NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF INDUSTRIAL TECHNOLOGY

BACHELOR OF ENGINEERING (HONS) DEGREE

Final examination June 2004

SPH 1104 **MODERN PHYSICS**

Duration of Examination 3 Hours

Instructions To Candidates:

1. Answer ALL parts of question 1 in Section A.
2. Answer any **THREE** questions from Section B
3. Section A carries 40 marks and Section B carries 60 Marks.
4. Show all your steps clearly in any calculation.

Planck's Constant --	h = 6.63×10^{-34}J.S
Electron rest Mass ---	M = 9.11×10^{-31} Kg
Speed of light --	C = 3.00×10^{8}ms^{-1}
1 electron volt --	eV= 1.60×10^{-19}J
Mass of electron --	Me = 5.48×10^{-4}u
Mass of proton --	Mp = 1.007825u
Mass of neutron ---	Mn = 1.008 665u
1 atomic mass unit --	1u = 931.49 MeV/c^2
Electronic charge --	e = 1.60×10^{19}C
Stefan-Boltzmann Constant --------------------------------	σ = 5.67×10^{-8}W/m^2.K^4
Wien's Constant ---	b = 2.898×10^{-3}m.K
Mass of $^{2}_{1}H_{1}$ ---	2.014102u
Mass of $^{56}_{26}Fe_{30}$ ---	55.934939u
Mass of $^{238}_{92}U_{146}$ --	238.049553u
1 Ci ---	3.70×10^{10} Bq

SECTION A

Question 1

a) (i) Define the binding energy of an atomic nucleus. [2]

(ii) Find the binding energy per nucleon $\left(\frac{B}{A}\right)$ for ${}^{2}_{1}H_{1}$, ${}^{56}_{26}Fe_{30}$ and ${}^{238}_{92}U_{146}$ [3]

(iii) Explain why $\left(B/_{A}\right)$ is lowest for the lightest nucleus and why it is lower in the heaviest of the above three compared to the medium sized. [2]

(iv) With reference to binding energy per nucleon, explain briefly "nuclear fission" and "nuclear fussion". [2]

b) (i) Make sketches on a diagram to show how the wavelength at maximum intensity (λ_{max}) varies with temperature for temperatures T_2 and T_2 where $T_1 > T_2$ for blackbody radiation. [4]

(ii) On the same graph, make a rough sketch to show how the Radiancy ($R_{(\lambda)}$) varies with the wavelength according to the Rayleigh-Jeans formula for a radiating black body. [2]

(iii) Explain "Ultraviolet catastrophe". [3]

c) (i) State the Stefan-Boltzmann law. [1]

(ii) Calculate power radiated by a cavity at 700K. [3]

d) (i) What is the voltage across an x-ray tube that will produce x-rays with a minimum voltage of $1,0\overset{0}{A}$? [3]

(ii) What is the minimum voltage needed across an x-ray tube if the subsequent Bremsstrahlung radiation is to be capable of pair production? [3]

e) Write a statement for Heisenberg's principle of uncertainty and write down the relationship for position and momentum. [3]

f) (i) A source emits light of wavelength $4,5 \times 10^{-7}$ m at a rate of 1.1W. How many photons leave the source every second? [4]

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

g) What do you understand by the "Ground State" for a hydrogen atom? Why is the energy associated with this state negative? [3]

SECTION B

Question 2

a) (i) What 3 observations in the photoelectric effect could not be explained by assuming the "wave picture" for light? [4]

(ii) How did Einstein explain the above observations? [4]

b) Irradiation of potassium with yellow $\left(\lambda = 5900\,\mathring{A}\right)$ and ultraviolet $\left(\lambda = 2537\,\mathring{A}\right)$ light liberates electrons with stopping potential 0,36V and 3,14V respectively.
Find.

(i) Planck's Constant h, using the above data. [4]

(ii) The work function for potassium. [4]

(iii) The threshold (cut-off) frequency of the photoelectric effect on potassium. [4]

Question 3

a) (i) Differentiate between a "black body" and a "grey body". [4]

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

$$R(\lambda)=\frac{2\pi C^2 h}{\lambda^5}\cdot\frac{1}{\left(e^{hc/\lambda kT}-1\right)}$$

reduces to Rayleigh-Jeans relation. [5]

(iii) Show that for the most intense part of radiation, Planck's radiation relation reduces to Wien's displacement law. [7]

b) Explain why a photon is said to have zero mass and rest energy. [4]

Question 4

a) An electron is accelerated through a potential difference of 55kV. After striking a target nucleus of a certain material, a photon of wavelength 0.51 x 10^{-10}m is liberated.

(i) What is the energy of the electron after the interaction? [5]

(ii) What is the maximum photon frequency that this accelerated electron is capable of generating in the material? [5]

b) A particular pair is produced such that the positron is at rest and the electron has a kinetic energy of 1.0MeV moving in the direction of flight of the pair producing photon.

(i) Neglecting the energy transferred to the nucleus of the nearby atom, find energy of the incident photon. [4]

(ii) What percentage of the photon's momentum is transferred to the nucleus? [4]

(iii) How is it possible that momentum is conserved if an incident photon gives up its energy to an electron that flies away in a direction exactly opposite to that of the incident photon? [2]

Question 5

a) (i) Observations show that a radioactive – decay process follows the exponential law:

$$N = N_o e^{-\lambda t}$$

Define all the quantities in the above expression. [3]

(iii) What do you understand by mean life time (τ) and half life $\left(T_{\frac{1}{2}}\right)$ for radioactive decay. [3]

b) (i) The following table shows the results of measuring the dependence of 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. [4]

(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]

c) 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]

Question 6

a) (i) Show that the radius for the nth 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 nth orbit is given by:

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

[5]

(iii) Find an expression for the energy quantum emitted when a hydrogen atom falls from its "second excited state" to the ground 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? [3]