THE UNIVERSITY OF NEW SOUTH WALES
SCHOOL OF PHYSICS

PHYS2040 QUANTUM PHYSICS

MIDSESSION EXAMINATION
APRIL 2007

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

Total number of questions – 4

Total number of marks – 25

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

Question 1 (8 Marks)

(a) List the main features of the Photoelectric effect that cannot be explained by classical physics.

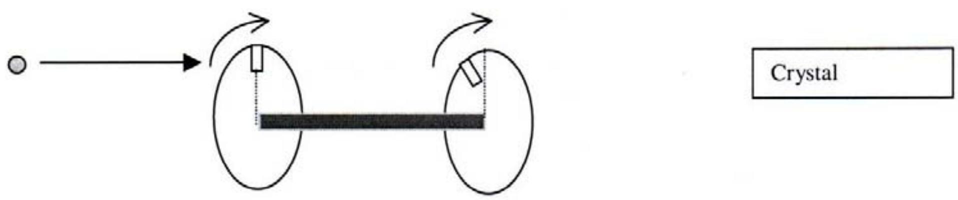
(b) State briefly the assumptions made by Einstein in order to explain the photoelectric effect.

(c) The cut-off wavelength for the emission of photo-electrons from a Cesium surface is 650 nm. Calculate **both** the work-function of Cesium and the maximum kinetic energy (in eV) that photo-electrons would have if light of wavelength 400 nm were incident on the Cesium surface.

Question 2 (7 Marks)

You wish to study a crystal's structure by diffracting thermal, non-relativistic neutrons from the crystal, so you go to a nuclear reactor and set up your diffraction experiment on one of the neutron beam-lines. The neutrons emerge from the reactor with a range of wavelengths (i.e., a range of energies/momenta), so you use a 'chopper' to select neutrons of a certain wavelength.

The simplest chopper consists of two disks made from a highly neutron absorbing material, mounted on an axle. The disks are 2 m apart. In each disk is a small slot (to let the neutrons through). There is an offset of 10° between the two slots and the chopper rotates rapidly.



The distance between the planes of atoms in the diffracting crystal is 1.73Å and you observe strong diffraction when the angle between the incident and diffracted neutron beams is 163°. Calculate the minimum rotational speed of the chopper in revolutions per minute.

Question 3 (10 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).