



INSTRUCTIONS

- Write your name and ID on all answer booklets used.
- There are TEN (10) questions in total.
- All questions are equally weighted.
- **Section A: all SIX (6) questions are compulsory.**
- **Section B: choose any TWO (2) of the four questions.**
- 3 hours are available.
- Closed-book exam, prohibited materials include:
 - PDAs
 - Cellphones
 - Notes/books

FUNDAMENTAL CONSTANTS:

h	$6.626 \times 10^{-34} \text{ Js}$	N_A	$6.022 \times 10^{23} \text{ mol}^{-1}$
\hbar	$1.055 \times 10^{-34} \text{ Js}$	k_B	$1.38 \times 10^{-23} \text{ JK}^{-1}$
q_e	$-1.602 \times 10^{-19} \text{ C}$	c	$2.998 \times 10^8 \text{ ms}^{-1}$
m_e	$9.11 \times 10^{-31} \text{ kg}$	μ_0	$4\pi \times 10^{-7} \text{ Hm}^{-1} (\text{WbA}^{-1}\text{m}^{-1})$
m_p	$1.67 \times 10^{-27} \text{ kg}$	ϵ_0	$8.854 \times 10^{-12} \text{ Fm}^{-1}$



Section A. GIVE ANSWERS IN POINT FORM TO ALL OF Q 1-6

1. The allotrope of carbon commonly known as *diamond* is the hardest naturally-occurring material known to the scientific community. It is also one of the best conductors of thermal energy (heat) and one of the poorest conductors of charge. With reference to the bonding of this material, explain these observations.
2. Describe the physical constraints to electrical conduction in metallic and non-metallic materials. To illustrate this, describe the temperature response of conductivity in both metallic and non-metallic systems.
3. The Hall coefficient $R_H = (q_e n)^{-1}$ for a material may be derived from a (conceptually) simple experiment. Describe this experiment and the material parameter that can be empirically recovered from a determination of R_H .
4. Consider a cube of intrinsic gallium arsenide (GaAs: $E_g = 1.42$ eV, $\epsilon_r = 13.1$, intrinsic carrier concentration at 298 K $n_i = 2.1 \times 10^6$ cm⁻³). Sketch the band structure of this material at room temperature showing (and explaining) the location of the Fermi level and state the concentrations of electrons and holes. Describe how (if at all) this diagram changes as the temperature is reduced to $T = 0$ K.
5. The frequency-dependent character (resonances) associated with the dielectric constant of a material may be used to characterize a range of different polarization mechanisms including electronic, ionic, orientational/dipolar and interfacial/space charge polarization. Spectroscopic data of this nature are often termed dielectric loss measurements. Consider a sample of dielectric material placed between parallel plates driven by a sinusoid whose frequency may be varied over a wide range. Describe the response of dipoles in the material as the frequency is swept, with particular reference to why materials exhibit resonant behavior such as this.
6. Use the general characteristics of hysteresis loops to distinguish between *hard* and *soft* ferromagnetic materials, explaining clearly what physical property is represented by the area of a hysteresis loop.

Section B. CHOOSE TWO OF Q 7 – 10 AND GIVE ANSWERS IN POINT FORM TO BOTH

7. Electrons may be emitted from a metallic system via the photoelectric effect or via thermionic emission. Summarize both these processes, explaining the origin of any dependence on temperature and the energy distribution associated with the electrons.
8. Draw a well-labelled band structure diagram of a pn-junction (diode) at equilibrium and explain the physical basis for I_s , the reverse saturation current. Summarize why a diode photodetector might be operated in the avalanche regime (reverse bias) and why it is desirable keep this device as cool as possible.
9. Ionic crystals such as barium titanate (BaTiO₃) can exhibit both *piezoelectric* and *ferroelectric* characteristics. Summarize both these material characteristics.
10. Magnetic resonance imaging machines typically use a single-loop coil of superconducting material to generate the stable background field (> 1 T) for the imaging process. With reference to the magnetic susceptibility, χ_m , distinguish between diamagnetic and paramagnetic materials and explain the consequences of $\chi_m = -1$ for a superconductor.