GEO-PHYSICS

Paper – II

Time Allowed : Three Hours | *Maximum Marks : 200*

Question Paper Specific Instructions

Please read each of the following instructions carefully before attempting questions :

*There are **TEN** questions divided under **TWO** sections.*

*Candidate has to attempt **SIX** questions in all.*

*Questions no. **1** and **6** are **compulsory**.*

*Out of the remaining **EIGHT** questions, **FOUR** questions are to be attempted choosing **TWO** from each section.*

The number of marks carried by a question / part is indicated against it.

Neat sketches may be drawn to illustrate answers, wherever required. These shall be drawn in the space provided for answering the question itself.

Unless otherwise mentioned, symbols and notations have their usual standard meanings.

Assume suitable data, if necessary, and indicate the same clearly.

Attempts of questions shall be counted in sequential order. Unless struck off, attempt of a question shall be counted even if attempted partly.

Any page or portion of the page left blank in the Question-cum-Answer Booklet must be clearly struck off.

*Answers must be written in **ENGLISH** only.*

Physical Constants :

Electron rest mass, m_e	=	$9{\cdot}109 \times 10^{-31}$ kg
Proton rest mass, m_p	=	$1{\cdot}672 \times 10^{-27}$ kg
Neutron rest mass, m_n	=	$1{\cdot}675 \times 10^{-27}$ kg
Atomic mass unit ($C^{12} \equiv 12$), a.m.u.	=	$1{\cdot}661 \times 10^{-27}$ kg
Bohr magneton, μ_B	=	$9{\cdot}27 \times 10^{-24}$ J/tesla
Nuclear magneton, μ_N	=	$5{\cdot}05 \times 10^{-27}$ J/tesla
Boltzmann constant, k_B	=	$1{\cdot}381 \times 10^{-23}$ J/K

Speed of light in vacuum, c	=	$2{\cdot}998 \times 10^{8}$ m/s
Electron charge, $\lvert e \rvert$	=	$1{\cdot}602 \times 10^{-19}$ C
Planck's constant, h	=	$6{\cdot}626 \times 10^{-34}$ J-s
Avogadro's number, N_A	=	$6{\cdot}023 \times 10^{23}$ /mole

$1 \text{ eV} = 1{\cdot}602 \times 10^{-19}$ J

mass of C^{14} = 14·003242 a.m.u.

mass of N^{14} = 14·003074 a.m.u.

$m_\pi = 139{\cdot}6 \text{ MeV/c}^2$

$m_\mu = 105{\cdot}7 \text{ MeV/c}^2$

$\varepsilon_0 = 8{\cdot}85 \times 10^{-12} \text{ C}^2/\text{Nm}^2$

SECTION A

Q1. (a) (i) A Ground-Penetrating Radar (GPR) in monostatic mode recorded a two-way travel time of 0·2985 μs over a two-layered medium involving non-conducting dry soil of relative permittivity ($\varepsilon_r = 5$), overlying water table. Find the depth of water table. (Consider velocity of light in vacuum, c to be 0·3 m/ns) *5*

(ii) A Magneto-Telluric (MT) sounding over a layered earth medium has yielded an apparent resistivity, ρ_a of 120 Ω-m at a time period, T of 0·1 s for an electric field amplitude of 10 mV/km. Compute the involved magnetic field amplitude in nT. *3*

(b) (i) State the necessary and sufficient conditions for the origin of gravity and magnetic anomalies separately. *4*

(ii) On the basis of intensity of magnetic anomalies, distinguish between intra-basement and supra-basement anomalies. Specify their geological applications. *4*

(c) An electrical sounding experiment using Schlumberger configuration has resulted in identical Vertical Electrical Sounding (VES) curves for the following two geoelectrical sections, A and B. Hence, estimate the thickness of sandwiched bed of geoelectric section B. *8*

Geoelectric Section A : $\rho_1 = 30$ Ω-m; $\rho_2 = 10$ Ω-m; $\rho_3 = 100$ Ω-m; $h_1 = 3$ m; $h_2 = 10$ m; $h_3 \to \infty$

Geoelectric Section B : $\rho_1' = 50$ Ω-m; $\rho_2' = 25$ Ω-m; $\rho_3' = 100$ Ω-m; $h_1' = 5$ m; $h_2' = ?$; $h_3' \to \infty$

(d) (i) What is capture cross-section ? What is the correlation between its conventional and SI units ? 3

(ii) If the total capture cross-section (Σ_{log}) is defined as the weighted sum of capture cross-section in matrix (Σ_{ma}) and fluid, the following relation holds good :

$$\Sigma_{log} = (1 - \phi)\, \Sigma_{ma} + \phi\, S_W \Sigma_W + \phi\, S_{HC} \Sigma_{HC}$$

Find the hydrocarbon pore volume in % when the following data is available : 5

$\Sigma_{log} = 5{\cdot}625$ barn

$\Sigma_W = 40$ barn

$\Sigma_{HC} = 5$ barn

$S_W = 50\%$

(e) Considering that conventional seismic data acquisition recommends a sample interval of 4 ms and a group interval of 10 m, find out the concerns for a temporal and spatial aliasing for the following parameters expected for a survey area : 8

Medium velocity 'V' = 2500 – 5000 m/s

Frequency bandwidth 'f' = 10 – 100 Hz

Structural dips 'θ' = 0 – 40°

Q2. (a) (i) Derive the governing equation for Ground-Penetrating Radar (GPR) by assuming Helmholtz equation. Also derive an expression for reflection coefficient involving relative permittivities ε_{1r} and ε_{2r} of a two-layered non-conductive medium. 8

(ii) The detector coil in Frequency Domain (FD) field system measures the secondary magnetic field produced by a subsurface conductor in the presence of primary magnetic field set by transmitter coil emitting low-frequency e.m. waves. Show that the resultant magnetic field sensed by detector is elliptically polarized. 7

(b) With the help of neat schematic diagrams, explain the dip angle measurements with a FD system for a fixed vertical loop transmitter over a steeply dipping conductor in the resistive half-space. Indicate the cross-over points in schematic dip-angle versus station distance plots along a profile across the conductor. 15

Q3. (a) (i) Derive from fundamentals an analytical expression for equivalent stratum in gravity prospecting. Mention one application of this concept. *8*

(ii) Discuss Talwani's method for computing gravity anomaly due to 2-D gravity anomaly source of arbitrary cross-section. *7*

(b) (i) Express the scalar magnetic potential due to an arbitrarily oriented dipole in free space as a convolution of Dirac delta function involving spatial position of dipole and distance function. Hence, derive the total magnetic field intensity anomaly at an arbitrary point in source-free region in convolution form. *5+7=12*

(ii) State the three key steps in interpretation of vertical magnetic field intensity anomaly profile across an inclined dyke of infinite depth extent within half-space using Koulomzine method. *3*

Q4. (a) From the two invasion profiles shown below, neatly draw the resistivity profiles for the following scenarios :

(i) Fresh-water mud *7*

(ii) Salt-water mud

Label the axes and different regions of the resistivity profile. State your assumptions clearly, if any. *8*

Horizontal section through a permeable oil-bearing bed

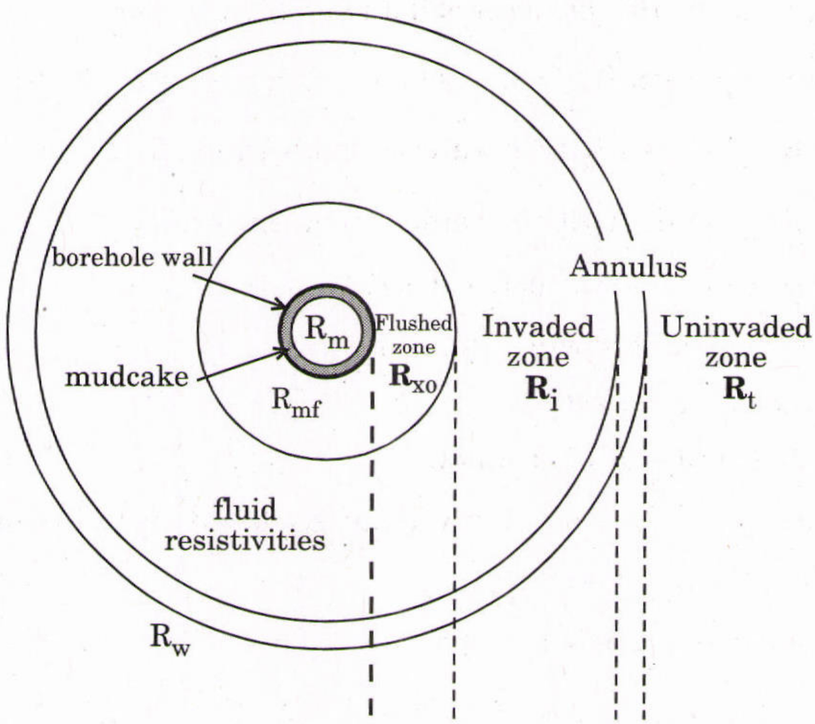

Figure 1

Horizontal section through a permeable water-bearing bed

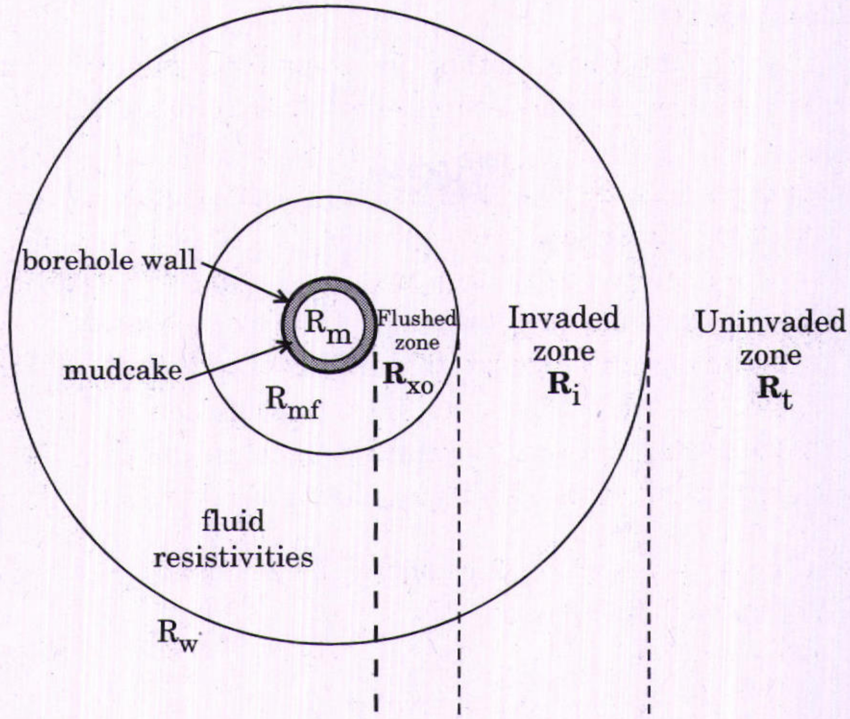

Figure 2

(b) Assuming a carbonate reservoir with matrix grain density $\rho_g = 2{\cdot}75$ g/cc, calculate the water saturation at the formation depth using Archie's equation using the given set of data and correlations : *15*

- Arp's equation $R_{w_2} = R_{w_1}\,[(T_1 + 21{\cdot}5)/(T_2 + 21{\cdot}5)]$ in ohm-m where

  $R_{w_2} \rightarrow$ Resistivity of water at temperature T_2

  $R_{w_1} \rightarrow$ Resistivity of water at temperature T_1
- Reservoir Depth = 5000 metres
- Geothermal Gradient = 20°C/km
- Bulk Density = 2·25 g/cc
- Bulk Resistivity = 30 ohm-m
- Formation water resistivity at surface facility = 1·00 ohm @ 30°C
- Fluid Density = 1·00 g/cc

  a = 1, m = 2, n = 2

Use the correlation $R_w = \dfrac{S_w^n\,\phi^m\,R_t}{a}$

Q5. (a) Assuming the general theory of elasticity for isotropic and homogeneous medium, derive the expression for Lame's parameter in terms of Young's Modulus and Poisson's Ratio. *15*

Use Hooke's law $\sigma_{ij} = \lambda \delta_{ij} \Delta + 2 \mu \varepsilon_{ij}$

(b) In order that both the horizontal-layer models given below should produce the same time-distance curves for head wave arrivals, what must be the thickness of the middle layer in Model 2 ? *15*

	Vel. (km/s)	Depth (km)
Model 1		
Layer 1	3·5	1·0
Layer 2	5·5	—
Model 2		
Layer 1	3·5	0·5
Layer 2	2·0	
Layer 3	5·5	

SECTION B

Q6. (a) Draw a schematic plot of binding energy per nucleon versus the mass number. Explain the release of energy due to phenomena of nuclear fusion and fission based on this plot. *8*

(b) What order of magnitude of magnetic field strength would be needed to see Paschen-Back effect rather than Zeeman effect for a typical nucleus ? *8*

(c) Prove that the reciprocal lattice of a BCC lattice is an FCC lattice. *8*

(d) Two spherical conducting shells of radii 1 m and 2 m respectively are arranged concentrically. The inner shell is grounded and outer shell is charged to the potential 100 V. Calculate electric displacement vector, $\vec{D}$ at the points between the shells. Assume free space between the shells. (Given value $\varepsilon_0 = 8{\cdot}85 \times 10^{-12}$ C^2/Nm^2). *8*

(e) Calculate the Poisson bracket $\{\phi, \vec{M} \cdot \hat{z}\}$ where ϕ is any scalar function constructed out of position vector $(\vec{r})$ and momentum vector $(\vec{p})$. $\vec{M} = \vec{r} \times \vec{p}$ is the angular momentum. *8*

Q7. (a) Discuss how the Stern-Gerlach experiment explains space quantization and electron spin. Find the value of an angle between the spin angular momentum and its z-component of an electron being along external magnetic field $\vec{B}$. *15*

(b) With the help of a schematic diagram, differentiate between a Scanning Electron Microscope (SEM) and a Transmission Electron Microscope (TEM). What are the advantages of a TEM over an SEM ? *15*

Q8. (a) What are the assumptions of single-particle shell model ?

Predict the spin-parity of the following odd–A nuclei on the basis of single-particle shell model : *15*

(i) ^{9}Be

(ii) ^{17}F

(iii) ^{27}Al

(iv) ^{33}S

(v) ^{39}Ca

(b) State CPT theorem and explain what is meant by CPT invariance.

Use the law of conservation of strangeness to find out which interaction is allowed from the following : *15*

(i) $\pi^- + p \rightarrow \Sigma^- + k^+$

(ii) $\pi^- + p \rightarrow k^+ + k^- + n$

(iii) $\pi^- + p \rightarrow \Sigma^+ + k^-$

(iv) $n + p \rightarrow \Lambda^0 + \Sigma^0$

Q9. (a) Consider an infinitely long straight wire having uniform charge density, λ (C/m) along z-direction. Calculate the expression for electric field, $\vec{E}$ at any arbitrary point. Show that $\vec{\nabla} \cdot \vec{E}$ vanishes everywhere except at the points on the wire. *15*

(b) Consider two inertial frames, S and S′. S is at rest and S′ is moving along x-axis with a constant velocity v with respect to S. Write down the Lorentz transformation which relates energy (E) and momentum ($\vec{p}$) of a particle in these two frames of reference. Show that $\frac{d^3 \vec{p}}{E}$ is Lorentz invariant. *15*

Q10. (a) Define canonical transformation. Show that the following transformation

$$P = \frac{1}{2} (p^2 + q^2), \quad Q = \tan^{-1} (q/p)$$

is canonical. Find a generating functional F(q, Q, t) for the above canonical transformation. *10*

(b) Construct the Hamiltonian for an electron moving in an external magnetic field, $\vec{B} = B_0 \hat{k}$, where B_0 is constant. *10*

(c) Show that the dynamics of a charged particle in the external electromagnetic field do not change under the gauge transformations of electromagnetic potentials. *10*