UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

MAIN 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) All objects at a temperature above absolute zero radiate electromagnetic energy. Why then is it not possible to see all objects in a dark room? **(6 marks)**

(b) The classical model of blackbody radiation given by the Rayleigh-Jeans law has two major flaws. Identify them and give the basis for the derivation of Planck's law, which matches blackbody radiation. **(6 marks)**

(c) Consider a blackbody of surface area 20.0 cm^2 and temperature of 5 000 K.

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

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

(iii) What is the spectral power per wavelength at the wavelength obtained in (ii)? **(5 marks)**

(d) When green light from a mercury lamp at 546.1 nm is used to illuminate a metal, a stopping potential of 0.376 V reduces the photocurrent to zero. What is the workfunction of this metal in electronvolts? **(4 marks)**

QUESTION 2

(a) The resolving power of a microscope depends on the wavelength used. To "observe" an atom, a resolution of approximately 1.00×10^{-11} m would be required.

(i) If electrons are used in an electron microscope, what minimum energy in electronvolts is required for the electrons? **(4 marks)**

(ii) What is the energy of photons in electron volts with the same energy as the electrons in (i)? Comment on this photon energy. **(3 marks)**

(b) Heisenberg Uncertainty Principle

(i) State Heisenberg uncertainty principle. **(3 marks)**

(ii) An electron and a bullet of mass 0.200 0 kg each have a velocity of magnitude 500 m/s, accurate to within 0.010 0%. Within what limits could the position of the object be determined along the direction of the velocity? Comment on your results. **(6 marks)**

(c) A hydrogen atom is at its first excited state (n = 2). Using the Bohr theory of the atom, calculate

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

(ii) the linear momentum of the electron, and **(2 marks)**

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

QUESTION 3

(a) Why do nearly all naturally occurring isotopes have more neutrons than protons? **(3 marks)**

(b) When a parent element disintegrates while at rest, the products acquire different kinetic energies. Show with the aid of an equation which has a greater kinetic energy between the smaller particle and a larger particle. **(5 marks)**

(c) A freshly prepared sample of a certain radioactive isotope has an activity of 10.0 mCi. After 4.00 h, its activity is 8.00 mCi.

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

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

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

(d) The nucleus $^{15}_{8}O$ decays by electron capture to $^{15}_{7}N$.

(i) Discuss what happens in electron capture and also write down the general equation of the reaction and the equation of the reaction process in the nucleus. **(5 marks)**

(ii) Write down the equation for the decay process referring to neutral atoms. **(1 mark)**

(iii) Determine the energy of the neutrino released. **(3 marks)**

QUESTION 4

(a) In a Young's double slit experiment, let the distance from the slits to the screen be L = 1.20 m and the distance of separation between the slits be d = 0.120 mm. Assume that the slits are illuminated with 500 nm light.

(i) Calculate the phase difference in degrees between the two wavefronts arriving at a point P on the screen when θ = 0.500°? **(4 marks)**

(ii) What is the phase difference when y = 5.00 mm? **(3 marks)**

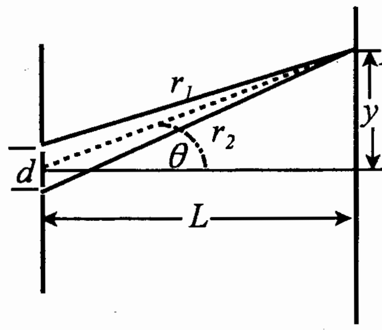


Figure 1. Illustration of Young's experiment

(b) Explain why it would be difficult to perform Young's experiment with white light? **(3 marks)**

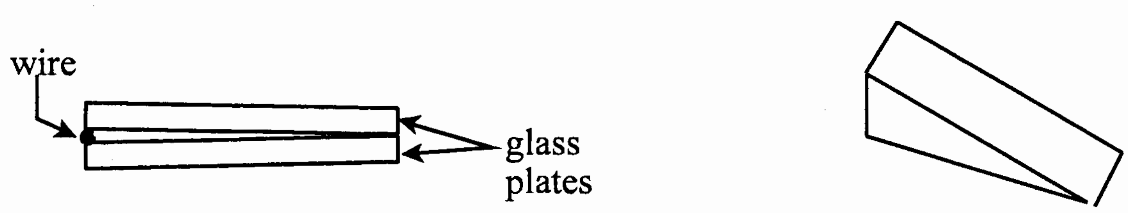
(c) An oil film (n = 1.45) floating on water (n = 1.333) is illuminated by white light at normal incidence. The film is 280 nm thick.

(i) Explain what happens to the two reflected rays upon reflection. **(3 marks)**

(ii) What colour is mostly reflected in the visible spectrum? **(5 marks)**

(iii) What colour in the visible spectrum is mostly transmitted? **(3 marks)**

(d) A air wedge is formed between two glass plates separated at one end by a very fine wire i.e. less than 1 mm. When the wedge is illuminated from above by 600 nm light and viewed from above, 30 dark fringes are observed. Calculate the radius of the wire. **(4 marks)**



(a) (b)

Figure 2. Illustration of physical set-up (a) and illustration of air wedge (b).

QUESTION 5

(a) Discuss in detail the behavior of light in birefringent materials. **(10 marks)**

(b) A helium-neon laser emits light that has a wavelength of 632.8 nm. The circular aperture through which the light emerges has a diameter of 0.500 cm. Estimate the diameter of the beam 10.0 km from the laser. **(6 marks)**

(c) A grating with 250 grooves/mm is used with a white light source. In how many orders can one see the entire visible spectrum? **(4 marks)**

(d) Draw a labeled schematic that illustrates laser operation. Do not discuss the laser operation. **(5 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 = 0.0529 nm
Rydberg constant RH = 1.097 373 2 x 10^7 m^{-1}
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} J·s
$\hbar$ = 1.054 572 x 10^{-34} J·s
hc = 1.986 447 x 10^{-25} J·m
$2\pi hc^2$ = 3.741 859 x 10^{-15} J·m^2s^{-1}
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 constant, 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
1Ci = 3.7 x 10^{10} Beq
$T_{1/2}(^{14}C)$ = 5730 years

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

Hydrogen (^1_1H) mass 1.007 825
Helium (^4_2He) mass = 4.002 602 u
Nitrogen ($^{15}_7N$) mass = 15.000 109 u
Oxygen ($^{15}_8O$)mass = 15.003 065 u
Fluorine ($^{19}_9F$) mass = 18.998 404 u

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

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

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

$$\Delta\nu = \frac{c}{2L}$$