THE OPEN UNIVERSITY OF SRI LANKA

DEPARTMENT OF PHYSICS

BACHELOR OF SCIENCE DEGREE PROGRAMME -2010/2011 - LEVEL 05

FINAL EXAMINATION - 2010

PHU3142 / PHE5142 – PHYSICAL BASIS OF QUANTUM THEORY, THEORY OF RELATIVITY AND SOLID STATE PHYSICS

TIME: TWO AND HALF HOURS (2 ½ hrs) **ANSWER FOUR QUESTIONS ONLY**

Date: 14.12.2010 Time: 1.00 pm – 3.30 pm

You may assume that, mass of electron $m_e = 9.1 \times 10^{-31}$ kg, $h = 6.63 \times 10^{-34}$ J s, $\hbar = 1.05 \times 10^{-34}$ J s, $c = 3 \times 10^{8}$ m s^{-1}, 1 eV = 1.6×10^{-19} J,
Avogadro number $N_A = 6.02 \times 10^{23}$ mol^{-1}, 1 a.m.u = 1.67×10^{-27} kg.

1) (a) Give an account of the Compton effect. Does it support the wave or the particle theory of light?

(b) Describe the term Ultraviolet Catastrophe (also known as the Rayleigh-Jeans catastrophe). How did Planck's hypothesis solve this problem?

(c) Wien's law could be written as:

$$E_\lambda = \frac{C_1}{\lambda^5} e^{-C_2/\lambda T}$$, where C_1 and C_2 are constants.

Show that $\lambda_{MAX} T =$ constant by differentiating it with respect to λ.

(d) The maximum energy of photoelectrons emitted from potassium is 2.1 eV when illuminated by light of wavelength 3×10^{-7} m. Use these results to calculate the minimum energy needed to free an electron from potassium.

2) Consider a particle in a one-dimensional symmetric, square well with a potential defined as:

$$V = 0 \quad -a \leq x \leq a$$
$$V = V_0 \quad |x| > a$$

(a) Considering only bound states where the total energy E is less than V_0, write down the Schrodinger equation and its solution in all three regions of the system.

(b) Write the appropriate conditions and show that the energy levels of the system can be determined by the two sets of solutions given by

$$\text{either } k \tan ka = q$$

$$\text{or } k \cot ka = -q$$

where

$$q = \left[\frac{2m(V_0 - E)}{\hbar^2}\right]^{\frac{1}{2}}$$

and

$$k = \left[\frac{2mE}{\hbar^2}\right]^{\frac{1}{2}}$$

3) (a) State the postulates of special relativity.

(b) An electron moves with a speed of 0.750c. Find its relativistic momentum and compare this value with the momentum calculated from the classical expression.

(c) The ^{216}Po nucleus is unstable and exhibits radioactivity. It decays to ^{212}Pb by emitting an alpha particle (a Helium nucleus, ^{4}He). Find the mass change in this decay and the energy released.

(d) Two protons are initially moving with equal speeds in opposite directions, towards each other. They continue to exist after a head-on collision that also produces a neutral pion of mass $m = 2.40 \times 10^{-28}$ kg. If the protons and the pion are at rest after the collision, find the initial speed of the protons.

Mass of ^{216}Po = 216.001905 a.m.u

^{212}Pb = 211.991888 a.m.u

^{4}He = 4.002603 a.m.u

4) (a) Write down the Lorentz transformation equations. Using these equations derive expressions for

(i) the length contraction

(ii) time dilation and

(iii) velocity transformation in x-direction

(b) A space probe is launched from the earth. It travels at a constant velocity of 0.70c in space. It has nuclear powered batteries which supply the energy to keep its data transmitter active continuously. The batteries have a lifetime of 15 years when measured in a rest frame. Calculate:

(i) The length of time the batteries last as measured by scientists on the earth.

(ii) How far away the probe is from the Earth when its batteries fail as measured by scientists on the earth.

(iii) How far away the probe is from the earth when its batteries fail, as measured by its built-in odometer (a device that measures distance).

(c) A student studying special relativity drives through a traffic light. He is stopped by a police officer at which point the student tells the police officer that the Doppler shift made the red light of wavelength 650 nm appear green to him, with a wavelength of 520 nm. Nonetheless, the police officer writes out a traffic citation for speeding. How fast was the student travelling, according to his own account?

5) Explain briefly the terms *Bravais lattice*, *primitive cell* and *unit cell.* Define *Miller indices* of a plane in a crystal.

(a) Draw $(\bar{1}11)$ and $(1\bar{1}1)$ planes inside the unit cell of a cubic crystal. Determine the Miller indices of the direction that is common to both planes.

(b) The lattice constant of an *fcc* lattice is 6.38 Å. Find

(i) the distance between a corner atom at the base and the atom at the centre of the top face.

(ii) The largest distance between two atoms in the cubic cell.

(c) Sodium Chloride (NaCl) crystal has a cubic structure. If the molecular weight of NaCl is 58.46 g and its density is 2.17 g cm^{-3}. Determine the

(i) number of atoms per unit volume

(ii) distance between two adjacent atoms

(iii) the lattice constant in the NaCl crystal.

6) Giving an example for each, distinguish between *ionic bond, covalent bond, metallic bond* and *Vander Waal's bond.*

a) The potential energy of a system of two atoms in a crystal is $U = -\frac{A}{r^n} + \frac{B}{r^m}$, where r is the interatomic distance, A, B, m and n are constants, and $m > n$.

(i) Show that the interatomic distance r_c at which the interatomic force F is a minimum, is greater than the spacing r_o at which a stable crystal is formed.

(ii) Show graphically the variation of U and F with r in a single diagram indicating the r_c and r_o.

b) The potential energy of a pair of atoms is $U = -\frac{A}{r^4} + \frac{B}{r^{12}}$, where r is the interatomic distance.

(i) Using part (a), find the value of r where a stable bond is formed.

(ii) Calculate the energy released when the atoms form a stable bond in terms of A and B.

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