3 marks]

Question 3c

The wave function of Schrödinger's theory can be thought of as a generalisation of the de Broglie hypothesis.

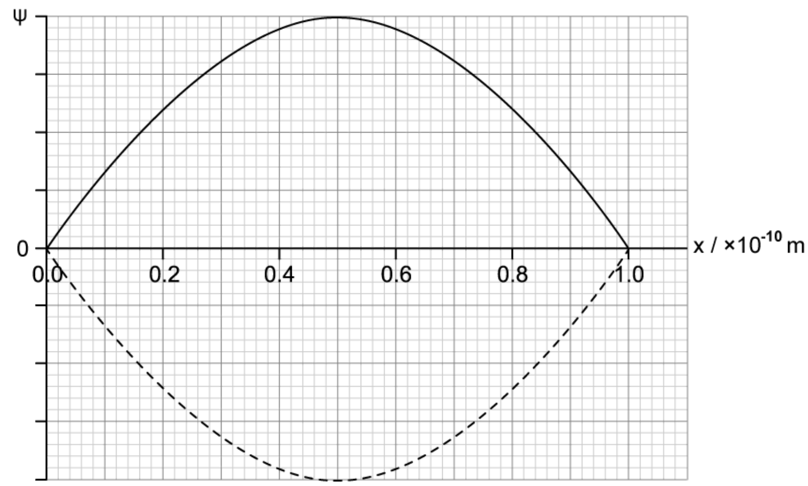
(c)
Outline the relationship between the wave function of Schrödinger's theory and the de Broglie hypothesis.

[3]

[3 marks]

Question 3d

The wave function ψ for an electron confined to length 1.0×10^{-10} m is a standing wave as shown.



(d)

(i)

Explain why the most likely position near which the electron is discoverable is the centre of the box.

[2]

(ii)

Calculate the momentum of the electron.

[2]

[4 marks]

Question 4a

One of the striking features of quantum theory is the ability of nature to convert matter into energy and vice versa.

Imagine an electron moving with kinetic energy E_k on a collision course with a positron moving in the opposite direction with the same kinetic energy. Following annihilation, two photons are produced.

(a)
Show that the wavelength λ of the two photons produced is given by the expression:

$$\lambda = \frac{2hc}{2m_e c^2 + m_e v^2}$$

where m_e is the mass of the electron.

[4]

[4 marks]

Question 4b

(b)
Hence, show that the maximum wavelength of photons produced during this annihilation is approximately 2.4×10^{-12} m.

[2]

[2 marks]

Question 4c

(c)
Show that the minimum wavelength of a photon that can produce an electron–positron pair is approximately 1.2×10^{-12} m.

[2]

[2 marks]

Question 4d

(d)
Explain why the value for wavelength in part (c) is only an estimate and not an accurate result.

[2]

[2 marks]

Question 5a

Monochromatic light is incident on a metal surface and electrons are emitted instantaneously from the surface.

(a)
Explain why:

(i)
electrons are emitted instantaneously.

[2]

(ii)
the energy of the emitted electrons does not depend on the intensity of incident light.

[2]

[4 marks]

Question 5b

The wavelength of light incident in part (a) is 450 nm and the work function of the metal is 2.0×10^{-19} J.

(b)
Determine the maximum kinetic energy of an electron emitted from the metal surface.

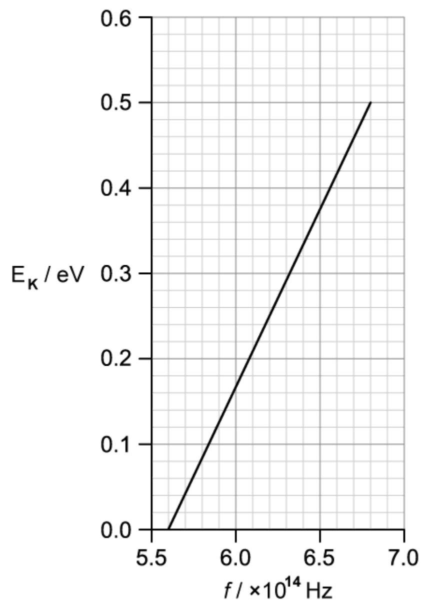
[2]

[2 marks]

Question 5c

The light source used in part (b) is now incident on a different metal surface. Its frequency is varied, such that the kinetic energy of emitted electrons can be recorded.

The graph shows how the maximum kinetic energy E_K of the ejected electrons varies with the frequency of incident light.



(c)
Use the graph to determine a value for the Planck constant *h*.

[2]

[2 marks]

Question 5d

(d)

Use the graph in part (c) to determine the work function of the metal.

[2]

[2 marks]