UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE AND ENGINEERING

DEPARTMENT OF PHYSICS

SUPPLEMENTARY EXAMINATION 2012/13

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) Young's double slit experiment is performed with the slits spaced a distance $d = 1.54$ mm apart and a light of wavelength λ is used. The distance between the slits and the screen is $L = 2.00$ m. The tenth ($m = 9$) interference minimum is observed 7.26 mm from the central maximum. Determine the wavelength of the light used in this experiment. **(8 marks)**

(c) A flat thin film of refractive index 1.33 is suspended flat in air such that it is surrounde by air. The thickness of the film is 115 nm.

(i) Analyse the problem properly (use diagrams) and determine the equations for constructive interference and destructive interference of the two reflected beams for light coming from the top. **(4 marks)**

(ii) What is the wavelength of the light most strongly reflected? **(4 marks)**

QUESTION 2

(a) Light of wavelength 587.5 nm illuminates a single slit of width $a = 0.750$ mm.

(i) At what distance from the slit should a screen be located if the first minimum in the diffraction pattern is to be 0.850 mm from the centre of the principal maximum (central maximum). **(6 marks)**

(ii) What is the width of the central maximum? **(3 marks)**

(b) Discuss, with the aid of diagrams and stressing the important points, the polarization of light by reflection. **(14 marks)**

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

QUESTION 3

a) Consider a blackbody of surface area 60.0 cm^2 and temperature of 5500 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, and 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 photoelectric 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 $n = 300$ to the $n = 299$ state.

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

ii. Use the empirical Balmer-Rhydberg equation to calculate the wavelength of the transition, and compare it to the result from the Bohr model. **(3 marks)**

c) What is a hydrogen–like ion, and how does it differ from hydrogen? **(5 marks)**

d) This question is on laser operation.

i. What is the critical condition for lasing? **(2 marks)**

ii. Make a diagram that illustrates laser operation. **(4 marks)**

iii. Discuss what each component does to support laser operation. **(3 marks)**

QUESTION 5

(a) With the knowledge that a sample emits radioactive radiation. Make a sketch and explain how you would determine the polarity of the emitted radiation? **(5 marks)**

(b) Make sketches of the proton-neutron and proton-proton potential energy functions and describe them. **(6 marks)**

(c) Radium ^{226}Ra undergoes a decay releasing an alpha particle and a radon (Rn) atom.

(i) Write down the equation for this process. **(2 marks)**

(ii) What is the Q-value for this reaction? **(4 marks)**

(d) A freshly prepared sample of a certain radioactive isotope has an activity of 10.0 mCi. After 4.00 hours, its activity drops to 8.00 mCi.

(i) Find the decay constant for this isotope. **(2 marks)**

(ii) Determine the half-life for the isotope. **(2 marks)**

(iii) Find the original number of isotopes in the freshly prepared sample? **(2 marks)**

(iv) What is the sample's activity 30.0 hours after its preparation? **(2 marks)**

SOME INFORMATION THAT MAY BE USEFUL IN SOME PROBLEMS

Avogadro's number A = 6.02 x 10^{23} particles per mole
Coulomb constant k_e = 8.987 551 788 x 10^9 N.m^2/C^2
Boltzmann's constant, k_B = 1.3801 x 10^{-23} J/K
Bohr radius a_0 = 5.291 772 x 10^{-11} m
Bohr magneton, μ_B = 9.27 x 10^{-24} J/T
Planck's constant, h = 6.626 075 x 10^{-34} Js
$\hbar$ = 1.054 572 x 10^{-34} Js
hc = 1.986 447 x 10^{-25} Jm
$2\pi hc^2$ = 3.741 859 x 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 x 10^7 m^{-1}.
Speed of light in vacuum, c = 2.997 924 58 x 10^8 m/s
Stefan-Boltzmann Constant σ = 5.669 6 x 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 x 10^{-19} C
Electron mass, m_e = 9.109 389 7 x 10^{-31} kg = 0.000 548 6 u
Neutron, m_n = 1.674 928 6 x 10^{-27} kg = 1.008 665 u
Proton mass, m_p = 1.672 623 x 10^{-27} kg = 1.007 276 u

1 atomic mass unit = 1 amu = 1 u = 1.660 540 2 x 10^{-27} kg ≡ 931.494 MeV rest mass energy
1 eV = 1.602 177 33 x 10^{-19} J: 1 MeV = 1.602 177 33 x 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 x 10^{10} Becquerel (Bq)
r_0 = 1.2 x 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 = 222.017 570 u
Ruthenium (^{98}Ru) atomic mass = 97.905 287 u
Tritium (^{3}T) atomic mass = 3.016 049 u
$\sin^2\theta = \frac{1}{2}(1 - \cos 2\theta)$