NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

APPLIED PHYSICS DEPARTMENT

SPH 1104/SPH 1106 - MODERN PHYSICS

BSC HONOURS PART 1 : DEC 2005 DURATION: 3 HOURS

ANSWER **ALL** PARTS OF QUESTION **ONE** 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	$M = 9.11 \times 10^{-31}$ Kg
Speed of light	$C = 3.00 \times 10^{8}\ ms^{-1}$
1 electron volt	$eV = 1.60 \times 10^{-19}$ J
Mass of electron	$Me = 5.48 \times 10^{-4}$ u
Mass of proton	$Mp = 1.007825$u
Mass of neutron	$Mn = 1.008\ 665$u
1 atomic mass unit	$1u = 931.49\ MeV/c^2$
Electronic charge	$e = 1.60 \times 10^{19}$ C
Stefan-Boltzmann Constant	$\sigma = 5.67 \times 10^{-8}\ W/m^2.K^4$
Wien's Constant	$b = 2.898 \times 10^{-3}$ 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

1. a) (i) Name the law that you could use to estimate the temperature of a glowing body. [2]

(ii) Write down the formula for the above law explaining all symbols used. [2]

(iii) Explain the origin of the "Ultraviolet catastrophe". [3]

(iv) Explain how Maxwell Planck solved the problem of the "Ultraviolet catastrophe". [3]

b) (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 ${}^{238}_{92}U_{146}$ [6]

(iii) Explain why $\left(\frac{B}{A}\right)$ is lowest for the lightest nucleus and why it is lower for the heaviest of the above three compared to the medium sized. [4]

(iv) With reference to binding energy per nucleon, explain briefly the terms "nuclear fission" and "nuclear fussion". [4]

c) (i) The sky is usually blue on a clear summer afternoon. What name is given to the process responsible for this phenomenon? [1]

(ii) Describe in full the phenomenon you have named above [4]

d) (i) Assume that a 120W light source delivers all its energy in the form of visible light, with an average photon wavelength of 550nm. Approximately how many photons per second strike a 20cm x 20cm sheet of paper, 1m from the light? [4]

(ii) What is the minimum voltage needed across an x-ray tube if the subsequent Bremsstrahlung radiation is to be capable of pair production? [2]

e) (i) Provide a name for the principle $\Delta x \Delta p \geq \hbar$. Also state this principle in your own words. [3]

SECTION B

2. a) (i) Make a list of 3 observations in the photoelectric effect that 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 $\left(\lambda = 5901\,\mathring{A}\right)$ and ultraviolet $\left(\lambda = 2538\,\mathring{A}\right)$ light liberates electrons with stopping potential 0.359V and 3.139V 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]

3. a) The universe is filled with thermal radiation which has a blackbody spectrum at an effective temperature of 288K.

(i) What is the peak wavelength of this radiation? [2]

(ii) What is the energy (in eV) of quanta at the peak wavelength? [2]

b) (i) Using appropriate diagrams for your illustrations, show that the Compton shift can be evaluated by using the expression:

$\lambda' - \lambda = \frac{h}{m_o c}[1 - \cos\vartheta]$, where all symbols have their usual meanings. [10]

(ii) What would be the effect of replacing "free electrons" with protons in the Compton scattering experiment? [2]

c) X-ray photons of wavelength 0.02480nm are incident on a target and the Compton-scattered photons are observed at 90°.

(i) Find the wavelength of the scattered photons. [2]

(ii) Find the momentum of the incident photons. [2]

4. 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:

$$R(\lambda) = \frac{2\pi c^2 h}{\lambda^5} \cdot \frac{1}{e^{hc/\lambda kT} - 1}$$ [5]

reduces to Rayleigh-Jeans relation.

(ii) Show that for the most intense part of radiation, Planck's radiation relation reduces to Wien's displacement law i.e. $T\lambda_{max}$ = Constant [11]

5. 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 the 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]

6. 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 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. [5]

- END OF EXAMINATION -