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UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

SUPPLEMENTARY EXAMINATION 2005

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

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QUESTION 1

(a) Give a detailed discussion of the photoelectric effect, including relevant equations and diagrams. **(10 marks)**

(b) X-rays having an energy of 450 keV undergo Compton scattering from a target. If the scattering rays are detected at 70° relative to the incident rays, find

(i) the Compton shift at this angle, and **(3 marks)**

(ii) the energy of the scattered X-rays. **(4 marks)**

(c) Discuss why light is considered as both a wave and a particle, and give examples where each behaviour is observed. **(8 marks)**

QUESTION 2

(a) A pendulum of string length l = 100 cm is swung over an angle of 15° and then let go.

(i) Find the quantum number for the system, assuming that it is quantised. **(6 marks)**

(ii) How much energy is emitted in one quantum change? **(2 marks)**

(b) Calculate the de Broglie wavelength for a rifle bullet of mass 100 g moving at a velocity of 400 m/s. From your results discuss whether or not it is possible to measure this wavelength. **(5 marks)**

(c) Discuss the origin of discrete spectra in atoms. **(6 marks)**

(d) A hydrogen-like lithium ion (Z = 3) is in its first excited state, use the Bohr model to compute

(i) the radius of orbit, and **(2 marks)**

(ii) the total energy of the system. **(4 marks)**

QUESTION 3

(a) Discuss the five pathways by which natural radioactivity occurs. Also write down the relevant equations making X the symbol for the original element and Y the daughter element. **(10 marks)**

(b) A piece of a wooden bowl is found in cave in Bulunga mountain. A sample of 200 g of the bowl is found to have a carbon 14 (^{14}C) activity R of 20 decays per second.

(i) Deduce an equation for determining the time since the person died in terms of the initial and final activity. **(3 marks)**

(ii) Find the decay constant λ of carbon 14. **(2 marks)**

(iii) What was the original number of ^{14}C nuclei in the 100 g sample when the person died? **(3 marks)**

(iv) What was the initial activity of the sample? **(1 mark)**

(v) How long ago did the person die assuming that the hat was made from freshly cut grass and twigs just after the person died? **(3 marks)**

(c) The uranium nucleus ^{238}U undergoes alpha decay according to the equation: $^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$. Calculate the Q value of this process in MeV. **(3 marks)**

QUESTION 4

(a) In Young's double slit experiment, write down the equations for constructive and destructive interference. Give an explanation for the equations and make a diagram for the experiment to illustrate the meaning of the equations. **(7 marks)**

(b) An oil film1000 nm thick with a refractive index of 1.6 floats on water of refractive index 1.33 and is illuminated by a continuous spectrum from the sun at midday. Some colours appear to be very strong compared to others when viewing the film from directly above. Determine which visible wavelengths are enhanced by the film, assuming that above the film is air of refractive index 1. **(10 marks)**

(c) A thin film of silicon monoxide (n = 1.45) is to be used to increase the transmission of an eye-piece made of extra dense flint glass (n = 1.75). In other words, the eyepiece must cause destructive interference for reflected light so that the light passes through with no reflection. The light used is the krypton line at 431.6 nm. Determine the minimum thickness for the film. **(5 marks)**

(d) With the help of a diagram show what kind of interference you would expect if the film was one and a half times the minimum thickness determined for the problem in part (c). **(3 marks)**

QUESTION 5

(a) (i) What is meant by the resolution of a telescope? **(3 marks)**
(ii) A telescope has a diameter of 5.08 m. What is the limiting resolution at a wavelength of 600 nm? **(3 marks)**

(b) With the aid of diagrams fully discuss polarization by reflection. **(10 marks)**

(c) A beam of unpolarized light travels along the *y*-axis toward a polarizing filter, which is in the *x-z* plane with its axis aligned in the *z*-direction. The incident beam has intensity I_0. Find the intensity of the beam emerging from the filter, and describe the emergent electric field. **(6 marks)**

(d) What is a half-wave plate. **(3 marks)**

SOME INFORMATION THAT MAY BE USEFUL IN SOME PROBLEMS

σ = 5.669 6 x 10^{-8} W/$(m^2K^2)^3$
Boltzmann's constant, k_B = 1.3801 x 10^{-23} J/K
Bohr magneton, μ_B = 9.27 x 10-24 J/T
Bohr radius a_0 = 0.052 9 nm
Speed of light in vacuum, c = 2.997 924 58 x 10^8 m/s
Planck's constant, h = 6.626 075 x 10^{-34} Js
$\hbar$ = 1.054 572 x 10^{-34}
hc = 1.986 447 x 10^{-25}
$2\pi hc^2$ = 3.741 859 x 10^{-15}
mass of an electron, m_e = 9.109 389 7 x 10^{-31} kg
mass of a proton, m_p = 1.672 623 x 10^{-27} kg
mass of a neutron, m_n = 1.674 928 6 x 10^{-27} kg
Coulomb constat, k_e = 8.987 551 787 x 10^9 Nm^2/C^2
electron charge, e = 1.602 177 33 x 10^{-19} C
1 atomic mass unit = 1 amu = 1 u = 1.660 540 2 x 10^{-27} kg = 931.494 MeV
1 eV = 1.602 177 33 x 10^{-19} J
$T_{1/2}(^{14}C)$ = 5730 years

$$\frac{N(^{14}C)}{N(^{12}C)} = 1.3x10^{-12}$$

Helium (^4He) mass = 4.002 602 u
Radon (^{222}Rn) mass = 222.017 571 u
Radium (^{226}Ra) mass = 226.025 402 u
Thorium (^{238}U) mass = 234.043 593 u
Uranium (234^{Th}) mass = 238.050 784 u

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

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

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

$$\int \cos^2 u du = \frac{u}{2} + \frac{1}{4}\sin 2u$$