Queen Mary
University of London

BSc/MSci EXAMINATION

PHY-215 Quantum Physics

Time Allowed: 2 hours 15 minutes

Date: 15/05/07

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	0.511 MeV/c^2
Proton Rest mass	m_p	938 MeV/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}

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

Section A: Answer all questions in this section.

A1. Is the non-relativistic approximation appropriate for an electron having kinetic energy of 100 eV ? What is the speed of the electron ? [4]

A2. State Wien's displacement law, which relates the wavelength of the peak of the black body radiation and the black body temperature. Is it possible to explain this law by means of classical physics only? Give reasons for your answer. [5]

A3. A sample of sodium metal is illuminated with monochromatic light of wavelength 4.2×10^{-7} m and emits electrons through the photo-electric effect. In these experimental conditions, the stopping potential is found to be 0.65 V. What is the stopping potential if the wavelength of the incident light is changed to 3.10×10^{-7} m ? [5]

A4. Describe briefly Young's double slit experiment to demonstrate the phenomenon of interference between two monochromatic and coherent waves of the same frequency. [3]

A5. Consider the Young's double slit experiment discussed in the previous question (A4). What is the distance between two consecutive interference maxima observed on the screen as function of the light wavelength λ, the slit separation d, and the distance R between the slits and the screen ? [4]

A6. In an electron microscope, electrons of kinetic energy equal to 3600 eV are used. Compute their de Broglie wavelength λ. [3]

A7. Give an estimate of the resolving power of the microscope considered in the previous question (A6). [3]

A8. In Bohr's model for the hydrogen atom the electron energy levels are given by

$$E_n = -\frac{m_e e^4}{8\epsilon_0^2 h^2 n^2} .$$

Derive the wavelength of the electromagnetic radiation that is capable of exciting the electron from the ground state to the first excited state. [6]

A9. State the Heisenberg uncertainty principle and briefly comment on its meaning. [4]

A10. Use Heisenberg uncertainty principle to estimate the momentum of a neutron confined to a nuclear size ($\approx 10^{-15}$ m). [3]

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Section B: Answer two questions in this section.

B1. Consider a particle of mass m 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 and the boundary conditions for the wavefunction Ψ. [8]

(ii) Find the general solution to the equations in part (i) and show that it implies the existence of an infinite number of discrete energy levels. [10]

(iii) What would change in (i) and (ii) above if the particle is constrained to move on a circle of circumference L instead of being in a box, but is otherwise free? [12]

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. [10]

(iii) After the collision the electron has a non-zero momentum p'_y also in the direction orthogonal to that of the incident photon. What is the angle of the scattered photon for which $|p'_y|$ reaches its maximum ? [12]

B3. A molecule of oxygen O_2 is a bound state of two oxygen atoms that can vibrate like an harmonic oscillator of mass $\mu = 1.33 \times 10^{-20}$ kg and Hooke's constant $k = 1.1 \times 10^3$ kg/s^2.

(i) Write down the (time independent) Schrödinger equation for this harmonic oscillator. [6]

(ii) At low temperatures the vibration of the atoms is described by the ground state wavefunction of the harmonic oscillator which is $\psi(x) = A \exp\left[-\frac{\sqrt{k\mu}}{2\hbar}x^2\right]$. Show that this wavefunction is a solution of the Schrödinger equation you found in part (i) and find the corresponding energy. [12]

(iii) If the oxygen molecule is in the situation described in part (ii), what are the average kinetic and potential energies stored in the vibration motion ? [12]

B4. Let $\Psi(x) = A\frac{\sqrt{x}}{(1+x^2)}$ be a wavefunction describing a particle that is confined to the region $x > 0$.

(i) Normalize this wavefunction appropriately. [10]

(ii) What is the most probable position for a particle described by $\Psi(x)$? [10]

(iii) What is the average momentum of this particle ? [10]

The integral

$$\int_0^\infty \frac{x}{(1+x^2)^2}\, dx = \frac{1}{2}$$

may be useful.

End of Examination Paper **Dr R Russo**