UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

SUPPLEMENTARY EXAMINATION 2006

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

DO NOT OPEN THE PAPER UNTIL PERMISSION HAS BEEN GIVEN BY THE CHIEF INVIGILATOR

QUESTION 1

(a) A star moving away from the earth at 0.280*c* emits radiation that we measure to be most intense at the wavelength of 500 nm. Determine the surface temperature of this star. First find the real frequency of the emitted radiation. **(6 marks)**

(b) Discuss the photo-electric effect. Include relevant equations. Also state whether the photoelectric effect favours the wave nature or particle nature of light.**(10 marks)**

(c) In Compton scattering, does the photon behave like a particle or wave? Explain how you draw your conclusion. **(3 marks)**

(d) *X*-rays of wavelength of $\lambda = 0.22$ nm are scattered by a block of material and the scattered waves are observed at 50° to the incident beam.

(i) Calculate the wavelength of the scattered *X*-rays. **(3 marks)**

(ii) What is the kinetic energy of the scattered electrons if they were initially at rest? **(3 marks)**

QUESTION 2

(a) The classical model of blackbody radiation given by the Rayleigh-Jones law has two major flaws. Identify them and explain how Planck's law deals with them. **(4 marks)**

(b) Consider a single electron orbiting a stationary nucleus with charge +*Ze*, where *e* is the charge of single proton and *Z* is the atomic number.

(i) What is the total energy of the system using a classical model? Clearly show with the aid of a diagram how you obtain your result. **(3 marks)**

(ii) Show that the n^{th} radius of orbit of the electron is given by

$$r_n = n^2 \frac{a_0}{Z},$$

Where $a_0 = \dfrac{\hbar^2}{m_e k_e e^2}$ is the Bohr radius. **(8 marks)**

(b) Use the Rydberg equation to calculate the wavelength of the radiation emitted by a hydrogen atom from n = 290 to *n* = 289 levels. **(3 marks)**

(c) Use classical mechanics to calculate the wavelength of the radiation at the *n* = 290 orbit, where its radius of orbit is *r* = 4.01 μm and its velocity is υ = 8.01×10^3 m/s. **(3 marks)**

(d) How do the two results from (b) and (c) compare and what does that prove? **(4 marks)**

QUESTION 3

(a) A radioactive sample contains 3.50 µg of pure carbon 11 $\left({}^{11}_{6}C\right)$, which has a half-life of 20.4 min.

(i) What is the number of nuclei in the sample? **(3 marks)**

(ii) Find the activity of the sample in becquerels initially. **(3 marks)**

(iii) Find the activity after exactly **(3 marks)**
eight hours. **(2 marks)**

(iii) What is the number of remaining nuclei after eight hours. **(2 marks)**

(b) Radium 226 decays spontaneously to produce radon 222 and an alpha particle, ${}^{226}Ra \rightarrow {}^{222}Rn + {}^{4}He.$ Calculate the Q value for this reaction in MeV. Use full calculator accuracy and round at the end to 3 significant figures. What kind of a reaction is this in terms of energy? **(6 marks)**

(c) When two protons approach each other very closely they experience both the Coulomb force and the nuclear force. State which force is attractive and which is repulsive. Also sketch the potential energy diagrams for each force. **(6 marks)**

QUESTION 4

(a) What do you understand by the terms interference and diffraction? You can use diagrams if helpful. **(4 marks)**

(b) In a double-slit experiment, the viewing screen is L = 1.2 m away. The slits are separated by a distance d of 0.02 mm. The second-order bright fringe (m = 2) is 5 cm from the axis.

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

(ii) What is the distance between adjacent bright fringes? **(4 marks)**

(c) 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)**

(d) 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)**

QUESTION 5

(a) A microscope eyepiece has an aperture diameter of 0.8 cm. A neon laser at 633 nm is used to view the object

(i) What is the limiting angle of resolution θ_{min}. **(2 marks)**

(ii) If oil of refractive index 1.6 is used to fill the space between the objective lens and the object, what is the limiting angle of resolution? **(3 marks)**

(iii) If violet light at 400 nm is used to view the object what is the limiting angle of resolution. **(2 marks)**

(iv) From your results in (i), (ii) and (iii) comment on the effect on θ_{min} when using a higher refractive index medium and when using a shorter wavelength. **(2 marks)**

(b) Determine the minimum distance between two point sources that the human eye can distinguish at the near point (25 cm), assuming a pupil diameter of 2 mm, and a wavelength of 589 nm. **(5 marks)**

(c) Discuss the principle of laser operation with the aid of diagrams. **(8 marks)**

(d) Briefly discuss why sunrise and sunset tend to be red. **(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
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) nuclear mass = 4.002 602 u
Radon (^{222}Rn) nuclear mass = 222.017 571 u
Radium (^{226}Ra) nuclear mass = 226.025 402 u

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

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

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

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