BINDURA UNIVERSITY OF SCIENCE EDUCATION

PHYSICS AND MATHEMATICS DEPARTMENT

PH104: OPTICS AND MODERN PHYSICS
DURATION: THREE HOURS

AUG 2023

Answer **ALL** parts of Section A and any **THREE** questions from Section B. Section A carries 40 marks and Section B carries 60 marks.

Proton	1.672621×10^{-27} kg	Neutron	1.674927×10^{-27} kg
Electron	0.000911×10^{-27} kg	Barium-141	233.9450×10^{-27} kg
Calcium-40	66.34121×10^{-27} kg	Krypton-92	152.6167×10^{-27} kg
Potassium-40	66.34446×10^{-27} kg	Uranium-235	390.2182×10^{-27} kg
Planck's constant	6.626×10^{-34} Js	Speed of light	2.988×10^{8} ms^{-1}
Electron charge	1.602×10^{-19} C	Electronvolt	1.602×10^{-19} J
Proton rest mass	1.6726×10^{-27} kg	Electron mass	9.1095×10^{-31} kg

SECTION A

1.a. In a handheld optical instrument used under water, light is incident from water onto the plane surface of flint glass at an angle of incidence of 45^0. The index of refraction is 1.33 for water and 1.63 for flint glass.

i. What is the angle of reflection of light off the flint glass? [2]

ii. Does the refracted ray bend toward or away from the normal? [2]

iii. What is the angle of refraction in the flint glass? [3]

b. A cylindrical glass rod (Figure 1.1) has index of refraction 1.52. It is surrounded by air. One end is ground to a hemispherical surface with radius $R = 2.00$ cm A small object is placed on the axis of the rod, 8.00 cm to the left of the vertex.

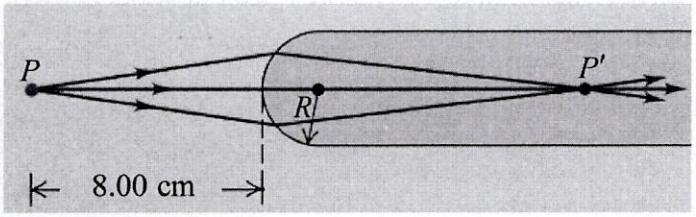

Figure 1.1: Image formed by a glass rod in air

Find

i. the image distance and [3]

ii. the lateral magnification. [3]

c. It is often desirable to radiate most of the energy from a radio transmitter in particular directions rather than uniformly in all directions. Pairs or rows of antennas are often used to produce the [6]

desired radiation pattern. As an example, consider two identical vertical antennas 400 m apart, operating at 1500 kHz (near the top end of the AM broadcast band) and oscillating in phase. At distances much greater than 400 m in what directions is the intensity from the two antennas greatest?

d. Parallel rays of light with wavelength $\lambda = 500$ nm are incident on a slit of width $a = 0.2$ mm. A diffraction pattern is formed on a screen at a distance $D = 2.5$ m from the slit. Find

i. the position of the first minimum and [5]

ii. the width of the central bright fringe. [3]

e. Evaluate the de Broglie wavelengths of a 46-g golf ball with a velocity of 30 m/s [4]

f. Calculate the threshold wavelength of light needed to just release electrons from gold. For Gold [4]
$W_0 = 7.68 \times 10^{-19}$ J

g. Experiments indicate that 13.6 eV is required to separate a hydrogen atom into a proton and an electron; that is, its total energy is $E_T = -13.6$ eV. Find the orbital radius and velocity of the electron in a hydrogen atom. [5]

SECTION B

2. Using a detailed diagram and explaining all terms used show that for a Hydrogen electron, the total energy E_T is given by equation 2.1. [20]

$$E_T = -\frac{e^2}{8\pi\varepsilon_0 r} \quad \text{..... (2.1)}$$

3.a The near point of a certain hyperopic eye is 100 cm in front of the eye. Find the focal length and power of the contact lens that will permit the wearer to see clearly an object that is 25 cm in front of the eye. [3]

b. The wavelength of yellow light in vacuum is 600 nm.

i. What is the speed of this light in vacuum and water? The refractive index of water is 1.333. [4]

ii. Prove that the frequency of light in vacuum is the same as that in water. [4]

iii. What is the wavelength of this light in water? [3]

c. Two narrow slits are separated by 0.06 mm and are 1.2 m away from a screen. When the slits are illuminated by light of unknown wavelength λ, we obtain fourth-order bright fringe 4.5 cm from the central line.

i. Evaluate the colour of this light. [4]

ii. Determine the angle that this fringe make with the central line [2]

4.a. With the aid of an appropriate construction, show that the *numerical aperture*, *NA* of a *step-index* fibre is given by: [8]

$$NA = \sqrt{n_1^2 - n_2^2}$$

where n_1 and n_2 are refractive indices of the core and cladding respectively.

b. i. The intensity at the centre of a single-slit diffraction pattern is I_0 What is the intensity at a point in the pattern where there is a 66-radian phase difference between wavelets from the two edges of the slit? [3]

ii. (b) If this point is 7.0° away from the central maximum, how many wavelengths wide is the slit? [3]

c. Sunlight reflects off the smooth surface of a swimming pool.

i. For what angle of reflection is the reflected light completely polarized? The refractive index of water is 1.33 [3]

ii. What is the corresponding angle of refraction? [3]

5.a In a photoelectric experiment, a student obtained the data shown in Table 5.1.

Table 5.1: Question 5.a.

Frequency of radiation $(10^{14}$ Hz)	9.9	7.7	4.7	3.2	2.3
Stopping voltage (V)	4.10	2.95	1.45	0.70	0.15

i. Draw a graph that shows the relationship between the frequency of the incident radiation and the stopping potential. [5]

ii. Using only your graph, determine the threshold frequency of the incident radiation [2]

iii. Calculate Planck's constant [5]

b. The isotope ^{57}Co decays by electron capture to ^{57}Fe with a half-life of 272 d. The ^{57}Fe nucleus is produced in an excited state, and it almost instantaneously emits gamma rays that we can detect. For ^{57}Co determine:

c. i. the mean lifetime [4]

d. ii. the decay constant [4]

6.a. For each of the four radioactive decays listed below, write the decay reaction and identify the daughter in the form $^{A}_{Z}X$

i. α decay of $^{239}_{94}Pu$ [2]

ii. β^- decay of $^{66}_{28}Ni$ [2]

iii. β^+ decay of $^{22}_{11}Na$ [2]

iv. γ decay of $^{231}_{90}Th$ [2]

b. Calculate the binding energy per nucleon in the calcium-40 nucleus. Calcium is atomic number 20. [5]

c. An electron is in a box 0.10 nm across, which is the order of magnitude of atomic dimensions. Evaluate its permitted energies [7]

END OF EXAM