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Internal Assessment Test 2 – February 2022

Sub:	Engineering Physics Theory					Sub Code:	21PHY12	Branch:	CS/IS/CIV/MECH	
Date:	28/02/2022	Duration:	90 min's	Max Marks:	50	Sem/Sec:	I Sem / A, B, C, D, E, F and G		OBE	

Answer any FIVE FULL Questions

Given: $c = 3 \times 10^8$ m/s; $h = 6.625 \times 10^{-34}$Js; $k = 1.38 \times 10^{-23}$ J/K; $m_e = 9.1 \times 10^{-31}$kg; $e = 1.6 \times 10^{-19}$C

		MARKS	CO	RBT
1 (a)	Discuss the theory of forced oscillations and hence classify the conditions of variation of amplitude and phase with angular frequency.	[07]	CO2	L2
(b)	Calculate the probability that an energy level at 0.2eV below Fermi level is occupied at temperature 500K.	[03]	CO3	L3
2 (a)	Explain the Quantum Mechanical modifications to the classical free electron theory of metals to explain the electrical conductivity in solids and its success.	[07]	CO3	L3
(b)	Find the resistivity in Intrinsic Germanium from the following data. $n = 2.4\text{x}10^{10}/\text{m}^3, \mu_e = 0.39\text{m}^2/\text{VS}$, $\mu_h = 0.19\text{m}^2/\text{VS}$	[03]	CO2	L2
3 (a)	Deduce the expression for electrical conductivity of a conductor using the quantum free electron theory of metals.	[06]	CO3	L2
(b)	Show that occupation probability at an energy $E_F+\Delta E$ is equal to non-occupation probability at the energy $E_F-\Delta E$.	[04]	CO3	L4
4 (a)	What is Hall effect? Obtain the expression for the Hall coefficient.	[07]	CO2	L3
(b)	The Hall coefficient of certain silicon specimen was found to be -7.35×10^{-5} m^3 C^{-1} . Determine the nature of the majority charge carriers and their number concentration.	[03]	CO2	L3

PTO

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PTO

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(b)	A free particle is executing S.H.M in straight line with a period of 5 seconds. At the equilibrium point, the velocity is found to be 0.7m/s. Find the displacement at the end of 10 seconds, and also the amplitude of oscillation.	[3]	CO3	L3
6 (a)	Define SHM and mention any two examples. Derive the differential equation using Hooke's law.	[6]	CO2	L3
(b)	Given the damping constant of the medium 0.1 kg s^{-1} calculate the amplitude of the oscillations at resonance given the mass attached to the spring-mass oscillator 50 x 10^{-3} kg, the amplitude of the applied periodic force 1N and the period of oscillations 1 second.	[4]	CO3	L4
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(b)	Discuss the variation of Fermi factor with temperature.	[6]	CO3	L3
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(b)	Derive the expression for the electrical conductivity of a semiconductor.	[4]	CO2	L3

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IAT-2 PHYSICS SCHEME

1.a) Let F = F_o Sin$\omega_f t$ be the oscillating applied force

The equation of motion is given by

$$F = ma = -kx - bv + F_o \sin \omega_f t$$

$$m\frac{d^2x}{dt^2} + b.\frac{dx}{dt} + kx = F_o \sin \omega_f t$$

$$\frac{d^2x}{dt^2} + \frac{b}{m}\frac{dx}{dt} + \frac{k}{m}x = \frac{F_o}{m}\sin \omega_f t$$

$$Let \quad \frac{b}{m} = 2R; \frac{k}{m} = \omega^2; \frac{F_o}{m} = F$$

$$\frac{d^2x}{dt^2} + 2R\frac{dx}{dt} + \omega_o{}^2 x = F \sin \omega_f t \,.....(1)$$

Let one particular solution be $x = A.\sin(\omega_f t - \phi)$ (2 marks)

$$\frac{dx}{dt} = \omega_f A.\cos(\omega_f t - \phi)$$

$$\frac{d^2x}{dt^2} = -\omega_f^2 A.\sin(\omega_f t - \phi)$$

Also

$$F \sin \omega_f t = F.\sin(\omega_f t - \phi + \phi)$$

$$= F \sin(\omega_f t - \phi)\cos\phi + F\cos(\omega_f t - \phi)\sin\phi$$

Substituting in (1)

$$-\omega_f^2 A.\sin(\omega_f t - \phi) + 2RA\omega_f \cos(\omega_f t - \phi) + \omega_o^2 A\sin(\omega_f t - \phi) = F\sin(\omega_f t - \phi)\cos\phi + F\cos(\omega_f t - \phi)\sin\phi$$

Comparing coefficients of $\sin(\omega_f t - \phi)$ *and* $\cos(\omega_f t - \phi)$ on both sides

$$A(\omega_o^2 - \omega_f^2) = F\cos\phi$$

$$2RA\omega_f = F\sin\phi$$

$$\therefore F^2 = A^2(\omega_o^2 - \omega_f^2)^2 + 4R^2A^2\omega_f^2$$

$$A = \frac{F}{\sqrt{(\omega_o^2 - \omega_f^2)^2 + 4R^2\omega_f^2}}$$

$$\tan\phi = \frac{2R\omega_f}{\omega_o^2 - \omega_f^2}$$ (3 marks)

Case 1: amplitude is infinity when at $\omega_0 = \omega_f$, damping is zero

Case 2: Amplitude is less when $\omega_0 \neq \omega_f$ (2 marks)

1B (Formula-1mark, Substitution- 1 mark, Answer- 1 mark)

$$f(E) = \frac{1}{e^{\left(\frac{E-E_F}{kT}\right)} + 1}$$

$$= \frac{1}{e^{\frac{-\Delta E}{1.38x10^{-23}X500}} + 1} = \frac{1}{e^{\frac{-0.02x1.6x10^{-19}}{1.38x10^{-23}x500}} + 1} = 0.99$$

2A

Success of quantum theory: Quantum theory modified the energy of free electrons in metal to be quantized as per Paulis exclusion Principle and their distribution is given by Fermi – Dirac theory as

n(E)dE = g(E) dE f(E)

Where n(E) is number of conduction electrons per unit energy range

n(E)dE = g(E)dE . f (E)

g(E) is density of states $= \frac{8\pi\sqrt{2}m^{\frac{3}{2}}}{h^3}E^{\frac{1}{2}}$

f(E) is the Fermi probability factor . (2 marks)

1. Specific heat: (1 mark)

Classical theory predicted high values of specific heat for metals on the basis of the assumption that all the conduction electrons are capable of absorbing the heat energy as per Maxwell - Boltzmann distribution i.e., $C_V = \frac{3}{2}R$

But according to the quantum theory, only those electrons occupying energy levels close to Fermi energy (E_F) are capable of absorbing heat energy to get excited to higher energy levels. Thus only a small percentage of electrons are capable of receiving the thermal energy and specific heat value becomes small.

It can be shown that $C_V = 10^{-4}R$.

This is in conformity with the experimental values. (2 marks)

2. **Temperature dependence of electrical conductivity.**

According to classical free electron theory,

Electrical conductivity $\propto \frac{1}{\sqrt{Temperature}}$

Where as from quantum theory

Electrical conductivity

$$\propto \frac{1}{\text{collisional area of crosssection of lattice atoms}} \alpha \frac{1}{\text{vibrational energy}} \alpha \frac{1}{\text{Temperature}}$$

This is in agreement with experimental values.

3. **Dependence of electrical conductivity on electron concentration:** (2 marks)

According to classical theory,

$$\sigma = \frac{ne^2\tau}{m} \Rightarrow \sigma \propto n$$

But it has been experimentally found that Zinc which is having higher electron concentration than copper has lower Electrical conductivity.

According to quantum free electron theory, Electrical conductivity $\sigma = \frac{ne^2}{m}\left(\frac{\lambda}{V_F}\right)$ where V_F is the Fermi velocity.

Zinc possesses lesser conductivity because it has higher Fermi velocity.

Metal	n	σ
Cu	$8.45x10^{28}/m^3$	$6x10^7(\Omega m)^{-1}$
Zn	$13x10^{28}/m^3$	$1x10^7(\Omega m)^{-1}$

2B (Formula-1mark, Substitution- 1 mark, Answer- 1 mark)

$$\rho = \frac{1}{\sigma} = \frac{1}{ne(\mu_e + \mu_h)} = 4.4x10^8\,\Omega m$$

3A.

Expression for Electrical conductivity:

Imagine a conductor across which an electric field E is applied. The free electrons acquire drift velocity and the matter wave number change from k_1 to k_2 in time interval τ_F in the presence of electric field.

The force on the free electron is

$$F = \frac{dp}{dt} = eE$$

$$k = \frac{2\pi}{\lambda} = \frac{2\pi}{h/p} = \frac{2\pi p}{h}$$

$$p = \frac{hk}{2\pi}$$

$$\frac{dp}{dt} = \frac{h}{2\pi}\left(\frac{dk}{dt}\right)$$

$$dk = \frac{2\pi}{h}eEdt$$

On integration $k_2 - k_1 = \Delta k = \frac{2\pi.eE.\tau_F}{h}$ ....(1) (4 marks)

From quantum theory, conductivity $J = \Delta k.ne.\frac{h}{2\pi.m^*}$ ....(2)

Substituting (1) in (2)

We get $J = \frac{ne^2\tau_F}{m^*}E$ ...(3)

Since from Ohm's, J = σE, conductivity σ can be written as

$$\sigma = \frac{ne^2\tau_F}{m^*} = \frac{ne^2}{m^*}\frac{\lambda}{v_F}$$ (2 marks)

3B For an energy level E above Fermi level by ΔE, Probability of occupation is

$$f(E) = \frac{1}{e^{(\frac{E-E_F}{kT})}+1} = \frac{1}{e^{\frac{+\Delta E}{kT}}+1}$$ (1 mark)

For an energy level E below Fermi level by ΔE, Probability of occupation is

$$f(E) = \frac{1}{e^{(\frac{E-E_F}{kT})}+1} = \frac{1}{e^{\frac{-\Delta E}{kT}}+1}$$ (1 mark1)

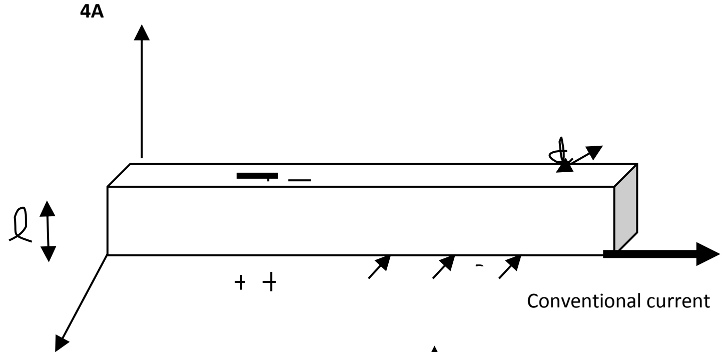
Non occupation probability = 1-f(E)

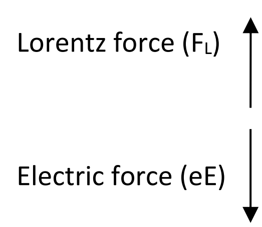
=

$$= 1 - \frac{1}{e^{\frac{-\Delta E}{kT}}+1} = \frac{e^{\frac{-\Delta E}{kT}}+1-1}{e^{\frac{-\Delta E}{kT}}+1} = \frac{1}{\frac{e^{\frac{-\Delta E}{kT}}}{e^{\frac{-\Delta E}{kT}}} + \frac{1}{e^{\frac{-\Delta E}{kT}}}} = \frac{1}{1+e^{\frac{+\Delta E}{kT}}}$$

(2 marks)

4A





Hall effect: When a conductor carrying current is placed in transverse magnetic field, an electric field is produced inside the conductor in a direction normal to both current and the magnetic field. (1 mark)

Here B is along –X , V is along –Y axis

Lorentz force= $-e\left(-\hat{j}\ X -\hat{i}\right) = +\hat{k}$

So the electron is deflected along + Z axis

Consider a rectangular slab of an n type semiconductor carrying a current I along + X axis. Magnetic field B is applied along –Z direction. Now according to Fleming's left hand rule, the Lorentz force on the electrons is along +Y axis. As a result the density of electrons increases on the upper side of the material and the lower side becomes relatively positive. This develops a potential V_H-Hall voltage between the two surfaces. Ultimately, a stationary state is obtained in which the current along the X axis vanishes and a field E_y is set up.

Expression for Hall Coefficient: (4 marks)

At equilibrium, Lorentz force is equal to force due to applied electric field

$$Bev_d = eE_H$$

Hall Field $E_H = BV_d$

$$Current\ \ density\ \ J = n_e e v_d$$

$$v_d = \frac{J}{n_e e}$$

$$E_H = B\frac{J}{n_e e}$$

Hence

$$\frac{E_H}{JB} = \frac{1}{n_e e} = R_H$$

Case 1: For P type semiconductor, the bottom surface will be at positive potential. (1 mark)

Case 2: For n type semiconductor, the bottom surface will be at positive potential (1 mark)

4B(Formula-1mark, Substitution- 1 mark, Answer- 1 mark)

$$R_H = -7.35x10^{-5} = \frac{1}{ne}$$

$$n = 8.5x10^{22} / m^3$$

$$N\ \ type$$

5A In damped oscillations, the oscillator looses energy due to frictional forces causing the decrease in amplitude. (1 mark)

Let us assume that in addition to the elastic force F =- kx, there is a force that is opposed to the velocity, F = b v where b is damping coefficient

For the oscillating mass in a medium with resistive coefficient b, the equation of motion is given by

$$m\frac{d^2x}{dt^2} + kx + b\frac{dx}{dt} = 0$$

This is a homogeneous, linear differential equation of second order.

The auxiliary equation is $D^2 + \frac{b}{m}D + \frac{k}{m} = 0$

The roots are $D_1 = -\frac{b}{2m} + \frac{1}{2m}\sqrt{b^2 - 4mk}$ and

$$D_2 = -\frac{b}{2m} - \frac{1}{2m}\sqrt{b^2 - 4mk}$$

The solution can be derived as

$$x(t) = Ce^{-\left(\frac{b}{2m} - \frac{1}{2m}\sqrt{b^2-4mk}\right)t} + De^{-\left(\frac{b}{2m} + \frac{1}{2m}\sqrt{b^2-4mk}\right)t}$$

…….(1)

Note: This can be expressed as x(t) = $Ae^{-\frac{b}{2m}t}\cos(\omega t - \phi)$

where $\omega = \sqrt{\frac{k}{m} - \left(\frac{b}{2m}\right)^2}$

$$A = \sqrt{C^2 + D^2} \quad \phi = \tan^{-1}(D/C)$$ (4 marks)

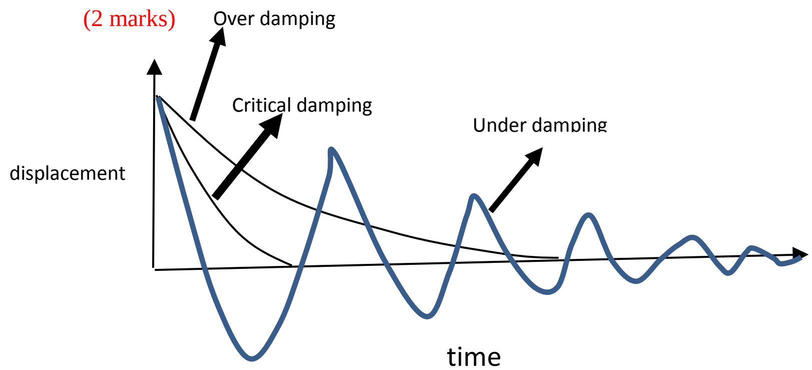
Here, the term $Ae^{-\frac{b}{2m}t}$ represents the decreasing amplitude and (ωt-ϕ) represents phase

Case 1: $b^2 > 4mk$ OVER DAMPING

Case 2: $b^2 < 4mk$ UNDER DAMPING

Case 3: $b^2 = 4mk$ CRITICAL DAMPING

(2 marks)



5B (Formula-1mark, Substitution- 1 mark, Answer- 1 mark)

$$\omega = \frac{2\pi}{T} = 1.25 rad/s$$

$$V_{max} = 0.7 m/s = \omega A$$

$$A = 0.56 m$$

$$x = A\sin(\omega t) = \text{ - } 0.037\ \text{m}$$

6A

SIMPLE HARMONIC MOTION

It is the periodic oscillations of an object caused when the restoring force on the object is proportional to the displacement. The restoring force is directed opposite to displacement.

Ex: 1. Oscillation of mass connected to spring

2. Oscilations of prongs of Tuning fork

3. Simple pendulum (2 marks)

Restoring force α – displacement

F = -k x

Here k is the proportionality constant known as spring constant. It represents the amount of restoring force produced per unit elongation and is a relative measure of stiffness of the material.

$$F_{\text{Re}\,storing} = -kx$$

$$m\frac{d^2x}{dt^2} = -kx$$

$$Let\ \omega_o^{\ 2} = \frac{k}{m}$$

$$\frac{d^2x}{dt^2} + \omega_o^{\ 2}x = 0$$

Here ω_o is angular velocity = 2.π.f

f is the natural frequency $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$

The Solution is of the form x(t) = A cosω_ot + B sinω_ot. (4 marks)

This can also be expressed as x(t) = C cos(ω_ot-ɵ) where

$C = \sqrt{A^2 + B^2}$ tanɵ = B/A

6B(Formula-2marks, Substitution- 1 mark, Answer-1 mark)

Amplitude of forced oscillations at resonance (ω_f=ω_0)

$$A = \frac{\frac{F_o}{m}}{\sqrt{(\omega_o^2 - \omega_f^2)^2 + \frac{b^2}{m^2}\omega_f^2}} = \frac{\frac{1}{0.05}}{\sqrt{0 + \frac{0.1^2}{0.05^2}X\,6.28^2}} = 1.59m$$

7A

It is the highest energy possessed by an electron at zero Kelvin. . (1 mark)

(Formula-1mark, Substitution- 1 mark, Answer- 1 mark)

$$E_F = \frac{h^2}{8m}\left(\frac{3n}{\Pi}\right)^{\frac{2}{3}}$$

$$\frac{3n}{\pi} = \left[\frac{8mXE_F}{h^2}\right]^{\frac{3}{2}}$$

$$n = 2.33x10^{28} / m^3$$

7B.

To show that energy levels below Fermi energy are completely occupied:

For E < E_F, at T = 0,

$$f(E) = \frac{1}{e^{(\frac{E-E_F}{kT})} + 1}$$. (1 mark)

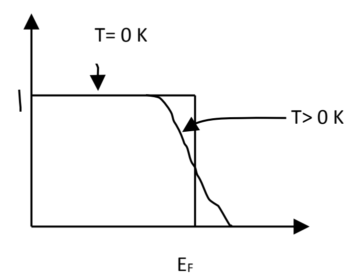
To show that energy levels above Fermi energy are empty:

For E > E_F , at T=0

$$f(E) = \frac{1}{e^{(\frac{E-E_F}{kT})} + 1} = 0$$

At ordinary temperatures, for E = E_F,

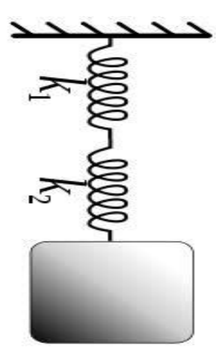
f(E) = $\frac{1}{2}$. (4 marks)



Graph (1 mark)

8A

Expression for Spring Constant for Series Combination(3 marks)



Consider a load suspended through two springs with spring constants k_1 and k_2 in series combination. Both the springs experience same stretching force. Let Δx_1 and Δx_2 be their elongation.

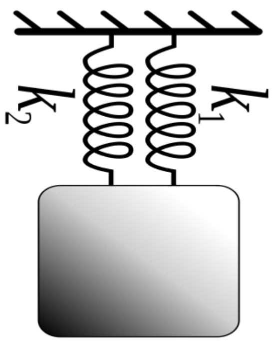
Total elongation is given by

$$\Delta X = \Delta X_1 + \Delta X_2 = \frac{F}{k_1} + \frac{F}{k_2}$$

$$\frac{F}{k_{eqv}} = \frac{F}{k_1} + \frac{F}{k_2}$$

$$\frac{1}{k_{eqv}} = \frac{1}{k_1} + \frac{1}{k_2}$$

Expression for Spring Constant forParallel Combination(3marks)



Consider a load suspended through two springs with spring constants k_1 and k_2 in parallel combination. The two individual springs both elongate by x but experience the load non uniformly.

Total load across the two springs is given by

$$F = F_1 + F_2$$

$$k_{eqv}.\Delta X = k_1.\Delta X + k_2.\Delta X$$

$$k_{eqv} = k_1 + k_2$$

8B

Electron current $I_e = n_h e A v_d(e)$

Hole current $I_h = n_h e A v_d(h)$

current density

$$J = \frac{I}{A} = \frac{I_e + I_h}{A} = n_h e v_d(h) + n_e e v_d(e) = \sigma E \text{ .....(1)}$$ (2 marks)

But drift velocity $V_d = \mu E = \mu.J/\sigma$ $\mu = V_d/E$

Using (1), $\sigma = n_e e \mu_e + n_h e \mu_h$

In an intrinsic semiconductor, number of holes is equal to number of electrons.

$$\sigma_{int} = n_e e[\mu_e + \mu_{hole}]$$ (2 marks)

n_e is the electron concentartion

n_p is the hole concentration

μ_e is the mobility of electrons

μ_h is the mobility of holes