

UNIVERSITY OF FORT HARE



University of Fort Hare
Together in Excellence
MODERN PHYSICS (PHY 311)

EXAMINATIONS

DATE: MAY 2023

DURATION: 3 HOURS

MARKS: 100

INTERNAL EXAMINER

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EXTERNAL EXAMINER

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THIS PAPER CONSISTS OF 6 PAGES INCLUDING COVER PAGE

INSTRUCTIONS:

1. Answer all the questions.
2. Write neatly and legibly.
3. Unless otherwise stated, all symbols retain their usual meanings.
4. Values of constants appear at end of the question paper

QUESTION 1

- 1.1. (i) What postulates were made by Planck in dealing with the problem of blackbody radiation? (2)
- (ii) The number of Planck's oscillators per unit volume, in the frequency interval ν and $\nu + d\nu$ is given by $N(\nu)d\nu = \frac{8\pi\nu^2}{c^3} d\nu$. Show that the Planck's radiation law is (18)

$$u(\lambda, T)d\lambda = \frac{8\pi hc}{\lambda^5} \frac{d\lambda}{e^{\frac{hc}{\lambda kT}} - 1}$$

[20]

QUESTION 2

- 2.1. What will the areas under the curves ($\frac{c}{4}u(\lambda, T)$ versus λ) of Planck's radiation spectrum represent? (2)
- 2.2. Derive Stephan's law from the Planck's Radiation law. Make the change of variable $x = \frac{hc}{\lambda kT}$ and use $\int_0^\infty \frac{x^3 dx}{e^x - 1} = \frac{\pi^4}{15}$ (5)
- 2.3. A black body at 7 500 K consists of an opening of diameter 0.050 0 mm, looking into an oven. Find the number of photons per second escaping the opening and having wavelengths between 500 nm and 501 nm (10)
- 2.4. Derive Rayleigh-Jean's law, $u(\lambda, T)d\lambda = \frac{8\pi kT d\lambda}{\lambda^4}$ from Planck's radiation law. (3)

[20]

QUESTION 3

- 3.1. Derive the Wien's displacement law, $\lambda_{max}T = 2.897755 \times 10^{-3} \text{ m} \cdot \text{K}$ (14)
from the Planck's radiation law.
- 3.2. The radius of our sun is $6.96 \times 10^8 \text{ m}$, and its total power output is $3.77 \times 10^{26} \text{ W}$.
- (i) Assuming that the sun's surface emits as a black body, calculate its surface temperature. (3)
- (ii) Using the results of part (i), find λ_{max} for the sun. (3)

[20]

QUESTION 4

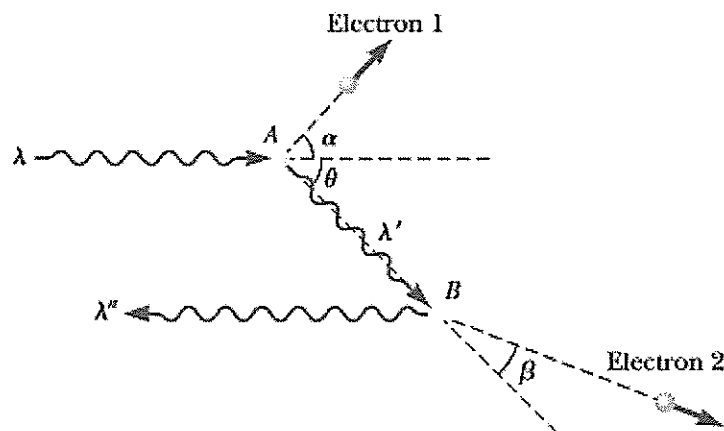
- 4.1. A photon of initial energy E_0 undergoes Compton scattering at an angle θ from a free electron (mass m_e) initially at rest. Derive the following relationship for the final energy E' of the scattered photon: (5)

$$E' = \frac{E_0}{1 + \left(\frac{E_0}{m_e c^2}\right)(1 - \cos\theta)}$$

- 4.2. X-rays with energy of 300 keV undergo Compton scattering from a target. If the scattered rays are detected at angle 30° relative to incident rays, find

- (i) The Compton shift at this angle, (3)
- (ii) The energy of the scattered x-rays, and (4)
- (iii) The energy of the recoil electron (3)
- 4.3. A photon having wavelength λ scatters off a free electron at A (see Figure below), producing a second photon having wavelength λ' . This photon then scatters off another free electron at B, producing a third photon having wavelength λ'' and moving in a direction directly opposite the original photon as shown in the figure. (5)

Determine the value of $\lambda'' - \lambda$



[20]

QUESTION 5

- 5.1. In the photoelectric effect, explain why the stopping potential depends on the frequency of light but not on the intensity. (2)
- 5.2. Two light sources are used in a photoelectric experiment to determine the work function for a particular metal surface. When green light from a mercury lamp ($\lambda = 546.1 \text{ nm}$) is used, a stopping potential of 0.376 V reduces the photocurrent to zero.
- (i) Based on this measurement, what is the work function for this metal? (4)
- (ii) What stopping potential would be observed when using the yellow light from a helium discharge tube ($\lambda = 587.5 \text{ nm}$)? (4)
- 5.3. A daredevil's favorite trick is to step out of a 16th-story window and fall 50.0 m into a pool. A news reporter takes a picture of the 75.0 kg daredevil just before he makes a splash, using an exposure time of 5.00 ms. Find
- (i) The daredevil's de Broglie wavelength at this moment, (4)
- (ii) The uncertainty of his kinetic energy measurement during the 5.00 ms time interval, (4)
- (iii) The percent error caused by such an uncertainty. (2)

[20]

Useful Constants and Conversion Factors

Speed of light in vacuum	$c = 2.998 \times 10^8 \text{ m/sec}$
Electron charge magnitude	$e = 1.602 \times 10^{-19} \text{ coul}$
Planck's constant	$h = 6.626 \times 10^{-34} \text{ joule} \cdot \text{sec}$ $\hbar = h/2\pi = 1.055 \times 10^{-34} \text{ joule} \cdot \text{sec}$ $= 0.6582 \times 10^{-15} \text{ eV} \cdot \text{sec}$
Boltzmann's constant	$k = 1.381 \times 10^{-23} \text{ joule/K}$ $= 8.617 \times 10^{-5} \text{ eV/K}$
Avogadro's number	$N_A = 6.023 \times 10^{23} / \text{mole}$
Electron rest mass	$m_e = 9.109 \times 10^{-31} \text{ kg} = 0.5110 \text{ MeV}/c^2$
Proton rest mass	$m_p = 1.672 \times 10^{-27} \text{ kg} = 938.3 \text{ MeV}/c^2$
Neutron rest mass	$m_n = 1.675 \times 10^{-27} \text{ kg} = 939.6 \text{ MeV}/c^2$
Stephan-Boltzmann constant	$\sigma = 5.670 \times 10^{-8} \text{ Wm}^{-2} \text{ K}^{-4}$
Bohr radius	$a_0 = 5.29 \times 10^{-11} \text{ m} = 0.529 \text{ \AA}$
Electron-volt	$1 \text{ eV} = 1.602 \times 10^{-19} \text{ joule}$
Angstrom	$1 \text{ \AA} = 10^{-10} \text{ m}$