NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

APPLIED PHYSICS DEPARTMENT

SPH 1104 MODERN PHYSICS

BSc HONOURS PART I: JANUARY 2004 *DURATION : 3 HOURS*

ANSWER **ALL** PARTS OF QUESTION 1 IN SECTION A AND ANY **THREE** QUESTIONS FROM SECTION B. SECTION A CARRIES 40 MARKS AND SECTION B CARRIES 60 MARKS

Planck's constant,	$h = 6.63 \times 10^{-34}$ J.s
Electron rest mass,	$m_e = 9.11 \times 10^{-31}$ kg
Speed of light,	$c = 3.00 \times 10^{8}$ m s^{-1}
1 electron volt	$e = 1.60 \times 10^{-19}$ J
Mass of electron,	$m_e = 5.48 \times 10^{-4}$ u
Mass of proton,	$m_p = 1.007\ 825$ u
Mass of neutron,	$m_n = 1.008\ 665$ u
1 atomic mass unit,	$1u = 931.49\ MeV/c^2$
Electronic Charge,	$e = 1.60 \times 10^{-19}$C
Stefan – Boltzmann constant	$\sigma = 5.67 \times 10^{-8}\ W/m^2.K^4$
Wein's constant,	$k = 2.899 \times 10^{-3}$ m .K
Mass of	${}^4H_e = 4.002\ 603u$
Mass of	${}^1H = 1.007825u$

SECTION A

1. (a) For the photoelectrical effect, define the following terms:
   - (i) work function,
   - (ii) photoelectron,
   - (iii) threshold frequency,
   - (iv) write down the photoelectric equation [5]

   (b) (i) What is the "ULTRAVIOLET CATASTROPHE"? [2]
   - (ii) For a black body at a temperature of 800k, find the wavelength of the most intense part of radiation that it emits. [3]

   (c) (i) State Bohr's postulates as well as the one he adopted from

Rutherford for his model of the atom. [3]

(ii) What does the "Ground state" mean for the hydrogen atom and why is energy associated with this state negative? [4]

(iii) State Wien's displacement law defining all symbols and explain why it is called a "Displacement Law" [3]

(d) (i) Why does the "Photoelectric effect" not work for free electrons? [2]

(ii) A source emits light of wavelength 4.5 x 10^{-7}m at a rate of 1.1W. How many photons leave the source every second? [4]

(e) A baseball player dispatches the ball of mass 150g at a speed of 115km/h. Determine its De Broglie wavelength. [2]

(f) (i) Define the terms "isotopes", "isotones" and "isobars" in terms of the mass number, A, neutron number N, and the atomic number Z. Give an example of each. [4]

(ii) The most abundant isotope of helium is ${}^{4}_{2}He$. Using atomic mass units and electron volts, Determine the mass deficit and the binding energy per nucleon of ${}^{4}_{2}He$. [4]

(g) Differentiate between continuous and line spectra and explain how you would go about producing each. [2]

(h) Write a statement for Heisenberg's principle of uncertainty and write down the relationship for position and momentum. [2]

SECTION B

2. (a) (i) What is your understanding of a 'black body'? [4]

(ii) Show that in the limits of long wavelengths, Planck's radiation equation given by:

$$R(\lambda) = \frac{2\pi c^2 h}{\lambda^5} \bullet \frac{1}{e^{hc/\lambda KT} - 1}$$

reduces to Rayleigh – Jean's equation or relation. [5]

(iii) Show that for the most intense part of radiation, Planck's radiation relation reduces to Wein's displacement law. [8]

(iv) Assuming that the earth has a mean temperature of 300K, determine the power radiated from $1cm^2$ of the earth. [3]

3. (a) Define the terms "fusion" and "fission". [2]

(b) Define life time T and half life $T_{\frac{1}{2}}$ as applied to radioactive decay. [4]

(c) (i) The following table shows the results of measuring the dependence of the activity A of a certain radioactive element on time t.

t(hrs)	0	3	6	9	12	15
A(mCi)	21.6	12.6	7.6	4.2	2.4	1.8

Find the half life of this element. [5]

(ii) A radioactive substance with decay constant λ has an activity A_1 at $t = t_1$ and activity A_2 at $t = t_2$. What is the total number of atoms that have decayed between t_1 and t_2? [5]

(d) Calculate the disintegration energy Q for the Beta decay of ^{32}P, given that the atomic masses are 31.97391U for ^{32}P and 31.97207U for ^{32}S. [4]

4. (a) (i) Show that the radius for the n^{th} orbit of Bohr's model of the hydrogen atom is given by:

$$r_n = \left(\frac{4\pi\varepsilon_o\hbar^2}{me^2}\right)n^2$$ [5]

(ii) Show also, that the energy of the electron in the n^{th} orbit is given by:

$$E_n = \frac{-me^4}{32\pi^2\varepsilon_o^2\hbar^2n^2}$$ [5]

(iii) Hence or otherwise find an expression for the energy quantum required to excite a hydrogen atom in its ground state to its "third excited state". [3]

(b) (i) List any three deficiencies of Bohr's model. [3]

(ii) What weaknesses led to Thomson's 'plum pudding' model being discarded? [4]

5. (a) (i) Briefly describe Compton's experiment and explain how it can be used as a basis to support the particulate nature of electromagnetic radiation. [4]

(ii) Show, using diagramatic illustrations, that the expression for the compton shift, $\Delta\lambda$ is given by:

$$\lambda^{1} - \lambda = \frac{h}{mec}(1 - Cos\theta),$$ where θ is the scattering angle of the photon. [8]

(b) In a Compton scattering experiment, x-rays of wavelength 0.015nm are scattered through an angle of 45° by 'free' electrons, what is their new wavelength. [2]

(c) At what angle θ does the maximum possible wavelength of the scattered x-rays occur. [2]

(d) Explain why in the Compton scattering experiment, the recoil electrons are regarded as 'free'. [2]

(e) What would be the effect of replacing electrons by protons? [2]

6. (a) What features of the photoelectric effect could not be explained by classical physics? How does Einstein explain these features? [6]

(b) When sodium metal is illuminated with light of wavelength 3.10×10^{2}nm, the stopping potential is 1.69V.

(i) Define the term 'stopping potential' [2]

(ii) Find the 'work function' of sodium. [3]

(iii) Calculate the kinetic energy of the most energetic electrons emitted from the sodium surface when it is illuminated with light of wavelength 2.9×10^{2}nm. [2]

(iv) Why do some electrons have kinetic energies smaller than K_{max}? [2]

(c) In the photo electric effect how can a photon moving in one direction eject an electron moving in a different direction? What happens to conservation of momentum? [2]

(d) Briefly explain the phrase 'wave-particle duality' [3]

- END OF EXAMINATION -