UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE AND ENGINEERING

DEPARTMENT OF PHYSICS

MAIN 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) Generally there is a condition that has to be met by the path difference δ or the phase angle ϕ, for destructive and constructive interference of two waves.

(i) Write down an equation that relates δ and ϕ, and also write each in terms of the other. **(3 marks)**

(ii) What are the conditions for δ and ϕ for constructive interference? **(3 marks)**

(iii) What are the conditions for δ and ϕ for destructive interference? **(3 marks)**

b) Why is it not possible to see an interference pattern from the two lights from a far away vehicle? **(3 marks)**

c) In Young's double slit experiment, the slits are vertically one above the other and their distance of separation is $d = 0.800$ mm. The screen is placed a distance $L = 1.42$ m from the slits and the illuminated light is from a HeNe laser with a wavelength of $\lambda = 632.8$ nm. Calculate the phase difference between the two waves fronts arriving at a point P along the y -axis

(i) when $\theta = 0.475°$ and **(3 marks)**

(ii) when $y = 6.54$ mm. **(3 marks)**

d) A substrate of refractive index $n_s = 3.50$ is coated with a thin film of thickness t and refractive index $n_f = 1.45$).

(i) Make a diagram that you can use as a basis to solve this problem. **(3 marks)**

(ii) What should be the film thickness to minimize reflection near the centre of the visible spectrum at 550 nm? **(4 marks)**

QUESTION 2

(a) Determine the minimum distance between two point sources that the human eye can distinguish at a near point 20 cm, assuming a pupil diameter of 3 mm, and a wavelength of 589.2 nm from a sodium lamp. **(5 marks)**

(b) What trade-offs are experienced when using a diffraction grating at low orders and at high orders? **(4 marks)**

(c) Discuss, with the aid of diagrams and stressing the important points, the polarization of light by double reflection (birefringence) **(11 marks)**

(d) What minimum thickness of sodium nitrate will make a quarter-wave plate for helium-neon laser light of wavelength $\lambda = 632.8$ nm. The indices of refraction for the *O* and the *E* rays are $n_O = 1.587$ and $n_E = 1.336$, respectively. **(5 marks)**

QUESTION 3

(a) What problems were experienced in attempting to use classical mechanics (Rayleigh-Jeans law) to explain blackbody radiation? **(4 marks)**

(b) When light from a hydrogen lamp at 486.1 nm is used to illuminate a metal, a stopping potential of 0.587 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. **(7 marks)**

(c) Discuss with the aid of diagrams and equation the Compton scattering, and state with justifications whether it supports the wave or particle nature of light. **(11 marks)**

QUESTION 4

(a) Explain whether a hydrogen atom in the ground state can absorb a photon of energy
   (i) less than 13.6 eV and **(2 marks)**
   (ii) greater then 13.6 eV. **(2 marks)**

(b) Derive an expression for the radius of an electron in the n^{th} Bohr orbit in hydrogen. You do not have to give all of Bohr's postulates. **(8 marks)**

(c) In interstellar space (space between stars in a galaxy) hydrogen can be excited to very high energy levels.
   (i) Use the empirical Balmer-Rydberg equation to calculate the wavelength of a highly excited hydrogen atom dropping from the $n = 273$ to the $n = 272$ level. **(3 marks)**
   (ii) Compare the result from (i) with the result from a calculation based on the Bohr model of the hydrogen atom which gives $\lambda = 0.926$ m for the same transition and give some explanation. **(2 marks)**

(d) Lasers are used to produce monochromatic light at a particular frequency.
   (i) What is the critical condition for a laser system to operate? **(2 marks)**
   (ii) List the major components of a laser system and state the purpose of each. **(6 marks)**

QUESTION 5

(a) The nucleus has positive protons packed in a very small space and is stable for most isotopes. Make a sketch that illustrates a plot of the neutron number N versus the atomic number Z, and discuss why this leads to stable nuclei. **(5 marks)**

(b) A piece of charcoal containing 25.0 g of carbon is found at Mdzimba mountains, and has an activity of 250 decays per minute.

(i) Develop an equation for determining the time since that part of the tree from which the charcoal came from died in terms of the initial and final activity. **(3 marks)**

(ii) Find the original number of ^{14}C nuclei in the 25.0 g sample at the time when the tree died? **(4 marks)**

(iii) What was the initial activity of the sample? **(3 marks)**

(iv) How long ago did the tree from which the charcoal was made die? **(3 marks)**

(c) Consider a neutron with very high kinetic energy traveling through matter. Discuss how such a neutron can be captured and write down the generic reaction equation for neutron capture and explain it. **(7 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
Helium (^{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
Ruthenium (^{98}Ru) atomic mass = 97.905 287 u
Tritium (^{3}T) atomic mass = 3.016 049 u

$\sin^2\theta = \frac{1}{2}(1 - \cos 2\theta)$