UNIVERSITY OF ESWATINI

FACULTY OF SCIENCE AND ENGINEERING

DEPARTMENT OF PHYSICS

MAIN EXAMINATION 2018/2019

TITLE OF PAPER:	WAVE OPTICS AND MODERN PHYSICS
COURSE CODE:	PHY232
TIME ALLOWED:	THREE HOURS

USEFUL INTSRUCTIONS:

1. There are five questions in this paper, and each question carries a total of 25 marks. Answer any four questions in your preferred order.
2. Additional materials included in this paper are a list of useful constants and the periodic table.

THIS PAPER SHOULD NOT BE OPENED UNLESS OTHERWISE ADVISED TO DO SO BY THE INVIGILATOR

THIS PAPER CONSISTS OF 9 PAGES WITH COVER PAGE AND ADDITIONAL BACK PAGE INCLUDED

Question One [25 marks]

(a) State *three* reasons why electrons cannot exist within the nucleus. (3)

(b) Determine the minimum kinetic energy of a proton in a nucleus of diameter 8.0×10^{-15} m. (3)

(c) Define the following terms:

(i) Nuclide. (1)

(ii) Isotopes. (1)

(iii) Isobars. (1)

(d) Determine the ratio of the radii of ^{238}U and ^{4}He nuclei. (2)

(e) (i) What is meant by the *binding energy* of a nucleus? (1)

(ii) Show that the nuclide $^{8}_{4}\mathrm{Be}$ has a positive binding energy but is unstable with respect to decay into two alpha particles. (5)

{Hint: Atomic masses are $m_n = 1.008665\,\mathrm{u}$, $M(^{1}\mathrm{H}) = 1.007825\,\mathrm{u}$, $M(^{4}_{2}\mathrm{He}) = 4.002603\,\mathrm{u}$, and $M(^{8}_{4}\mathrm{Be}) = 8.005305\,\mathrm{u}$.}

(iii) Calculate the binding energy per nucleon for $^{20}_{10}\mathrm{Ne}$, $^{56}_{26}\mathrm{Fe}$, and $^{238}_{92}\mathrm{U}$. (6)

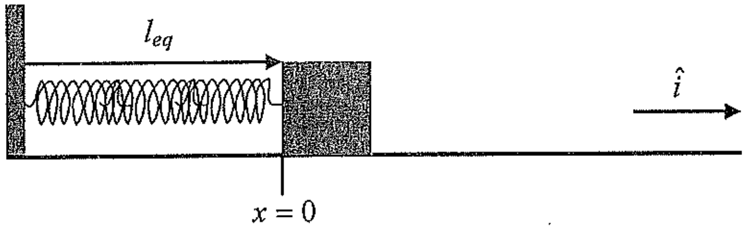
{Hint: Atomic masses are $m_n = 1.008665\,\mathrm{u}$, $M(^{1}\mathrm{H}) = 1.007825\,\mathrm{u}$, $M(^{20}_{10}\mathrm{Ne}) = 19.992440\,\mathrm{u}$, $M(^{56}_{26}\mathrm{Fe}) = 55.938909\,\mathrm{u}$, and $M(^{238}_{92}\mathrm{U}) = 238.050783\,\mathrm{u}$.}

(f) Calculate the activity in $\mu\mathrm{Ci}$ for a sample of $^{210}\mathrm{Po}$ which α decays with a half life of $t_{1/2} = 138$ days if observed to have 2000 disintegrations per second. (2)

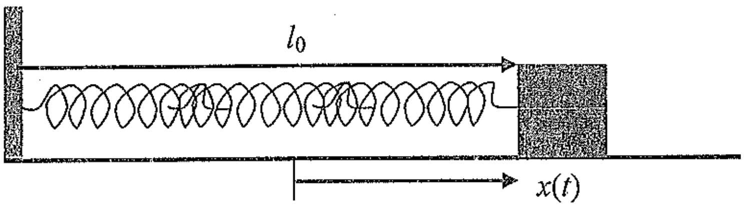
Question Two [25 marks]

(a) State evidence for the wave and particle characters of light. (4)

(b) Fig. 2.1 illustrates a spring-mass system on a frictionless surface. Using this diagram, or otherwise, derive the simple harmonic oscillator equation and solve it delineating all crucial parameters to your solution. (6)



Equilibrium position



Stretched position

Fig. 2.1

(c) (i) In a Young's double slit experiment, the two slits are made to be 1 mm apart and the observation screen placed 1 m away. Determine the separation of consecutive fringes when blue-green light of wavelength 600 nm is used. (2)

(ii) Suppose monochromatic light of wavelength of 600 nm passes through a slit which has a width of 0.800 mm. Calculate the distance between the slit and the screen if the first minimum in the diffraction pattern is at a distance of 1.00 mm from the center of the screen. (3)

(d) Fig. 2.2 illustrates one of the crucial steps involved in finding the wavelength of a light source by Fresnel's mirror interference.

(i) Determine the actual separation a between the two virtual light sources S_1 and S_2 with $L_1 = 22.5 \pm 0.1\,\text{cm}$, $L_2 = 154 \pm 1\,\text{cm}$, and $A = 4 \pm 1\,\text{mm}$. (5)

{Hint: $a = \left(\frac{L_1}{L_2}\right) A$, and $s_a = \sqrt{\left(\frac{\partial a}{\partial L_1} \cdot s_{L_1}\right)^2 + \left(\frac{\partial a}{\partial L_2} \cdot s_{L_2}\right)^2 + \left(\frac{\partial a}{\partial A} \cdot s_A\right)^2}$ }

(ii) Determine the wavelength of the light source if the distance of the sources S_1 and S_2 from the observation screen is $L = 177 \pm 0.1\,\text{cm}$ and the fringe separation is $d = 2 \pm 1\,\text{mm}$. (5)

{Hint: $\lambda = \left(\frac{d}{L}\right) a$, and $s_\lambda = \sqrt{\left(\frac{\partial \lambda}{\partial d} \cdot s_d\right)^2 + \left(\frac{\partial \lambda}{\partial L} \cdot s_L\right)^2 + \left(\frac{\partial \lambda}{\partial a} \cdot s_a\right)^2}$ }

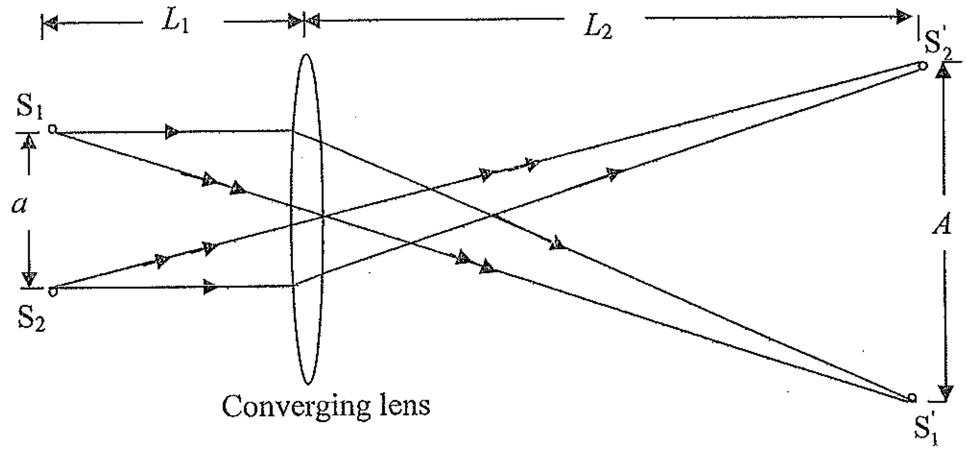


Fig. 2.2

Question Three [25 marks]

(a) (i) Define *blackbody radiation.* (2)

(ii) State two characteristic observations that were made from the spectral distribution of blackbody radiation. (2)

(iii) State Wien's displacement law in equation form in relation to the spectral distribution of blackbody radiation. (2)

(iv) A furnace has its walls at a temperature of 1600 °C. Determine the wavelength of maximum intensity emitted when a small door is opened. (2)

(b) (i) State four mechanisms of electron emission from the surface of a material. (4)

(ii) Photoelectrons may be emitted from sodium ($\phi = 2.36\,\mathrm{eV}$) even for light intensities as low as $I = 10^{-8}\ \mathrm{W/m^2}$. Calculate classically the amount of time required for light to shine so that there is a photoelectron produced with kinetic energy of 1.00 eV. (10)

{Hint: Na has a gram molecular weight of 23 g/mol and gram density of 0.97 g/cm^3, and Avogadro's number is $N_A = 6.02 \times 10^{23}$ atoms/mol. Assume a simple cubic structure to estimate the thickness of one layer of atoms in sodium.}

(iii) Light of wavelength 400 nm is incident upon lithium ($\phi = 2.93\,\mathrm{eV}$). Calculate the photon energy E and the stopping potential V_0. (3)

Question Four [25 marks]

(a) Fig. 4.1 shows the Compton scattering of a photon of energy E by an electron that is at rest in the target.

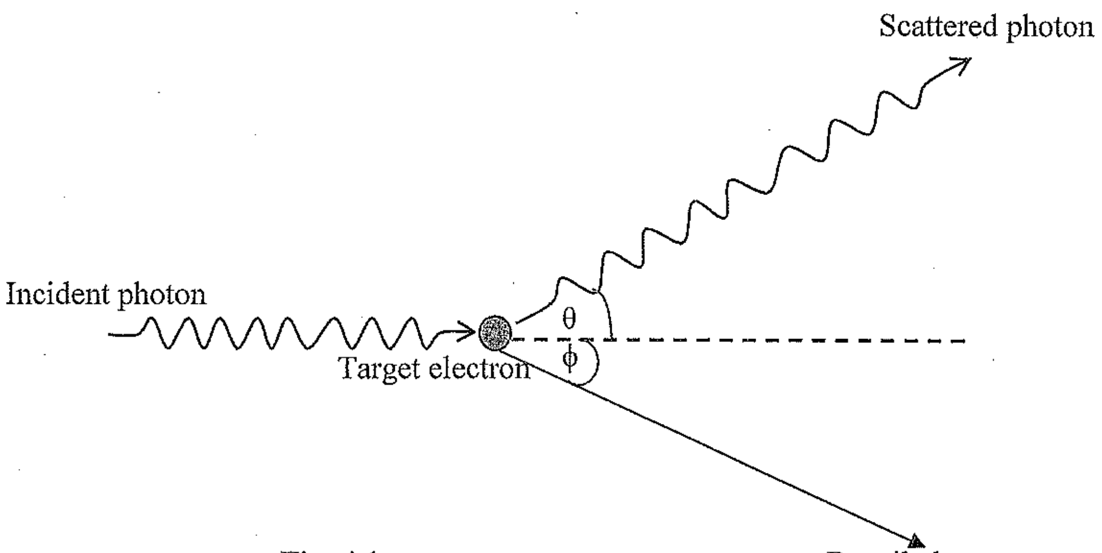


Fig. 4.1

(i) Briefly describe this process, citing how Compton's theory deviated from the classical theory of electromagnetic radiation. (5)

(ii) Show that the shift in the wavelength of the incident photon to the scattered photon is given by $\Delta\lambda = (\lambda' - \lambda) = \frac{h}{mc}(1 - \cos\theta)$ (15)

{Hint: Use the conservation of energy and momentum principle for the entire system, and the fact that the electron's energy after the collision is given by $E_e^2 = (mc^2)^2 + p_e^2 c^2$.}

(b) Calculate the minimum kinetic energy of an electron that is localized within a typical nuclear radius of 6.00×10^{-15} m. (5)

Question Five [25 marks]

(a) (i) State the four postulates made by Niels Bohr in modelling the hydrogen atom. (4)

(ii) Show that, according to Bohr's model, the only allowed orbits in an atom are given by

$$r_n = \frac{4\pi\varepsilon_o n^2\hbar^2}{me^2} \equiv n^2 a_o; \quad n = 1, 2, 3, \ldots \qquad (6)$$

(iii) Show that, according to Bohr's model, the energies of the stationary states in the atom are given by $E_n = -\dfrac{e^2}{8\pi\varepsilon_o a_o n^2}$; $\quad n = 1, 2, 3, \ldots$ (6)

(iv) Using the second postulate made by Bohr in modelling the hydrogen atom and the above results, show that the frequencies of all possible transitions in atomic hydrogen can be deduced from the relationship $\dfrac{1}{\lambda} = R_\infty\left(\dfrac{1}{n_l^2} - \dfrac{1}{n_u^2}\right)$ (5)

(b) Fig. 5.1 is a schematic of a four-level laser. Briefly describe the production of a laser beam by this system using as much information possible depicted in the figure. (4)

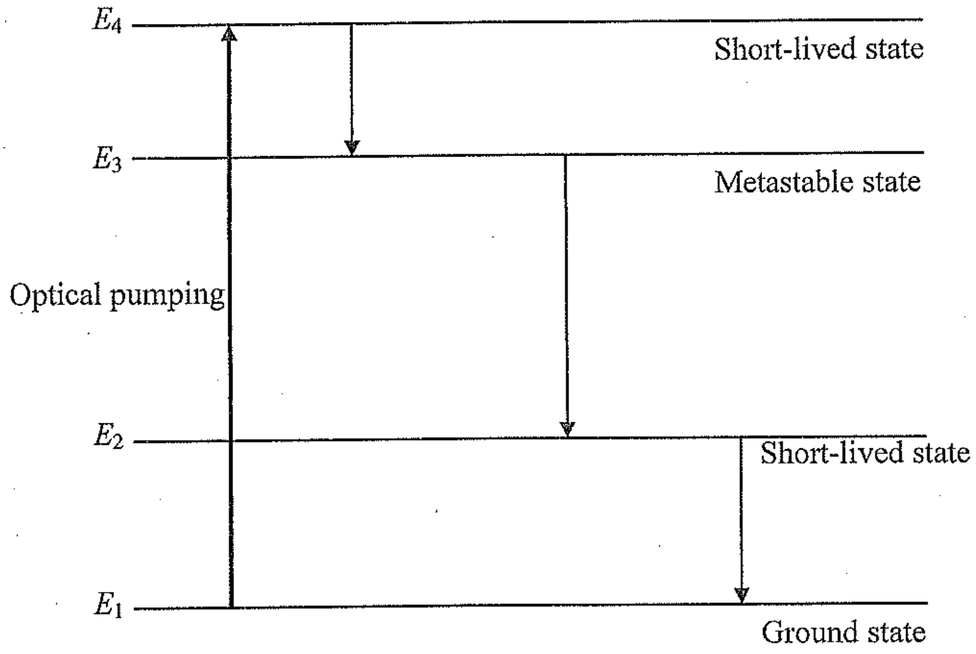


Fig. 5.1

Fundamental Constants

Quantity	Symbol	Value
Elementary charge	e	1.6022×10^{-19} C
Speed of light in vacuum	c	2.9979×10^{8} m/s
Permeability of vacuum	μ_0	$4\pi\times10^{-7}$ $\mathrm{N\cdot A^{-2}}$
Permittivity of vacuum	ε_0	8.8542×10^{-12} $\mathrm{F\cdot m^{-1}}$
Planck constant	h	6.6261×10^{-34} $\mathrm{J\cdot s}$
		4.1357×10^{-15} $\mathrm{eV\cdot s}$
Avogadro constant	N_A	6.0221×10^{23} $\mathrm{mol^{-1}}$
Boltzmann constant	k	1.3807×10^{-23} $\mathrm{J\cdot K^{-1}}$
Stefan-Boltzmann constant	σ	5.6704×10^{-8} $\mathrm{W\cdot m^{-2}\cdot K^{-4}}$
Atomic mass unit	u	1.66053886×10^{-27} kg
		$931.494061\ \mathrm{MeV/c^2}$

Particle masses

Particle	Mass in units of kg	Mass in units of MeV/c²	Mass in units of u
Electron	9.1094×10^{-31}	0.5110	5.4858×10^{-4}
Proton	1.6726×10^{-27}	938.27	1.00728
Neutron	1.6749×10^{-27}	939.57	1.00866
Deuteron	3.3436×10^{-27}	1875.61	2.01355
α particle	6.6447×10^{-27}	3727.38	4.00151

Conversion factors

$1\ \mathrm{MeV/c} = 5.344\times10^{-22}\ \mathrm{kg\cdot m/s}$

$1\ \mathrm{u} = 1.66054\times10^{-27}\ \mathrm{kg}$

$1\ \mathrm{Ci} = 3.7\times10^{10}\ \mathrm{Bq}$

$1\ \mathrm{eV} = 1.6022\times10^{-19}\ \mathrm{J}$

Useful Combinations of Constants

$\hbar = h/2\pi = 1.0546\times10^{-34}\ \mathrm{J\cdot s} = 6.5821\times10^{-16}\ \mathrm{eV\cdot s}$

$hc = 1.9864\times10^{-25}\ \mathrm{J\cdot m} = 1239.8\ \mathrm{eV\cdot nm}$

$\hbar c = 3.1615\times10^{-26}\ \mathrm{J\cdot m} = 197.33\ \mathrm{eV\cdot nm}$

$\frac{1}{4\pi\varepsilon_0} = 8.9876\times10^{9}\ \mathrm{N\cdot m^2\cdot C^{-2}}$

Compton wavelength $\lambda_C = \frac{h}{m_e c} = 2.4263\times10^{-12}\ \mathrm{m}$

$\frac{e^2}{4\pi\varepsilon_0} = 2.3071\times10^{-28}\ \mathrm{J\cdot m} = 1.4400\times10^{-9}\ \mathrm{eV\cdot m}$

Rydberg constant $R_\infty = 1.09737\times10^{7}\ \mathrm{m^{-1}}$

The periodic table of elements with their atomic numbers

I	II											III	IV	V	VI	VII	VIII
^{1}H																	^{2}He
^{3}Li	^{4}Be											^{5}B	^{6}C	^{7}N	^{8}O	^{9}F	^{10}Ne
^{11}Na	^{12}Mg											^{13}Al	^{14}Si	^{15}P	^{16}S	^{17}Cl	^{18}Ar
^{19}K	^{20}Ca	^{21}Sc	^{22}Ti	^{23}V	^{24}Cr	^{25}Mn	^{26}Fe	^{27}Co	^{28}Ni	^{29}Cu	^{30}Zn	^{31}Ga	^{32}Ge	^{33}As	^{34}Se	^{35}Br	^{36}Kr
^{37}Rb	^{38}Sr	^{39}Y	^{40}Zr	^{41}Nb	^{42}Mo	^{43}Tc	^{44}Ru	^{45}Rh	^{46}Pb	^{47}Ag	^{48}Cd	^{49}In	^{50}Sn	^{51}Sb	^{52}Te	^{53}I	^{54}Xe
^{55}Cs	^{56}Ba		^{72}Hf	^{73}Ta	^{74}W	^{75}Re	^{76}Os	^{77}Ir	^{78}Pt	^{79}Au	^{80}Hg	^{81}Tl	^{82}Pb	^{83}Bi	^{84}Po	^{85}At	^{86}Rn
^{87}Fr	^{88}Ra		^{104}Rf	^{105}Db	^{106}Sg	^{107}Bh	^{108}Hs	^{109}Mt	^{110}Ds	^{111}Rg	^{112}Cn	^{113}Nh	^{114}Fl	^{115}Mc	^{116}Lv	^{117}Ts	^{118}Og