UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

MAIN EXAMINATION 2009/10

TITLE O F PAPER:	MODERN PHYSICS & WAVE OPTICS
COURSE NUMBER:	P231
TIME ALLOWED:	THREE HOURS
INSTRUCTIONS:	ANSWER ANY FOUR OUT OF FIVE QUESTIONS
	EACH QUESTION CARRIES 25 MARKS
	MARKS FOR EACH SECTION ARE IN THE RIGHT HAND MARGIN

THIS PAPER HAS SEVEN PAGES INCLUDING THE COVER PAGE

THE LAST PAGE CONTAINS FORMULAE AND CONSTANTS THAT MAY BE USEFUL IN SOME PROBLEMS

DO NOT OPEN THE PAPER UNTIL PERMISSION HAS BEEN GIVEN BY THE CHIEF INVIGILATOR

QUESTION 1.

(a) Most of the interference experiments discussed in this course deal with the interference of two coherent beams of light. Consider two coherent light waves of the same angular frequency ω moving along the positive x axis towards a screen, and described by the following equations:

$$y_1 = A\sin(kx - \omega t), \text{ and}$$
$$y_2 = A\sin(kx - \omega t + \phi).$$

Find the sum of the two waves $y = y_1 + y_2$, describe the wave formed and determine the phase angles ϕ for constructive and destructive interference. **(10 marks)**

(b) In Young's double slit experiment $L = 1.20$ m, $d = 0.120$ mm and the illuminating light has a wavelength $\lambda = 500$ nm.

(i) Calculate the phase difference between the two waves fronts arriving at P when $\theta = 0.500°$ and for $y = 5.00$ mm. **(6 marks)**

(ii) What is the value of θ for $\phi = 0.333$ rad? **(2 marks)**

(iii) What is the value of θ for the path difference $\delta = \lambda/4$? **(2 marks)**

(c) A film of magnesium fluoride (MgF_2) with a refractive index of 1.38 and a thickness of 1.00×10^{-5} cm is used to coat a camera lens of refractive index 1.57. Determine whether any wavelengths in the visible spectrum are intensified in the reflected light. **(5 marks)**

QUESTION 2

(a) Determine the minimum distance between two point sources that the human eye can distinguish at the near point (25 cm), assuming that the pupil diameter is 2 mm, and that a wavelength of 500 nm is used. **(5 marks)**

(b) The hydrogen spectrum has a red line at 656 nm and a blue line at 434 nm and is observed with a grating of 4500 grooves per cm.

(i) What is the grating spacing for this grating? **(2 marks)**

(ii) What are the angular separations between these two spectral lines in the first order spectrum? **(5 marks)**

(iii) At what angle do each of the two lines appear in the fourth order spectrum? **(4 marks)**

(c) What minimum thickness of calcite will make a half-wave plate for the sodium line at 589.6 nm? The refractive indices for calcite perpendicular to the optic axis are $n_O = 1.6584$ and $n_E = 1.4864$.. **(9 marks)**

QUESTION 3

(a) Give a detailed discussion of the photoelectric effect, including relevant equations and diagrams, give some justification whether this experiment supports the wave or particle nature of light. **(15 marks)**

(b) A 0.00160 nm photon scatters from a free electron. For what scattering photon angle does the recoiling electron have the same kinetic energy as the scattered photon? **(6 marks)**

(c) Find the wavelength of an electron that has an energy of 3.00 eV. **(4 marks)**

QUESTION 4

(a) Discuss the four ideas of Bohr from which he derived the Bohr atomic model.

(8 marks)

(b) Consider a Hydrogen-like helium ion.

(i) What is a "hydrogen-like ion" and how does it differ from hydrogen? **(3 marks)**

(ii) Determine the energy levels for a hydrogen-like helium ion for the states $n = 1$ to $n = 5$, and comment on the spacing of the energy levels with increase in n.

(6 marks)

(iii) What is the ionization energy for a hydrogen-like helium ion? **(2 marks)**

(c) Figure 1. shows an x-ray spectrum for tungsten. Discuss the origin of the continuous x-ray spectrum and the sharp x-ray lines. **(6 marks)**

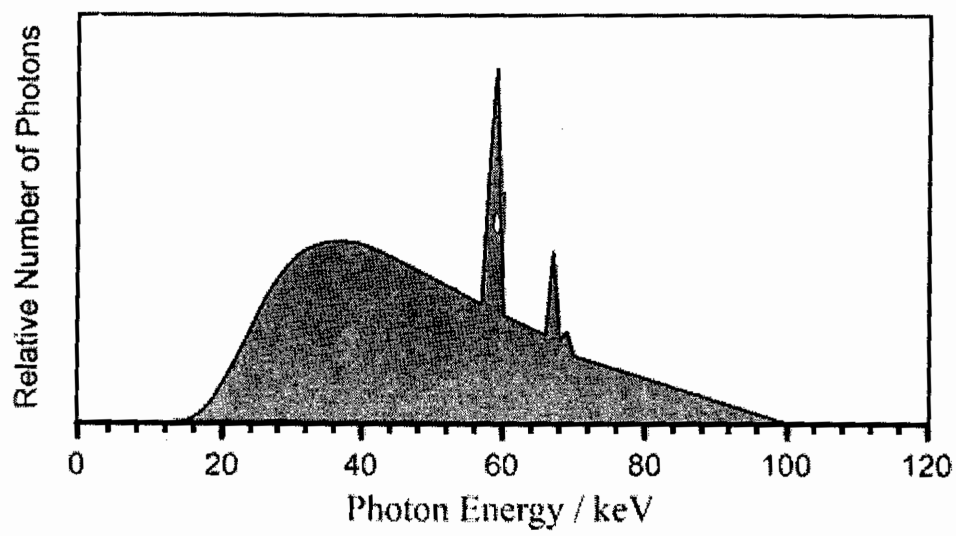

Figure 1. X-ray spectrum for tungsten.

QUESTION 5

(a) Find the radii of the helium ^{4}He and uranium ^{238}U nuclei, and compare these radii with the first orbit of the electron in the hydrogen atom. **(4 marks)**

(b) A certain wooden artifact is found to have a carbon-14 activity of 0.12 ± 0.01 Bq per gram of carbon. The activity of atmospheric carbon is taken to be 0.25 Bq per gram. The value of the half life of carbon 14 is assumed to be known with certainty.

(i) Derive an expression that can enable you to find the age of the sample in terms of $T_{½}$, R_0 and R. **(6 marks)**

(ii) In what age range does the age of the object lie? **(4 marks)**

(c) Calculate the binding energy per nucleon for ^{56}Fe. **(3 marks)**

(d) Consider a neutron with an energy above 1 MeV traveling through matter. Discuss how such a neutron can be captured by the nucleus. Also write down the equation for neutron capture and explain it. **(8 marks)**

SOME INFORMATION THAT MAY BE USEFUL IN SOME PROBLEMS

Avogadro's number $A = 6.02 \times 10^{23}$ particles per mole
Stefan-Boltzmann Constant $\sigma = 5.669\ 6 \times 10^{-8}$ W/(m^{2}K^2)^3
Coulomb constant $k_e = 8.987\ 551\ 788 \times 10^9$ N.m^2/C^2
Boltzmann's constant, $k_B = 1.3801 \times 10^{-23}$ J/K
Bohr radius $a_0 = 5.291\ 772 \times 10^{-11}$ m
Bohr magneton, $\mu_B = 9.27 \times 10^{-24}$ J/T
Radii of orbit for the hydrogen aton $r_n = n^2\, a_0$
Planck's constant, $h = 6.626\ 075 \times 10^{-34}$ Js
$\hbar = 1.054\ 572 \times 10^{-34}$ Js
$hc = 1.986\ 447 \times 10^{-25}$ Jm
$2\pi hc^2 = 3.741\ 859 \times 10^{-15}$ Jm^{2}s-1
Rydberg constant $R_H = 1.097\ 373 \times 10^7$ m^{-1}.
Speed of light in vacuum, $c = 2.997\ 924\ 58 \times 10^8$ m/s
mass of an electron, $m_e = 9.109\ 389\ 7 \times 10^{-31}$ kg = 0.000 548 6 u
mass of a proton, $m_p = 1.672\ 623 \times 10^{-27}$ kg = 1.007 276 u
mass of a neutron, $m_n = 1.674\ 928\ 6 \times 10^{-27}$ kg = 1.008 665 u
Coulomb constat, $k_e = 8.987\ 551\ 787 \times 10^9$ Nm^2/C^2
electron charge, $e = 1.602\ 177\ 33 \times 10^{-19}$ C
1 atomic mass unit = 1 amu = 1 $u = 1.660\ 540\ 2 \times 10^{-27}$ kg $\equiv$ 931.494 MeV rest mass energy
1 eV = $1.602\ 177\ 33 \times 10^{-19}$ J
$T_{1/2}(^{14}C)$ = 5730 years

Ratio of carbon 14 to carbon 12 in the atmosphere, $\frac{N(^{14}C)}{N(^{12}C)} = 1.2987 x 10^{-12}$

Helium (^4He) mass = 4.002 603 u
Molybdenum (^{94}Mo) mass = 93.905 088 u
Ruthenium (^{98}Ru) mass = 97.905 287 u
Cerium (^{140}Ce) mass = 139.905 434 u
Neodymium (^{144}Nd) mass = 143.910 083 u
Iron (^{56}Fe) mass = 55,934 942 u.

$$\lambda_{\max} = \frac{hc}{4.965kT}$$

$$\theta_{min} = 1.22\lambda/D$$

$$I = \frac{2\pi hc^2}{\lambda^5\left(e^{\frac{hc}{\lambda kt}} - 1\right)}$$

$$\int \cos^2 au\,du = \frac{u}{2} + \frac{\sin 2au}{4a}$$