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UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

SUPPLEMENTARY EXAMINATION 2011/12

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 INFORMATION THAT MAY BE USEFUL IN SOME PROBLEMS

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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 and wave number k moving along the positive x axis towards a screen, and described by the following equations:

$y_1 = A\sin(kx - \omega t)$

and

$y_2 = A\sin(kx - \omega t + \phi)$

Find the sum of the two waves $y = y_1 + y_2$. **(9 marks)**

b) In Young's double slit experiment $L = 2.00$ m, $d = 0.200$ mm and the illuminating light has a wavelength $\lambda = 589.2$ nm.

i. Calculate the distance between successive bright fringes. **(6 marks)**

ii. If light at the shortest wavelength of the visible spectrum is used, what is the distance between successive bright fringes? **(2 marks)**

c) Consider a thin film of thickness t where the refractive indices are such that $n_a < n_f > n_b$, where n_a, n_f and n_b are the refractive index of the medium above the film, refractive index of the film, and refractive index of the medium below the film, respectively.

i. With the aid of a diagram, discuss what happens when light incident from the medium above is reflected from the top film surface, and when light from the film is reflected from the bottom medium. **(4 marks)**

ii. Analyse the problem properly and determine the equations for constructive interference and destructive interference of the two reflected beams. **(4 marks)**

QUESTION 2

a) An object is viewed with a microscope with an objective diameter of 0.800 cm.

   i. What is the limiting angle of resolution (θ_{min}) when 700 nm and when 400 nm light is used to view the object. **(4 marks)**

   ii. Comment on the results from i, and ii. **(2 marks)**

   iii. Determine what would happen to the angle of resolution if oil of refractive index 1.750 fills the space between the object and the objective. **(5 marks)**

b) Discuss, with the aid of diagrams and stressing the important points, the polarization of light by reflection. **(12 marks)**

c) What is a quarter-wave plate? **(2 marks)**

QUESTION 3

a) Consider a blackbody of surface area 50.0 cm^2 and temperature of 6 500 K.

  i. How much power does it radiate? **(2 marks)**

  ii. At what wavelength does it radiate most intensely? **(2 marks)**

b) When light from a sodium lamp at 589.2 nm is used to illuminate a metal, a stopping potential of 0.467 V reduces the photocurrent to zero.

  i. What is the maximum speed of the ejected electrons? **(3 marks)**

  ii. Determine the work function, cut-off frequency and cut-off wavelength for this metal. **(8 marks)**

c) Discuss with the aid of diagrams and equations the Compton-effect, and state with justifications whether it supports the wave or particle nature of light. **(10 marks)**

QUESTION 4

a) What are the four postulates Bohr made to derive the energy levels of the hydrogen atom? **(4 marks)**

b) A photon is emitted as a hydrogen atom undergoes a transition from the $n = 8$ state to the $n = 2$ state.

   i. Use the Bohr model of the atom to calculate the energy and the wavelength of the emitted photon. **(4 marks)**

   ii. Calculate the wavelength using the empirical Balmer-Rhydberg equation and compare to the result from the Bohr model. **(3 marks)**

c) What is a hydrogen –like ion, and how does it differ from hydrogen? **(4 marks)**

d) An electron is restricted to move from $x = 0$ to $x = L$ and has the wave function: $\psi(x) = \sqrt{\frac{2}{L}} sin\left(\frac{2\pi x}{L}\right)$. Find an expression for the probability of finding the electron between $x = 0$ and $x = L/4$. **(6 marks)**

e) Discuss what you understand by the Pauli Exclusion Principle. **(4 marks)**

QUESTION 5

a) A star of mass 1.989 x 10^{30} kg ends its life by combining its protons and electrons to form a neutron star. Find the final radius of the star. **(4 marks)**

b) The nucleus radium $^{226}_{88}Ra$ decays by the emission of an alpha particle.

   i. Write the equation for the α decay reaction, first in general and using the data provided to write the correct equation for the radium decay. **(2 marks)**

   ii. Calculate the Q-value for this reaction. **(4 marks)**

c) A radioactive sample contains 6.45 μg of pure nitrogen 13 which has a half-life of 9.96 min.

   i. What is the number of nuclei in the sample? **(3 marks)**

   ii. Find the activity of the sample in becquerels initially. **(3 marks)**

   iii. Find the activity of the sample after exactly eight hours. **(2 marks)**

   iv. What is the number of remaining nuclei after eight hours? **(2 marks)**

d) Why is the temperature required for deuterium-tritium fusion less than that needed for the deuterium-deuterium fusion? **(5 marks)**

SOME INFORMATION THAT MAY BE USEFUL IN SOME PROBLEMS

Avogadro's number $A = 6.02 \times 10^{23}$ particles per mole
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
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
$2\pi hc^2 = 3.741\ 859 \times 10^{-15}$ J·m^2·s^{-1}
Radii of orbit for the hydrogen atom $r_n = n^2 a_0$
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
Stefan-Boltzmann Constant $\sigma = 5.669\ 6 \times 10^{-8}$ W/(m^{2}K^2)
Wien's displacement law $\lambda_{max} = \frac{hc}{4.965 k_B T}$

Nuclear Data
Electron charge, $e = 1.602\ 177\ 33 \times 10^{-19}$ C
Electron mass, $m_e = 9.109\ 389\ 7 \times 10^{-31}$ kg = 0.000 548 6 u
Neutron, $m_n = 1.674\ 928\ 6 \times 10^{-27}$ kg = 1.008 665 u
Proton mass, $m_p = 1.672\ 623 \times 10^{-27}$ kg = 1.007 276 u

1 atomic mass unit = 1 amu = 1 u = $1.660\ 540\ 2 \times 10^{-27}$ kg ≡ 931.494 MeV rest mass energy
1 eV = $1.602\ 177\ 33 \times 10^{-19}$ J: 1 MeV = $1.602\ 177\ 33 \times 10^{-13}$ J
$T_{1/2}(^{14}C)$ = 5730 years
Ratio of carbon 14 to carbon 12 in the atmosphere = $\frac{N(^{14}C)}{N(^{12}C)} = 1.2987 \times 10^{12}$
1Curie (Ci) = 3.7×10^{10} Becquerel (Bq)
$r_0 = 1.2 \times 10^{-15}$ m

Cerium (^{140}Ce) atomic mass = 139.905 434 u
Deuterium (^{2}D) atomic mass = 2.014 102 u
Alpha particle (α) (^{4}He) atomic mass = 4.002 603 u
Hydrogen (^{1}H) atomic mass = 1.007 825 u
Hydrogen molecular mass = 1.007 94 u
Iron (^{56}Fe) atomic mass = 55.934 942 u
Molybdenum (^{94}Mo) mass = 93.905 088 u
Neodymium (^{144}Nd) atomic mass = 143.910 083 u
Oxygen ^{15}O atomic mass = 15 .003 065 u
Nitrogen ^{15}N atomic mass = 15.000 109 u
Radium ($^{226}_{88}Ra$) atomic mass = 226.025 403 u
Radon ($^{222}_{86}Rn$) atomic mass = 2226.017 570 u
Ruthenium (^{98}Ru) atomic mass = 97.905 287 u
Tritium (^{3}T) atomic mass = 3.016 049 u
$\sin^2\theta = \frac{1}{2}(1 - \cos 2\theta)$