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**UPSC**  
**Comb. Geo-Scientist**  
**(Mains)**

**Previous Year Paper**  
**(Geo-Physics) Paper-II**  
**24 June, 2023**



**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 (QCA) Booklet must be clearly struck off.

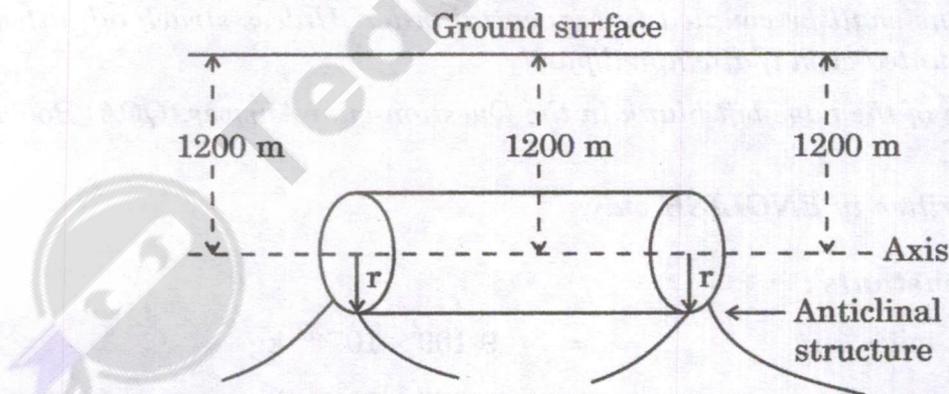
Answers must be written in **ENGLISH** only.

**Physical Constants :**

Electron rest mass, $m_e$	=	$9.109 \times 10^{-31}$ kg
Proton rest mass, $m_p$	=	$1.672 \times 10^{-27}$ kg
Neutron rest mass, $m_n$	=	$1.675 \times 10^{-27}$ kg
Atomic mass unit ( $C^{12} \equiv 12$ ), a.m.u.	=	$1.661 \times 10^{-27}$ kg
Bohr magneton, $\mu_B$	=	$9.27 \times 10^{-24}$ J/tesla
Nuclear magneton, $\mu_N$	=	$5.05 \times 10^{-27}$ J/tesla
Boltzmann constant, $k_B$	=	$1.381 \times 10^{-23}$ J/K

### SECTION A

- Q1.** (a) Describe two most commonly used point-electrode systems — the Wenner and Schlumberger Arrays. Derive apparent resistivity equation for Wenner and Schlumberger Array. 8
- (b) (i) Cement Bond Logging (CBL) of production logging, works on which physical principle?
- (ii) Give the reason for using CBL tool before and during hydrocarbon production.
- (iii) Given for flushed zone, the fluid resistivity ( $R_{xw}$ ) is  $0.15 \Omega m$ , and the rock matrix resistivity for the flushed zone ( $R_{xo}$ ) is  $15 \Omega m$ . Consider 100% water saturated, constants  $a = 0.64$ ,  $m = 2$ . Find the porosity in % for the flushed zone. 2+2+4
- (c) What is Sampling theorem in data processing? Compute the sampling and Nyquist interval for analogue waveforms having maximum frequencies 250 Hz, 500 Hz and 1000 Hz respectively. Give answer in milliseconds. 8
- (d) (i) Calculate the maximum gravity anomaly at ground level over a buried anticlinal structure of equal depth as shown in the figure with radius 800 m and density contrast  $190 \text{ kg/m}^3$ . Also the given equal depth of anticline axis is at 1200 m. Given Universal Gravity Constant as  $G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$ . Answer to be in milligal.  
 $r = 800 \text{ m}$  (radius of anticlinal structure)

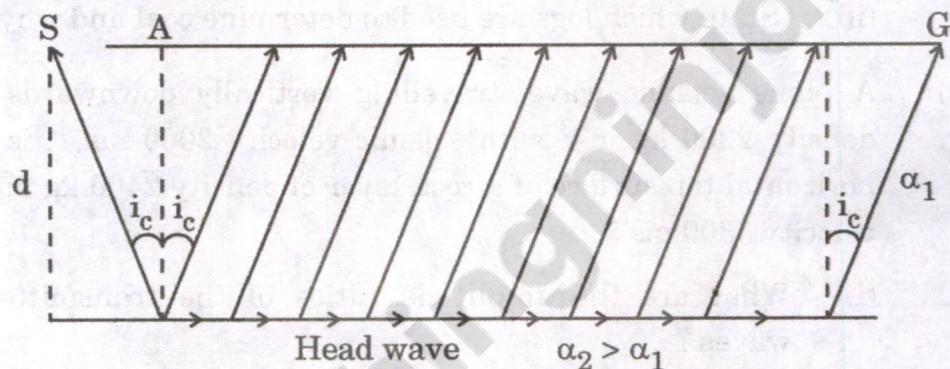


- (ii) Suppose you have a gravity reading as 955.4 scale units and you are provided with calibration constant as 1.0345 milligal per scale division and reading accuracy as 0.1 milligal (approximately). Determine the final converted reading in milligal. 6+2
- (e) (i) State the original problem faced in the portable Fluxgate Magnetometer and how it was overcome.
- (ii) State how relatively high noise level caused by Hysteresis effect in the core of a Fluxgate Magnetometer can be reduced.

- (iii) For the given Proton Precession Magnetometer, the constant  $\gamma_p$  (Gyromagnetic ratio of the proton) is given as  $\frac{2\pi}{25}$  Hz/nT. Also the precession frequency ( $\nu$ ) of the proton is given as 2130 Hz.

Calculate the magnetic field in nT. Draw a figure to explain the proton precession with respect to the Earth's magnetic field. Answer to be in the units of nT. 2+3+3

- Q2.** (a) Derive travel time equation of refraction at a horizontal interface separating medium having  $\alpha_2 > \alpha_1$  and having thickness of layer as  $d$ . Also derive equation of  $x_{cr}$  and  $d$ , where  $x_{cr}$  is crossover distance. Show in travel time versus distance curve, the direct ray, reflected and refracted rays. For derivation use the diagram below. 10



where  $\alpha_1$  is velocity of P wave in first layer and  $\alpha_2$  is velocity of P wave in second layer.

- (b) For a clastic shaly formation if we cross plot porosity determined from neutron log ( $\phi_N$ ) versus porosity determined from density log ( $\phi_D$ ),
- Provide a labelled diagram of cross plot  $\phi_N$  versus  $\phi_D$ , mentioning the shale point (with maximum percentage of shale), shale line, and sand line.
  - Also label the probable three kinds of shale distribution zones in the cross plot  $\phi_N$  versus  $\phi_D$ . 5+5
- (c) (i) State which continuation of gravity data is preferred i.e. upward or downward continuation and why.
- (ii) A gravity field strength observed during upward continuation for a gravity survey across an anomalous 2D mineral deposit as 30 milligal at a height 2 km for the wavelength 200 m. What will be the anomaly value at a height 5 km for the wavelength 200 m? Consider the upward continuation observations are above mean sea level. Answer to be given in the units of milligal. 2+8

- Q3.** (a) Derive the expression for penetration depth  $D$  and resistivity  $\rho$  in terms of  $E$  and  $H$  field in Magnetotelluric method. 10

$$\rho \approx \frac{T}{2\pi\mu} \left| \frac{E_x}{H_y} \right|^2$$

$$D \approx \frac{T}{2\pi\mu} \left| \frac{E_x}{H_y} \right|$$

- (b) (i) What is the principle of PE (photoelectric) log ?  
 (ii) Give the unit of PE log and also state which has higher PE value, limestone or dolomite, and why.  
 (iii) State which logs are used to determine coal and why. 4+4+4
- (c) A plane seismic wave, travelling vertically downwards in a rock of density  $2200 \text{ kg m}^{-3}$  with seismic velocity  $2000 \text{ ms}^{-1}$ , is incident on a horizontal top surface of a rock layer of density  $2400 \text{ kg m}^{-3}$  and seismic velocity  $3300 \text{ ms}^{-1}$ .
- (i) What are the amplitude ratios of the transmitted and reflected waves ?  
 (ii) What fraction of the energy of the incident wave is transmitted into the lower medium ? 8

- Q4.** (a) (i) Give three reasons for poor determination of geometry and magnetization of source body generating magnetic anomalies.  
 (ii) Calculate magnetic anomaly  $\Delta F$  (in nT) from field components  $\Delta x$  as 275 nT,  $\Delta y$  as 225 nT, and  $\Delta z$  as 900 nT, where the declination ( $D$ ) of Earth/Polarizing field is  $90^\circ$ , local magnetic inclination ( $I$ ) is  $90^\circ$ .  
 Consider the anomalous field is very small in the direction of total field, which includes the anomalous component, and can be taken to be the same as the undisturbed field  $\Delta F$ . Provide labelled figure for the given problem. Answer to be given in the units of nT. 2+8
- (b) Derive reflection travel time equation for single horizontal reflector. Also derive equation of moveout and normal moveout for horizontal reflector. Compute normal moveout for offset  $x = 40 \text{ m}$ , two-way travel time ( $t_0$ ) = 1.4 s and  $V = 8 \text{ km/s}$ . Give the normal moveout in the unit of milliseconds. 10

- (c) (i) Consider a Sonic Log which has reading ( $t_{Log}$ ) at 500 m depth as 382  $\mu\text{sec/m}$ . Given that for matrix ( $t_{ma}$ ) as 189  $\mu\text{sec/m}$ , for fluid ( $t_f$  – saturated fresh water mud system) as 620  $\mu\text{sec/m}$ . Determine the porosity  $\phi$  in %.
- (ii) Evaluate  $\phi$  in % for the above same values of Sonic Log, where we consider the layer was considered under compaction with the constant factor  $C = 0.67$ .
- (iii) State the condition where we will not get SP deflection, where we will get positive deflection, and where we will get negative deflection.

Also provide relevant labelled figure to support your claim with corresponding sand/shale lithology. 4+3+3

- Q5.** (a) (i) Define various types of seismic velocities i.e. Interval Velocity ( $V_{int}$ ), Average Velocity ( $V_{av}$ ) and Root Mean Square Velocity ( $V_{rms}$ ). Using the DIX's equation, compute  $V_{int}$  from  $V_{rms}$  for two reflectors  $t_1 = 0.1$  s,  $t_2 = 0.5$  s with corresponding  $V_{rms1} = 4$  km/s and  $V_{rms2} = 8$  km/s. Give the velocity in km/s. 7+3
- (ii) Give factors affecting seismic velocities. 7+3
- (b) (i) Assume that the core of an anticline is made of basalt, the host formation is limestone, and the rocks are vertically magnetized with susceptibilities given by the median susceptibility value of Basalt as  $1.9 \times 10^{-1}$  (SI) and the median susceptibility value of Limestone as  $3.1 \times 10^{-4}$  (SI).  
Calculate the induced magnetization contrast when the vertical magnetic field intensity is 38,000 nT.  
(Consider  $\mu_0 = 4\pi \times 10^{-7}$  N/A<sup>2</sup>)  
Answer should be in the units of A/m.
- (ii) During magnetic survey using Proton Precession Magnetometer, we are supposed to orient the sensor in a particular direction with respect to Earth's magnetic field. State the direction of orientation of the sensor and the reason. 8+2
- (c) Calculate the "skin depths" of penetration in granite ( $\rho = 5100 \Omega\text{m}$ ) and for electromagnetic waves in surveys employing
- (i) Electromagnetic induction ( $f = 1$  kHz)
- (ii) Ground penetrating radar ( $f = 100$  MHz). 5+5  
(Consider  $\mu_0 = 4\pi \times 10^{-7}$  N/A<sup>2</sup>)

### SECTION B

- Q6.** (a) Show that  $u(q, p, t) = \ln(p + im\omega q) - i\omega t$  is a constant of motion for a one-dimensional simple harmonic oscillator defined by the Hamiltonian

$$H(q, p) = \frac{p^2}{2m} + \frac{1}{2}m\omega^2 q^2. \quad 8$$

- (b) A monoatomic ideal gas of volume  $V$  initially at  $32^\circ\text{C}$  is suddenly compressed to volume  $V/8$ . Calculate the temperature after the compression. If a diatomic gas is chosen instead of a monoatomic gas, will the rise in temperature be more or less? Explain. 8
- (c) Two lumps of clay each of mass  $m$  collide head on at speed  $v$  each. They stick together and stay at rest. If the mass of the final composition is  $3m$ , find the speed  $v$ . 8
- (d) Write the Lande Interval Rule in L.S. coupling under spin-orbit interaction. If the separations between adjacent energy levels of increasing energy in a multiplet are in the ratio  $3 : 5$ , then using the Lande Interval Rule, assign the quantum numbers  $S$ ,  $L$  and  $J$  to these levels. 4+4
- (e) Explain Binding Energy Curve. From binding energy considerations show that two alpha particles cannot form a stable  ${}^8\text{Be}$  nucleus. 4+4

- Q7.** (a) The Lagrangian of a system of  $N$  particles is given by

$$L = \frac{1}{2} \sum_{i=1}^N m_i \dot{x}_i^2 - \frac{1}{2} K \sum_{i=1}^N \sum_{j=1}^N (x_i - x_j)^2$$

where mass, generalized coordinate and generalized velocity of the  $i$ -th particle are given by  $m_i$ ,  $x_i$ , and  $\dot{x}_i$  respectively. Find equations of motion for all the particles. 10

- (b) An electron in 3-dimensional space moves in the influence of the following electromagnetic fields :

$$\vec{B} = B_0 \hat{k}, \quad \vec{E} = E_0 \hat{i}$$

$B_0, E_0$  are constants,  $\hat{i}$  and  $\hat{k}$  denote unit vectors in  $x$  and  $z$  directions respectively. Construct the Hamiltonian of the system to describe the dynamics of the electron. 10

- (c) A 3-dimensional quantum, isotropic harmonic oscillator with angular frequency  $\omega$  is in thermal equilibrium with a heat bath at a temperature  $T$ . Find the condition on  $T$  for which  $E_1 = \frac{9}{2} \hbar\omega$  level will be more populated than the level at  $E_2 = \frac{7}{2} \hbar\omega$ . 10

- Q8.** (a) The partition function of a system is given by  $Q = c e^{\alpha T^3 V}$ , where  $c$  and  $\alpha$  are constants. Calculate the pressure, the entropy and the specific heat,  $C_v$  for this system. 10
- (b) Consider the adiabatic mixing of two ideal gases with mole fractions  $f_1$  and  $f_2$ . Respective exponents of the gases are  $\gamma_1$  and  $\gamma_2$ . Calculate the effective exponent  $\gamma$  for the mixture. 10
- (c) What do you understand by fundamental quarks ? Write the basic constituent of the following particles in terms of quarks : 6+4=10
- $P, N, K^0, K^+, \pi^-, \pi^+, \Delta^+, \Omega^-$

- Q9.** (a) What do you understand by Paschen – Back effect ? Explain. By taking the transition  ${}^2P \rightarrow {}^2S$  in a strong magnetic field, draw the splittings of the terms :  ${}^2P$  and  ${}^2S$ . 5+5=10
- (b) What are the limitations of TEM to examine the solid substrate ? How is this problem overcome in SEM ? Explain. 5+5=10
- (c) What do you understand by magic and doubly magic nuclei ? Write the evidence for the existence of magic numbers. 10

- Q10.** (a) Obtain the first order correction to the ground state energy of the hydrogen atom due to relativistic effect.

[Given  $\left\langle \psi_n \left| \frac{1}{r} \right| \psi_n \right\rangle = \frac{1}{n^2 a}$ ,  $\left\langle \psi_n \left| \frac{1}{r^2} \right| \psi_n \right\rangle = \frac{1}{\left(l + \frac{1}{2}\right) n^3 a^2}$ ] 10

- (b) What do you understand by the critical size of a reactor ? Write in brief about reactor design, fuel, moderators, coolants and shielding materials. 2+8=10
- (c) (i) A particle of mass  $m$  moving in 3-dimensional space under the influence of the potential
- $$V(x, y, z) = \frac{1}{2} K (x^2 + y^2).$$
- Find the conserved quantities for this particle.
- (ii) How many generalized coordinates are needed to describe the motion of a rigid body in 3-dimension when it is (I) moving freely, and (II) constrained to move on plane ? Justify your answer with arguments. 5+5

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