THE UNIVERSITY OF NEW SOUTH WALES
SCHOOL OF PHYSICS

PHYS2040 QUANTUM PHYSICS

MIDSESSION EXAMINATION
APRIL 2009

Time allowed – 55 minutes (start 12:05 end 13:00)

Total number of questions – 3

Total number of marks – 32

Answer ALL questions

The questions are NOT of equal value

This examination paper has 3 pages.

This paper may be retained by the candidate

Portable battery-powered electronic calculators (without alphabetic keyboards) may be used.

All answers must be in ink. Except where they are expressly required, pencils may only be used for drawing, sketching or graphical work.

The following information is supplied as an aid to memory.

Planck's constant $h = 6.626 \times 10^{-34}$ Js

Fundamental charge unit $e = 1.60 \times 10^{-19}$ C

Speed of light (vacuum) $c = 3.0 \times 10^{8}$ m/s

Electron mass = 9.1×10^{-31} kg

Neutron mass = 1.675×10^{-27} kg

Proton mass = 1.672×10^{-27} kg

Boltzmann's constant $k = 1.38 \times 10^{-23}$ $\mathrm{JK^{-1}}$

Angstrom (Å) = 1.0×10^{-10} m

Permittivity constant $\varepsilon_o = 8.85 \times 10^{-12}$ $\mathrm{Fm^{-1}}$

Gravitational constant $G = 6.67 \times 10^{-11}$ $\mathrm{Nm^2/kg^2}$

Time-independent Schrödinger Equation: $-\frac{\hbar^2}{2m}\frac{d^2\psi(x)}{dx^2} + V\psi(x) = E\psi(x)$

Time-dependent Schrödinger Equation: $-\frac{\hbar^2}{2m}\frac{\partial^2\psi(x,t)}{\partial x^2} + V(x)\psi(x,t) = i\hbar\frac{\partial\psi(x,t)}{\partial t}$

$$\int \sin^2(bx)dx = \frac{x}{2} - \frac{\sin(2bx)}{4b}$$

$$\int x\sin^2(x)dx = \frac{x^2}{4} - \frac{x\sin(2x)}{4} - \frac{\cos(2x)}{8}$$

$$\int x^2\sin^2(bx)dx = \frac{x^3}{6} - \left(\frac{x^2}{4b} - \frac{1}{8b^3}\right)\sin(2bx) - \frac{x\cos(2bx)}{4b^2}$$

$$\int_{-\infty}^{\infty} e^{-bx^2}dx = \sqrt{\frac{\pi}{b}}$$

$$\int_{0}^{\infty} x^n e^{-bx}dx = \frac{n!}{b^{n+1}}$$

$$\sin(2\theta) = 2\sin\theta\cos\theta$$

Bragg's law: $n\lambda = 2d\sin\theta$

Compton Shift: $\Delta\lambda = \frac{h}{mc}(1-\cos\theta)$

Relativistic E-p relation: $E^2 = (pc)^2 + (mc^2)^2$ = Kinetic energy + Rest mass energy

Non-relativistic E-p relation: $E = p^2/2m$

Question 1 [14 Marks]

(a) In one or two sentences, explain briefly the Photoelectric Effect.

(b) Light of frequency ν and relatively low intensity I shines on a metal cathode and the photoelectrons are collected by an anode at a positive potential V. The photocurrent i is reduced to zero by a reverse potential $V = -V_0$ (where $V_0 > 0$). The work function of the cathode is ϕ. Assuming that the quantum theory of light is correct, sketch 4 graphs showing the variation of:

(i) Photocurrent i with light intensity I for $V > 0$ and $\nu > \nu_0$, the cutoff frequency.

(ii) Photocurrent i with frequency ν for $V > 0$ and constant I.

(iii) Stopping potential V_0 with intensity I at constant ν.

(iv) Stopping potential V_0 with frequency ν at constant I.

You should identify key features (intercepts, gradients, etc. where possible).

(c) What are the three aspects of the photoelectric effect that cannot be explained by classical physics? How did Einstein's explanation of this effect overcome the problems with the classical interpretation?

(d) As a result of shining monochromatic light with wavelength λ on a metal surface, electrons are ejected with maximum kinetic energy T. If one changes the wavelength of the light to $\lambda/4$, electrons are ejected with a maximum kinetic energy $5T$. Obtain an expression for T in terms of λ.

Question 2 (12 Marks)

A particle in an infinite square well has an eigenfunction:

$$\psi(x) = A\sin\left(\frac{2\pi x}{L}\right) \text{ for } 0 \le x < L \quad \text{and} \qquad \psi(x) = 0 \text{ elsewhere}$$

(a) Calculate the expectation value of x.

(b) Calculate the probability of finding the particle within $\pm L/100$ of the center of the well.

(c) Calculate the probability of finding the particle within $\pm L/100$ of $x = L/4$.

(d) In a few sentences, explain the relationship between your results in (a), (b) and (c).

Question 3 (6 Marks)

(a) Does the uncertainty principle set a limit on how well you can make any single measurement of position? Briefly discuss.

(b) Suppose an electron has a kinetic energy of 3 keV, which has an uncertainty ΔE = 30 eV. What will be the corresponding uncertainty in its position Δx?

(hint: obtaining the derivative dE/dp might be helpful in attacking this problem.)