UNIVERSITY OF FORT HARE

University of Fort Hare
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PHY 311

DEGREE EXAMINATIONS

MAY / JUNE

2025

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Time: 3 Hours

Subject: Physics 311 (Modern Physics)

Marks: 100

This paper consists of 7 pages including the cover page

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External Examiner
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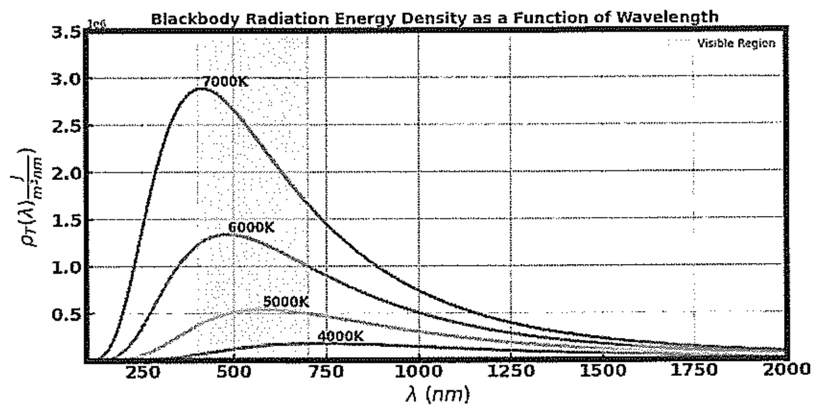
INSTRUCTION

Answer 5 Questions Only

QUESTION ONE [20]



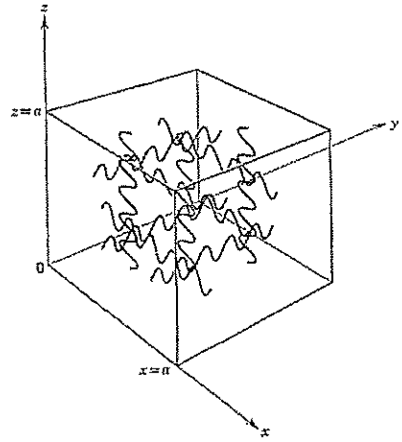
The figure above represents the visualization of the Planck's energy density of blackbody radiation at various temperatures as a function of wavelength.

1.1 Explain the term blackbody radiation [2]

1.2 What insights would you deduce from the curves at various temperatures? [6]

1.3 Find the frequencies at the peaks associated with the 4 temperatures in the curves. [12]

QUESTION TWO [20]

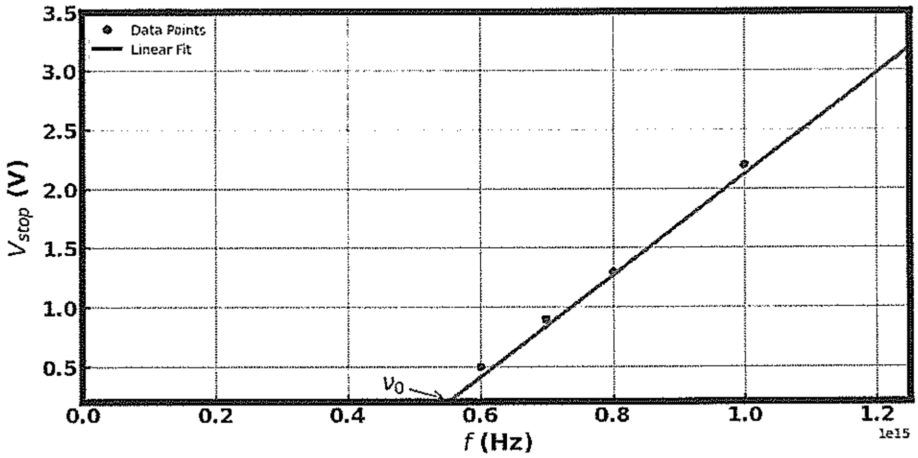


The figure above shows a metallic walled cubical cavity filled with electromagnetic radiation, showing three non-interfering components of that radiation bouncing back and forth between the walls and forming standing waves with nodes at each wall

2.1 Derive the equation, which gives the number of allowed electromagnetic standing waves in each frequency interval for the case of a three-dimensional cavity in the form of a metallic-walled cube of edge length *a*. [14]

2.2 Find the number of electromagnetic modes per unit frequency interval at $\nu = 10^{10}$ Hz to $\nu = 10^{10} + 10^{8}\ Hz$ in a 1 cubic meter (V= 1 m³) cavity. [8]

QUESTION THREE [20]



The figure above shows the visualization of the stopping potential (V_{stop}) at various frequencies for sodium. There exists a characteristic cutoff frequency (υ_0), upon which any frequency less than υ_0 , the photoelectric effect does not occur, no matter how intense the illumination.

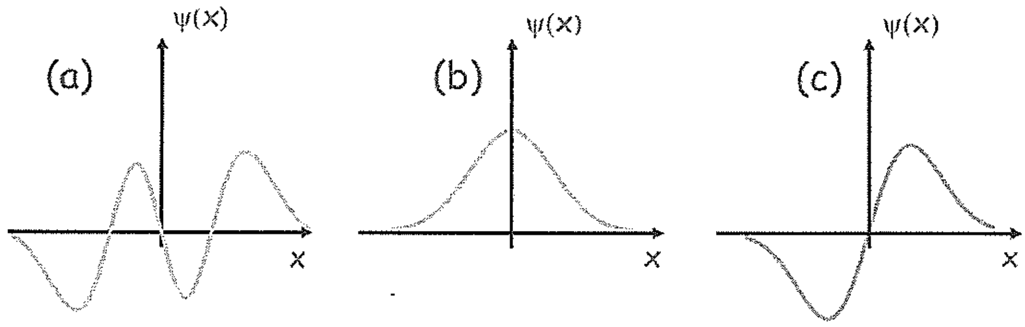
3.1 Explain the term photoelectric effect **[4]**

3.2 Calculate the work function (Φ) of the sodium if the $\nu_0 = 5.5\ x\ 10^{14}\ Hz$ **[4]**

3.3 What could be the physical interpretation of the work function? **[4]**

3.4 When light of wavelength ((λ) = 400 nm shines on sodium, the stopping voltage of the electron is V_{stop} = 0.21 V. What is the work function of sodium? **[8]**

QUESTION FOUR [20]



The three wave functions above represent the states of a particle in the same potential and over the same range (x)

4.1 Which of these wave functions represent the particle with the highest kinetic energy and why? **[2]**

4.2 Consider a particle with a definite momentum. Its wave function is $\Psi(x) = \cos(kx)$, where the $momentum\ (p) = \frac{h}{\lambda} = \hbar k$. Determine the total energy (E) of the particle using the one-dimensional time-independent Schrödinger's equation. $Take\ (x) = 0$. **[4]**

4.3 Consider a quantum particle confined to a region, $0 < x < L$, by infinite potential walls described piecewise by the following: **[14]**

$$\begin{cases} U = 0 & for \quad 0 < x < L \\ U = \infty & everywhere\ else \end{cases}$$

Using the one-dimensional time-independent Schrödinger's equation, find the energy eigenvalues of the confined particles.

QUESTION FIVE [20]

5.1 A light source of wavelength (λ) illuminates a metal and ejects photoelectrons with a maximum kinetic energy of 1 eV. A second light source with half the wavelength of the first ejects photoelectrons with maximum kinetic energy of 4 eV. What is the work function of the metal? [10]

5.2 The threshold wavelength for the ejection of photoelectrons from sodium metal is 5420 Å. Calculate the velocity of photoelectrons ejected by light of wavelength 4000 Å. [10]

QUESTION SIX [20]

6.1 Derive the Wien's displacement law, $\lambda_{max}T = 0.2014\frac{hc}{k}$, by solving the equation $\frac{d\rho_T(\lambda)}{d\lambda} = 0$. (Hint: Set $\frac{hc}{\lambda kT} = x$ and show that the equation quoted leads to $e^{-x} + \frac{x}{5} = 1$. Then show that x = 4.965 is the solution). Where $\rho_T(\lambda) = \frac{8\pi hc}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda kT}}-1}$ [10]

6.2 If we assume that stellar surfaces behave like blackbodies we can get a good estimate of their temperature by measuring λ_{max}. For the sun λ_{max} = 5100 Å, whereas for the North Star λ_{max} = 3500 Å. Find the surface temperature of these stars. (One *angstrom* = 1 Å =10^{-10} m). [4]

6.3 Using Stefan's law, and the temperatures just obtained, determine the power radiated from 1 cm^2 of stellar surface. [6]

DATA SHEET

CONSTANTS

Speed of light in vacuum	c	=	$3\ x\ 10^{8} ms^{-1}$
Electron charge	e	=	$1.6\ x\ 10^{-19}\ C$
Boltzmann constant	k	=	$1.381\ x\ 10^{-23} JK^{-1}$
Electron rest mass	m_e	=	$9.11\ x\ 10^{-31} kg$
Planck's constant	h	=	$4.136\ x\ 10^{-15} eV.s$
	h	=	$6.626\ x\ 10^{-34} Js$
	hc	=	1240 eV-nm
Electron-volt	1eV	=	$1.602\ x\ 10^{-19} J$
Angstrom	1Å	=	$10^{-10} m$
Stefan-Boltzmann Constant	σ	=	$5.670\ x\ 10^{-8} Wm^{-2}K^{-4}$

FORMULAE

Energy density as a function of frequency	$\rho_T(\nu)$	=	$\frac{8\pi\nu^2}{c^3}\frac{h\nu}{e^{\frac{h\nu}{kT}}-1}$
Energy density as a function of wavelength	$\rho_T(\lambda)$	=	$\frac{8\pi hc}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda kT}}-1}$
Compton shift	$\lambda' - \lambda$	=	$\frac{h}{m_e c}(1-cos\theta)$
Wien's displacement law	$\lambda_{max}T$	=	$2.9\ x\ 10^{-3} m.K$
Energy of photon in (eV)	$\frac{hc}{\lambda}$	=	$\frac{1240\ eV.nm}{\lambda}$