UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

SUPPLEMENTARY EXAMINATION 2006/07

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) Which two experiments support the wave nature of light and which two support the particle nature of light? **(4 marks)**

(b) Give a detailed discussion of the photoelectric effect, including relevant equations and diagrams. **(9 marks)**

(c) When light from a sodium lamp at 589.2 nm is used to illuminate a metal, a stopping potential of 0.657 V reduces the photocurrent to zero. What is the workfunction of this metal in electron volts? **(5 marks)**

(d) X-rays having an energy of 300 keV undergo Compton scattering from a target. If the scattering rays are detected at 37° relative to the incident rays, find

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

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

QUESTION 2

(a) X- rays of wavelength $\lambda = 0.0552$ nm are Compton scattered by electrons in a graphite target at an angle of 70° with their original direction.

(i) What is the wavelength of the scattered electrons? **(4 marks)**

(ii) What is the kinetic energy in eV of the scattered electrons if they were at rest? Assume elastic scattering. **(4 marks)**

(b) An electron and a bullet of mass 0.150 0 kg each have a velocity of magnitude 450 m/s, accurate to within 0.010 0%. Within what limits could the position of each object be determined along the direction of the velocity? **(4 marks)**

(c) A hydrogen-like lithium ion is at its third excited state (n = 4). This problem is based on a single electron Lithium ion (Li^{2+}), Z = 3. Using the Bohr theory of the atom, calculate

(i) What is the equation of the radii of orbit for a hydrogen atom? **(2 marks)**

(ii) What is the equation for the radii of orbit for the hydrogen-like Lithium ion? **(2 marks)**

(iii) Find the radius of orbit for the excited state stated in the problem. **(2 marks)**

(iv) Find the linear momentum of the electron in this problem. **(2 marks)**

(v) Find the total mechanical energy of the system in electron volts. **(5 marks)**

QUESTION 3

(a) List the particles that are released in natural radioactivity and state their properties. **(7 marks)**

(b) Plutonium (^{239}Pu) initially at rest undergoes alpha decay to neptunium (^{235}Np).

(i) What is the Q value of the reaction in MeV? **(3 marks)**

(ii) Since the reaction is initiated from inside the nucleus, the momentum of the daughter element and that of the alpha particle are equal but opposite. Show that the alpha particle ends up with more of the disintegration energy. **(5 marks)**

(c) freshly prepared sample of a certain radioactive isotope has an activity of 48.0 mCi. After 24.00 h, its activity is 12.00 mCi.

(a) Find the decay constant and half life of the isotope. **(4 marks)**

(b) How many nuclei were present in the fresh sample? **(2 marks)**

(d) At first glance the model for the nucleus of an atom other than hydrogen is not supposed to be stable. Discuss why this is so and what leads to nuclear stability. **(4 marks)**

QUESTION 4

(a) A single slit of width *d* is placed in front of a lens of focal length *f* and is illuminated normally with light of wavelength λ. The first minima on either side of the central maximum of the diffraction pattern observed in the focal plane of the lens each is a distance *b* from the centre of the central maximum. What is the value of *d* in terms of *f*, λ and *b*? **(7 marks)**

(b) An oil film is 400 nm thick with a refractive index of 1.6 floats on water of refractive index 1.33 and is illuminated by a continuos spectrum of light from the sun. Some colours appear to be very strong compared to others when viewing the film. Determine which visible wavelengths are suppressed by the film. Above the film is air of refractive index 1. **(6 marks)**

(c) (i) Two wavelengths λ and λ + Δλ (Δλ<<λ) are incident on a diffraction grating of slit spacing *d*. Show that the angular separation between the m[th] order spectra is given by

$$\Delta\theta = \frac{\Delta\lambda}{\sqrt{(d/m)^2 - \lambda^2}}.$$

(6 marks)

(ii) Sodium yellow light consist of the two wavelengths 589.0 nm and 589.6 nm. This light falls normally on a plane diffraction grating with 1500 rulings per cm. What is the angular separation of the two lines observed in the first order spectrum. **(4 marks)**

(d) Show that

$$\frac{\Delta\nu}{\nu} = -\frac{\Delta\lambda}{\lambda},$$

where ν is frequency and λ is wavelength. **(2 marks)**

QUESTION 5

(a) A beam of unpolarised 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.

(i) Find the intensity of the beam emerging from the filter, and describe the emergent electric field. **(6 marks)**

(ii) What is the intensity if a second polariser is placed after the first with an orientation at 60° with the first? **(2 marks)**

(b) Discuss with the aid of diagrams polarisation by reflection. **(9 marks)**

(c) Discuss with the aid of a diagram how a laser works. (List the important things for laser operation) **(8 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 (^{234}Th) mass = 234.043 593 u
Uranium (^{238}U) mass = 238.050 784 u
Neptunium (^{235}Np) mass = 235.044 056 u
Plutonium (^{239}Pu) mass = 239.052 156 u

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

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

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

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