Queen Mary
University of London

BSc/MSci EXAMINATION

PHY-215 Quantum Physics

Time Allowed: 2 hours 15 minutes

Date: 22/05/08

Time: 10:00

Answer ALL questions in section A. Answer ONLY TWO questions from section B. Section A carries 40 marks, each question in section B carries 30 marks. An indicative marking-scheme is shown in square brackets [ ] after each part of a question.

COMPLETE ALL ROUGH WORKINGS IN THE ANSWER BOOK AND CROSS THROUGH ANY WORK WHICH IS NOT TO BE ASSESSED.

NUMERIC CALCULATORS ARE PERMITTED IN THIS EXAMINATION.

Speed of light	c	3.0×10^8 ms^{-1}
Planck's constant	h	4.14×10^{-21} MeV s
		$= 6.63 \times 10^{-34}$ J s
	$\hbar$	$= 6.58 \times 10^{-22}$ MeV s
Electron/Positron Rest mass	m_e	≈ 0.5 MeV/c^2
Proton Rest mass	m_p	≈ 1 GeV/c^2
permittivity of free space	ϵ_0	8.85×10^{-12}C^2/(Nm^2)
Electron Charge	$-e$	$= -1.6 \times 10^{-19}$ C
	1 eV	$= 1.6 \times 10^{-19}$ J
Boltzmann constant	k_B	1.38×10^{-23}JK^{-1}

Examiners: Dr. R. Russo and Prof. D. Dunstan

YOU ARE NOT PERMITTED TO START READING THIS QUESTION PAPER UNTIL INSTRUCTED TO DO SO BY AN INVIGILATOR

Questions:

Section A Answer all questions in this section.

A1. State the Stefan-Boltzmann law for the total intensity of the electromagnetic radiation emitted by a blackbody. Is it possible to explain this law by means of classical physics only? Explain your answer. [5]

A2. The total radiation emitted by a certain star is a factor 16 times that of a second star of equal size. Calculate the ratio between the temperatures of the two stars. [3]

A3. Describe briefly Young's double slit experiment to demonstrate the phenomenon of interference between two monochromatic and coherent waves of the same frequency. [4]

A4. The maximum wavelength of electromagnetic radiation that will result in the photoelectric emission of electrons from a sample of silver is 2.6×10^{-7} m. Find the work function for silver. [4]

A5. Consider electrons of kinetic energy equal to 1 eV. Calculate the de Broglie wavelength, λ, of these electrons, justifying any approximation you may make. [5]

A6. Use de Broglie's idea of standing waves to find a quantization condition on the angular momentum of a particle moving around a circular orbit. [3]

A7. In Bohr's model for the hydrogen atom the electron energy levels are given by

$$E_n = -\frac{m_e e^4}{8\epsilon_0^2 h^2 n^2}, \quad \text{with } n = 1, 2, \ldots$$

Derive the wavelength of the electromagnetic radiation that is capable of exciting the electron from the second ($n = 2$) to the third ($n = 3$) level. [5]

A8. State the Heisenberg uncertainty principle and briefly comment on its meaning. [4]

A9. Use Heisenberg uncertainty principle to estimate the minimal kinetic energy of a particle of mass m confined to a box of size L. [4]

A10. Consider a harmonic oscillator of mass $\mu = 1 \times 10^{-20}$ kg and Hooke's constant $k = 1 \times 10^3$ kg/s^2. What is the energy of the ground state according to Quantum Mechanics ? [3]

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Section B: Answer two questions in this section.

B1. Consider an electron that is constrained to be in a one-dimensional box of size L, but is otherwise free to move inside the box.

(i) Write down the (time independent) Schrödinger equation for this particle, the boundary conditions for the wavefunction Ψ and find an expression for the energy levels. [12]

(ii) Consider the process where the electron decays from the n^{th} energy level to the ground state by emitting a photon. Find the wavelength of the emitted photon as function of L, n and m_e. [8]

(iii) Consider now an electron that can freely move in a two dimensional square box. What are the energy levels in this case ? Please motivate your answer. [10]

B2. (i) Describe the main features of the Compton-scattering between X-ray photons and free electrons initially at rest. [8]

(ii) By using energy and momentum conservation derive the following relation:

$$\lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta) ,$$

where λ is the wavelength of the incident X-rays and λ' that of the outgoing ones and θ is the angle between the incident and the outgoing X-rays. [14]

(iii) In a Compton experiment, the X-rays scattered through an angle $\theta = 60°$ have wavelength λ' which is 10% bigger than the wavelength λ of the incident X-rays. What is the energy of the incident X-rays ? [8]

B3. In the Bohr model of the hydrogen atom angular momentum $L = mvr$ is quantized to be $n\hbar$ where n is a positive integer.

(i) Assume that the nucleus is at rest. By considering centripetal and electrostatic forces, find an expression for the radius of the n-th Bohr orbit. [10]

(ii) Find the speed of the electron in the n-th Bohr orbit, and hence show numerically why a non-relativistic treatment is justified. [10]

(iii) Consider an ionized Helium atom He^+, that is an ion with a nucleus of charge $2|e|$ and a single electron. Use the same approach as in point (i) above to estimate the ionization energy required to remove the remaining electron. [10]

B4. (i) Let $\Psi(x) = A(1 - x^2)$ be a wavefunction describing a particle that is confined to the region $-1 \leq x \leq 1$. Normalize this wavefunction appropriately and calculate the average position and momentum for this particle. [10]

(ii) Use the same wavefunction and calculate the probability of finding the particle in the region $1/2 \leq x \leq 1$. [8]

(iii) Use the same wavefunction and verify explicitly that the uncertainties for the position and momentum do satisfy the Heisenberg principle. [12]

End of Examination Paper
Dr R. Russo

