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	Hard

Time allowed: 20

Score: /10

Percentage: /100

Question 1

An electron in a one-dimensional box, known as the "electron in a box" model, is a fundamental quantum mechanical approximation describing the translational motion of a single electron confined inside an infinitely deep well from which it cannot escape.

According to the "electron in a box" model, which of the following expressions is **not** a permitted value for the momentum of an electron moving in a box of length *L*?

A. $\frac{h}{4L}$

B. $\frac{3h}{2L}$

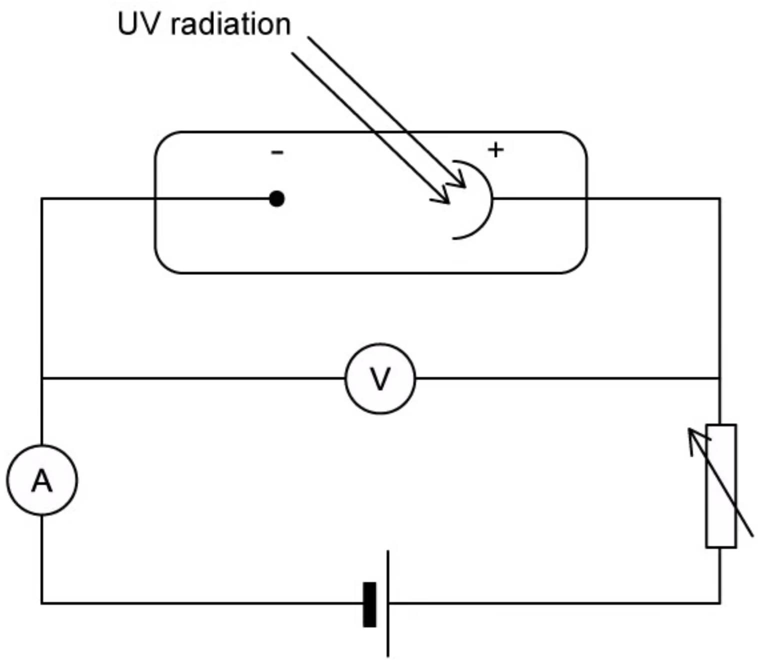
C. $\frac{3h}{L}$

D. $\frac{4h}{L}$

[1 mark]

Question 2

A vacuum photocell is connected in series with a power supply, a variable resistor, and a sensitive ammeter. A voltmeter is connected in parallel across the photocell.



Monochromatic light of frequency *f* illuminates the cathode, which has a threshold frequency f_0. Photoelectrons are emitted and collected by the anode. A photocurrent is measured by the ammeter.

The potential difference across the photocell, *V*, is increased until the ammeter reads zero.

Which of the equations below does **not** correctly relate the potential *V* at which the current decreases to zero to the threshold frequency f_0 and frequency *f*?

A. $V = \frac{h}{e}(f - f_0)$

B. $f_0 = \frac{hf - eV}{h}$

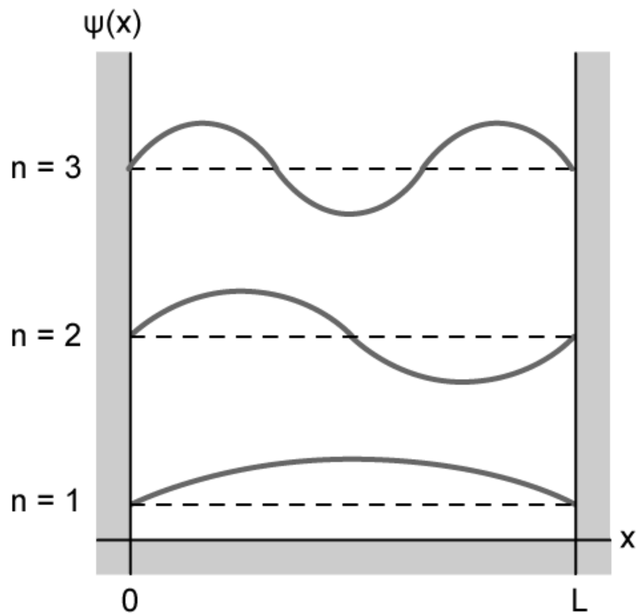
C. $h = \frac{eV}{(f - f_0)}$

D. $V = \frac{e}{hf_0 - hf}$

[1 mark]

Question 3

The first three wavefunctions are shown for a particle confined in a box of length L.



For which wave function is the probability of finding the particle near $x = \frac{L}{2}$ the smallest?

A. $n = 1$

B. $n = 2$

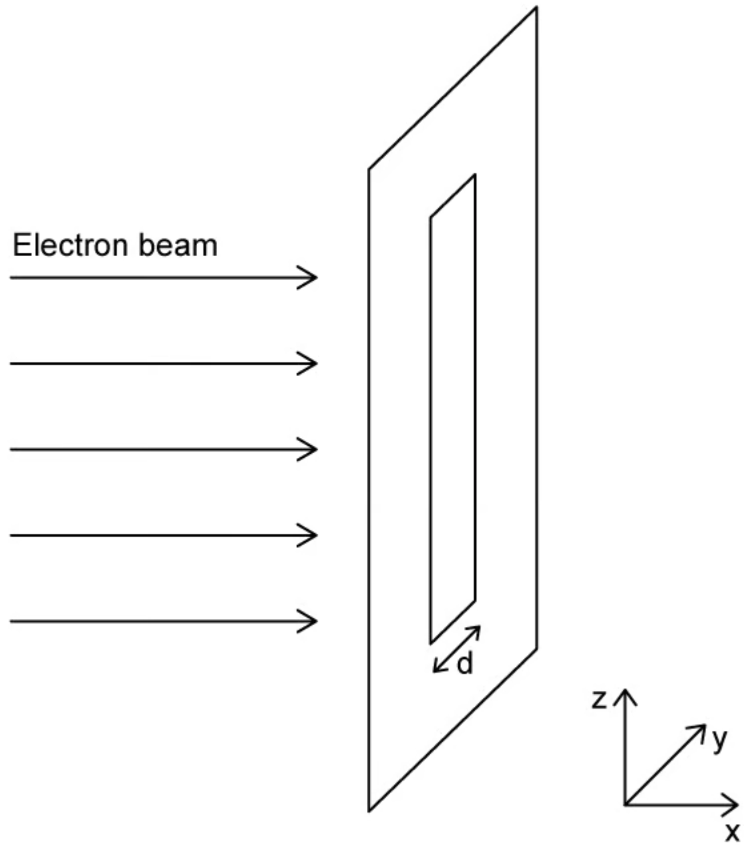
C. $n = 3$

D. The probability is the same (and non-zero) for each wavefunction

[1 mark]

Question 4

A beam of electrons of wavelength λ is incident on an aperture of width *d*. The beam is travelling along the z direction. The width *d* is of a size comparable to λ.



After passing through the aperture, the component of momentum in the x direction is p_x, the component in the y direction is p_y and the component in the z direction is p_z.

Which of the following shows the uncertainty in p_x, p_y and p_z?

	Δp_x	Δp_y	Δp_z
A.	$\frac{h}{4\pi d}$	$\frac{h}{4\pi d}$	$\frac{h}{4\pi d}$
B.	$\frac{h}{4\pi d}$	$\frac{h}{4\pi d}$	0
C.	0	0	$\frac{h}{4\pi d}$
D.	0	$\frac{h}{4\pi d}$	0

[1 mark]

Question 5

In 1890 Johannes Rydberg discovered an empirical formula that enabled the wavelengths of the light in the atomic line spectrum of hydrogen to be calculated. The formula is:

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n^2} - \frac{1}{m^2}\right)$$

Where λ is the wavelength, n and m are integers and R_H is the Rydberg constant.

In 1913 Niels Bohr published his theory of the hydrogen atom. This theory enabled the Rydberg formula to be derived. His theory also showed that the energy levels E_n of the hydrogen atom are given by the formula:

$$E_n = \frac{2.2 \times 10^{-18}}{n^2}$$

Where E_n is measured in joules.

Which of the following is a valid expression for the Rydberg constant?

A. $R_H = 2.2 \times 10^{-18}$

B. $R_H = \dfrac{2.2 \times 10^{-18}}{hc\left(1 - \frac{n^2}{m^2}\right)}$

C. $R_H = \dfrac{2.2 \times 10^{-18}}{hc}$

D. $R_H = 2.2 \times 10^{-18}\left(\dfrac{n^2 - m^2}{m^2 - n^2}\right)$

[1 mark]

Question 6

An electron is confined to a box. The energy difference between the first and the fourth states is 15.0 eV.

Which would be the best order of magnitude estimate for the length of the box?

A. 10^{-9} m

B. 10^{-10} m

C. 10^{-11} m

D. 10^{-12} m

[1 mark]

Question 7

A square plate made of zinc with side length d is given a charge of Q and then illuminated with an ultraviolet lamp of wavelength λ. The lamp has an output power of 100 W.

The lamp is placed a distance r above the surface and positioned such that the UV light is incident normally on the zinc surface.

Which of the following is the correct expression for the time taken for the zinc plate to become electrically neutral?

A. $\frac{hc}{100e}\left(\frac{Q}{\lambda d^2}\right)$

B. $\frac{hc}{100e}\left(\frac{Q}{\lambda r^2}\right)$

C. $\frac{hc}{25\pi e}\left(\frac{Qd^2}{\lambda r^2}\right)$

D. $\frac{\pi hc}{25e}\left(\frac{Qr^2}{\lambda d^2}\right)$

[1 mark]

Question 8

An alpha particle with energy E is incident upon a potential barrier and has a certain probability of quantum tunnelling through the barrier.

Consider the following statements:

I. The energy of the alpha particle is increased

II. The width of the potential barrier is increased

III. The alpha particle is replaced by an electron with energy E

Which statements would lead to an increase in the probability of finding a particle that has escaped a potential barrier?

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

[1 mark]

Question 9

Consider the following statements regarding the Bohr model of the hydrogen atom:

I.
The momentum of an electron is equal to the Planck constant divided by its de Broglie wavelength
II.
The angular momentum of the atom is quantised
III.
The energy levels are quantised

Which statements originate from the idea that the circumference of the orbit must be an integer number of the de Broglie wavelength?

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

[1 mark]

Question 10

An atom in an excited state has an orbital radius of 10^{-12} m.

Which would be the best order of magnitude estimate for the energy of this state according to the uncertainty principle?

A. 10^{1} eV

B. 10^{3} eV

C. 10^{6} eV

D. 10^{10} eV

[1 mark]