UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

MAIN EXAMINATION 2010/11

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) Consider two light waves of the same amplitude a, but with slightly different wavelengths λ and λ' and slightly different velocities υ and υ', where $\lambda < \lambda'$ and $\upsilon < \upsilon'$. The propagation constant and the angular frequency will differ such that $k > k'$ and $\omega > \omega'$. The two waves are given by:

$$y_1 = a\sin(\omega t - kx), \text{ and}$$

$$y_2 = a\sin(\omega' t - k' x).$$

Find the sum of the two waves $y = y_1 + y_2$, discuss the result and write down the equations for the group and phase velocities. **(10 marks)**

(b) In Young's double slit experiment, the slits are separated by 0.25 mm and are illuminated by green light at $\lambda = 546.1$ nm. The interference pattern is observed on a screen 1.2 m from the plane of the slits. Calculate the distance between the bright fringes. **(5 marks)**

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

(i) Find the wavelengths most reflected in the first three orders (m = 0, 1, 2) and state the region of the electromagnetic spectrum in which they appear. **(5 marks)**

(ii) Which wavelengths in the first three orders are most strongly transmitted. Also state where they lie in the electromagnetic spectrum? **(5 marks)**

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QUESTION 2

(a) A screen is placed 50 cm from a single slit, which is illuminated with 690 nm light. If the distance between the first and third minimum in the diffraction pattern is 3 mm, what is the width of the slit? **(7 marks)**

(b) A grating with 250 grooves/mm is used with an incandescent light source.

(i) What is the grating spacing *d*? **(2 marks)**

(ii) In how many orders can one see the entire visible spectrum? **(6 marks)**

(c) Discuss in detail polarization by double refraction (birefringence). **(10 marks)**

QUESTION 3

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(a) In a photoelectric experiment to determine the work function for a particular metal surface, green light from a mercury lamp (λ = 546.1 nm) is used, and a stopping potential of 0.376 V reduces the photocurrent to zero. Find the work function for the metal. **(5 marks)**

(b) Electrons from a metallic surface are ejected with speeds ranging up to 6.6 x 105 m/s when light of wavelength 625 nm is used. Determine the work function, cut-off frequency and cut-off wavelength for this metal. **(6 marks)**

(c) Discuss with justification whether the Compton effect supports the wave nature or particle nature of light. **(7 marks)**

(d) An electron and a bullet of mass m = 0.02 kg each have a velocity of magnitude 500 m/s, accurate to within 0.01%. Within what limits can we determine the position of the objects along the direction of the velocity? Comment on the results. **(7 marks)**

QUESTION 4

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(a) A photon is incident on a hydrogen atom at the ground state. What could happen if the photon energy is

(i) less than the ionization energy of hydrogen 13.6 eV, **(3 marks)**

and

(ii) when it is greater than 13.6 eV? **(2 marks)**

(b) A photon is emitted as a hydrogen atom undergoes a transition from the $n = 6$ state to the $n = 2$ state.

(i) Calculate the energy of the photon emitted and the wavelength of the emitted photon. **(5 marks)**

(ii) Calculate the wavelength using the empirical Balmer-Rhydberg equation and compare to the result from the Bohr model. **(3 marks)**

(c) This question is on laser operation.

(i) Draw a labeled sketch that illustrates laser operation. **(6 marks)**

(ii) Give the three conditions that must be satisfied for laser operation. **(3 marks)**

(iii) What are the three primary properties of laser light? **(3 marks)**

QUESTION 5

(a) A freshly prepared sample of a certain radioactive isotope has an activity of 10 mCi. After 4 h its activity is 8 mCi.

(i) Find the decay constant. **(4 marks)**

(ii) Calculate the half-life. **(2 marks)**

(iii) How many nuclei of the isotope were contained in the fresh sample? **(2 marks)**

(iv) Determine the activity of the sample 30 h after its preparation. **(2 marks)**

(b) Why is the temperature required for deuterium-tritium fusion less than that needed for the deuterium-deuterium fusion? **(4 marks)**

(c) Consider a local dam with an average inflow of water at a rate of 2 kg/min. All the deuterium in the water is to be extracted for a newly developed controlled nuclear fusion power station to run all year round. Of the hydrogen in the water 0.03% is deuterium. The overall efficiency of the system is 45%. The deuterium in this newly developed controlled fusion is for the following reaction:

$${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{4}_{2}He.$$

(i) Find the Q-value for this reaction. **(3 marks)**

(ii) Find the capacity of the power plant that has to be constructed to utilise the extracted deuterium. **(8 marks)**

SOME INFORMATION THAT MAY BE USEFUL IN SOME PROBLEMS 49

Avogadro's number $A = 6.02 \times 10^{23}$ particles per mole
Stefan-Boltzmann Constant $\sigma = 5.669\,6 \times 10^{-8}$ W/(m^{2}K^2)^3
Coulomb constant $k_e = 8.987\,551\,788 \times 10^9$ N.m^2/C^2
Boltzmann's constant, $k_B = 1.3801 \times 10^{-23}$ J/K
Bohr radius $a_0 = 5.291\,772 \times 10^{-11}$ m
Bohr magneton, $\mu_B = 9.27 \times 10^{-24}$ J/T
Radii of orbit for the hydrogen atom $r_n = n^2\, a_0$
Planck's constant, $h = 6.626\,075 \times 10^{-34}$ Js
$\hbar = 1.054\,572 \times 10^{-34}$ Js
$hc = 1.986\,447 \times 10^{-25}$ Jm
$2\pi hc^2 = 3.741\,859 \times 10^{-15}$ Jm^{2}s-1
Rydberg constant $R_H = 1.097\,373 \times 10^7$ m^{-1}.
Speed of light in vacuum, $c = 2.997\,924\,58 \times 10^8$ m/s
mass of an electron, $m_e = 9.109\,389\,7 \times 10^{-31}$ kg = 0.000 548 6 u
mass of a proton, $m_p = 1.672\,623 \times 10^{-27}$ kg = 1.007 276 u
mass of a neutron, $m_n = 1.674\,928\,6 \times 10^{-27}$ kg = 1.008 665 u
Coulomb constat, $k_e = 8.987\,551\,787 \times 10^9$ Nm^2/C^2
electron charge, $e = 1.602\,177\,33 \times 10^{-19}$ C
1 atomic mass unit = 1 amu = 1 u = $1.660\,540\,2 \times 10^{-27}$ kg $\equiv$ 931.494 MeV rest mass energy
1 eV = $1.602\,177\,33 \times 10^{-19}$ J: 1 MeV = $1.602\,177\,33 \times 10^{-13}$ J
$T_{1/2}(^{14}C)$ = 5730 years

Ratio of carbon 14 to carbon 12 in the atmosphere, $\frac{N(^{14}C)}{N(^{12}C)} = 1.2987x10^{-12}$

Hydrogen (H) atomic mass = 1.007 825 u and 1.00794 u chemical atomic mass
Hydrogen molecular mass = 1.0079 u
Deuterium (D) mass = 2.014 102 u
Helium (^{4}He) mass = 4.002 603 u
Molybdenum (^{94}Mo) mass = 93.905 088 u
Ruthenium (^{98}Ru) mass = 97.905 287 u
Cerium (^{140}Ce) mass = 139.905 434 u
Neodymium (^{144}Nd) mass = 143.910 083 u
Iron (^{56}Fe) mass = 55,934 942 u.

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

$$I = \frac{2\pi hc^2}{\lambda^5\left(e^{\frac{hc}{\lambda kt}} - 1\right)} \qquad \theta_{min} = 1.22\lambda/D$$

$$\int \cos^2 au\,du = \frac{u}{2} + \frac{\sin 2au}{4a}$$