# GATE Biomedical Engineering

## Sample Paper – 3

**Duration: 128 Minutes** **Maximum Marks: 72**

### Instructions

- This paper contains **46 questions** covering the core **Biomedical Engineering** subject of the GATE paper conducted by the IITs and IISc (General Aptitude and Engineering Mathematics are provided as separate papers).
- **Q1–Q20 carry 1 mark each** and **Q21–Q46 carry 2 marks each**, for a total of **72 marks**.
- Each question carries **negative marking of one-third of its allotted marks**: a wrong 1-mark question costs **0.33** and a wrong 2-mark question costs **0.67**. Unattempted questions carry no penalty.
- Every question here is a single-correct **MCQ**. The real GATE paper also has Multiple Select (MSQ) and Numerical Answer Type (NAT) questions, and **those carry no negative marking**.
- Attempt this paper in one timed sitting of about **128 minutes**, the share this core subject earns at GATE's overall pace of 180 minutes for 65 questions. Use standard physiological values (resting membrane potential $\approx -70$ mV, speed of sound in soft tissue $\approx 1540$ m/s) unless stated otherwise.

## Human Anatomy and Physiology

**Q1.** The partial pressure of oxygen ($P_{O_2}$) in normal systemic *arterial* blood of a healthy adult breathing room air is nearest to: **[1 mark]**

(A) $40$ mmHg

(B) $100$ mmHg

(C) $159$ mmHg

(D) $46$ mmHg

**Q2.** The residual volume (RV), the volume of air that remains in the lungs even after a maximal forced expiration, of a healthy adult is nearest to: **[1 mark]**

(A) 500 mL

(B) 3000 mL

(C) 1200 mL

(D) 150 mL

**Q3.** Within a single nephron, the tuft of capillaries where blood plasma is filtered under hydrostatic pressure to form the initial filtrate is the: **[1 mark]**

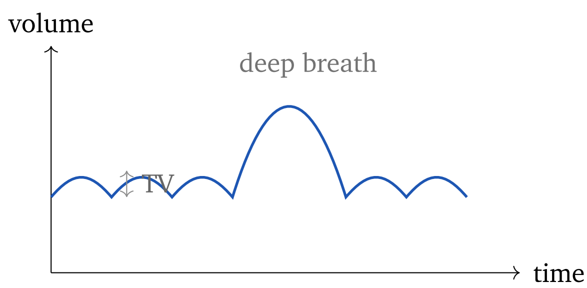
(A) loop of Henle

(B) glomerulus

(C) collecting duct

(D) distal convoluted tubule

**Q4.** The spirogram below records lung volume during quiet breathing followed by one deep breath. The small volume swing labelled **TV** (the air moved per quiet breath) of a healthy adult is nearest to: **[1 mark]**




(A) 1200 mL

(B) 500 mL

(C) 2500 mL

(D) 4800 mL

**Q5.** The hormone that acts on the collecting ducts of the kidney to increase water reabsorption, concentrating the urine and conserving body water, is: **[1 mark]**

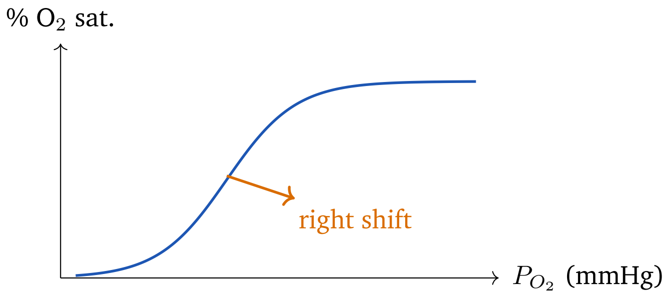
(A) insulin

(B) glucagon

(C) renin

(D) antidiuretic hormone (ADH / vasopressin)

**Q6.** The oxygen–haemoglobin dissociation curve is sigmoidal, as sketched. A **rightward** shift of this curve (the Bohr effect, caused by higher $CO_2$ or lower pH) means that the affinity of haemoglobin for oxygen has: **[1 mark]**




(A) increased

(B) become independent of $P_{O_2}$

(C) doubled

(D) decreased (oxygen is released more readily to the tissues)

## Electric Circuits, Signals and Systems

**Q7.** A sinusoidal voltage $v(t) = 20\sin(100\pi t)$ V is applied to a biomedical amplifier input. The root-mean-square (RMS) value of this voltage is nearest to: **[1 mark]**

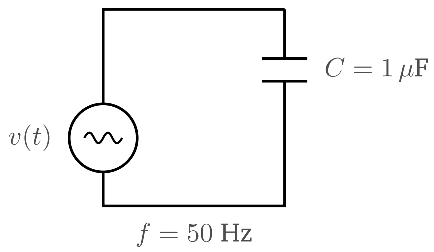
(A) $20$ V

(B) $14.14$ V

(C) $10$ V

(D) 28.28 V

**Q8.** In the AC circuit shown, a capacitor $C = 1\ \mu$F is driven at a supply frequency of $f = 50$ Hz. Its capacitive reactance $X_C = \dfrac{1}{2\pi f C}$ is nearest to: **[1 mark]**



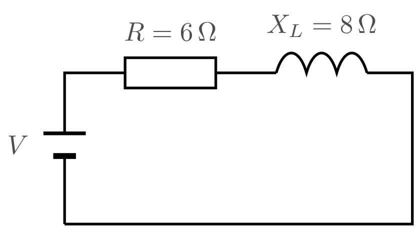

(A) 318 Ω

(B) 31.8 kΩ

(C) 3.18 kΩ

(D) 318 kΩ

**Q9.** In the series $RL$ circuit shown, the resistance is $R = 6\ \Omega$ and the inductive reactance at the operating frequency is $X_L = 8\ \Omega$. The magnitude of the total impedance seen by the source is: **[1 mark]**




(A) 10 Ω

(B) 14 Ω

(C) 2 Ω

(D) 48 Ω

**Q10.** In an AC series circuit the resistance is $R = 10\ \Omega$ and the inductive reactance is $X_L = 10\ \Omega$. The phase angle of the total impedance, $\theta = \tan^{-1}\left(\dfrac{X_L}{R}\right)$, is: **[1 mark]**

(A) $0^\circ$

(B) $90^\circ$

(C) $45^\circ$

(D) $30^\circ$

**Q11.** A series $RLC$ circuit has $L = 1$ mH and $C = 1$ $\mu$F. Its resonant frequency $f_0 = \dfrac{1}{2\pi\sqrt{LC}}$ is nearest to: **[1 mark]**

(A) 5.03 kHz

(B) 1 kHz

(C) 50 kHz

(D) 503 Hz

**Q12.** An AC load draws an RMS current of $I = 2$ A at an RMS voltage of $V = 100$ V with a power factor $\cos\phi = 0.8$. The real (average) power delivered, $P = VI\cos\phi$, is: **[1 mark]**

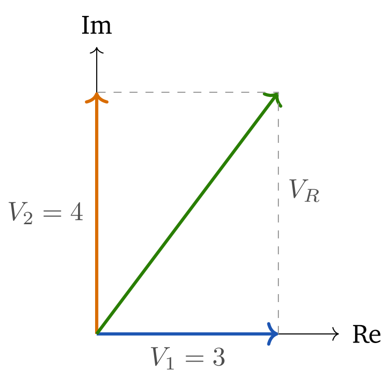
(A) 200 W

(B) 160 W

(C) 120 W

(D) 256 W

**Q13.** Two AC voltage phasors, $V_1 = 3\angle 0^\circ$ V and $V_2 = 4\angle 90^\circ$ V, are added in series as shown. The magnitude of the resultant phasor $V_R = V_1 + V_2$ is: **[1 mark]**




(A) 7 V

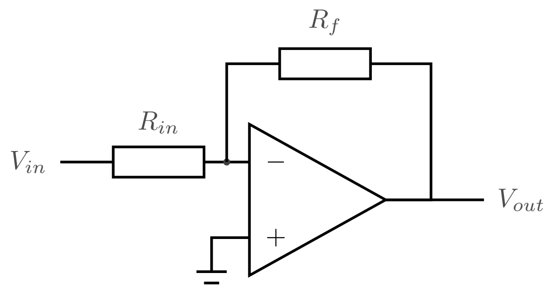
(B) 1 V

(C) 3.5 V

(D) 5 V

## Analog and Digital Electronics

**Q14.** For the ideal inverting operational-amplifier stage shown, $R_{in} = 5$ k$\Omega$ and $R_f = 100$ k$\Omega$. The closed-loop voltage gain $V_{out}/V_{in}$ is: **[1 mark]**



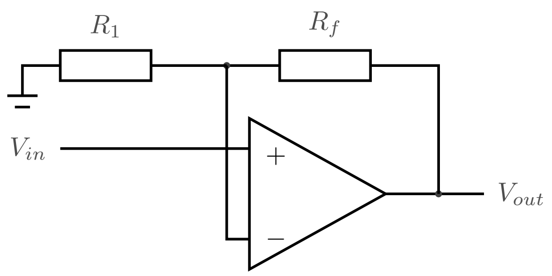

(A) $+20$

(B) $+21$

(C) $-21$

(D) $-20$

**Q15.** For the ideal non-inverting operational-amplifier stage shown, $R_1 = 10$ k$\Omega$ (to ground) and $R_f = 40$ k$\Omega$ (feedback). The closed-loop voltage gain $V_{out}/V_{in}$ is: **[1 mark]**




(A) 4

(B) $-5$

(C) 5

(D) $-4$

**Q16.** The three-op-amp instrumentation amplifier is the preferred front end for amplifying small biopotentials (such as the ECG). Its most important advantage for this task is its: **[1 mark]**

(A) very low input impedance

(B) high output impedance

(C) inability to reject common-mode interference

(D) very high input impedance combined with a high common-mode rejection ratio

**Q17.** A three-op-amp instrumentation amplifier has its differential gain set by a single external resistor $R_G$ through $A = 1 + \frac{2R}{R_G}$, where the two internal gain-setting resistors are $R = 25\ \text{k}\Omega$ each. For $R_G = 1\ \text{k}\Omega$, the differential gain $A$ is: **[1 mark]**

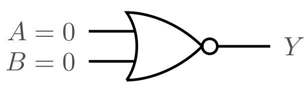
(A) 51

(B) 50

(C) 101

(D) 26

**Q18.** For the two-input NOR gate shown, both inputs are held LOW, i.e. $A = 0$ and $B = 0$. The logic level at the output $Y$ is: **[1 mark]**




(A) 0

(B) high impedance

(C) undefined

(D) 1

**Q19.** A 10-bit analog-to-digital converter (ADC) digitises an input over a full-scale range of 0 to 10 V. Taking the number of steps as $2^{10}$, the resolution (voltage per least-significant bit) is nearest to: **[1 mark]**

(A) $4.88$ mV

(B) $9.77$ mV

(C) $19.5$ mV

(D) $1024$ mV

## Sensors, Bioinstrumentation and Measurements

**Q20.** A strain-gauge load cell converts an applied mechanical force into an electrical signal. The bonded metal-foil gauges on the cell body transduce the force by exhibiting a: **[1 mark]**

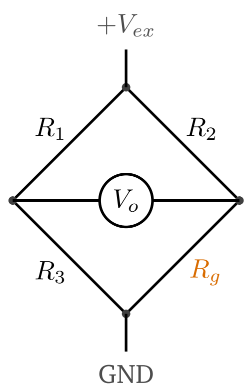
(A) change in capacitance with plate spacing

(B) generation of piezoelectric charge

(C) change in mutual inductance between coils

(D) change in electrical resistance produced by strain

**Q21.** A metal-foil strain gauge of gauge factor $2.0$ and unstrained resistance $350\ \Omega$ is bonded to a load-cell flexure and forms one arm of the bridge shown. Under load the gauge experiences a longitudinal strain of $2000\ \mu\varepsilon$ ($\varepsilon = 2 \times 10^{-3}$). The change in the gauge resistance $\Delta R$ is: **[2 marks]**




(A) $0.7\ \Omega$

(B) $1.4\ \Omega$

(C) $2.8\ \Omega$

(D) $0.14\ \Omega$

**Q22.** A load cell built as a *full* Wheatstone bridge with four active gauges has output $V_o = V_{ex} \cdot \text{GF} \cdot \varepsilon$. With excitation $V_{ex} = 10$ V, gauge factor GF $= 2.0$ and strain $\varepsilon = 500\ \mu\varepsilon$, the bridge output voltage is: **[2 marks]**

(A) $2.5$ mV

(B) $5$ mV

(C) $10$ mV

(D) $20$ mV

**Q23.** A commercial load cell is specified with a rated output of $2$ mV/V. When it is powered with a bridge excitation voltage of $10$ V, the bridge output voltage at full-scale (rated) load is: **[2 marks]**

(A) $20$ mV

(B) $2$ mV

(C) $12$ mV

(D) $200$ mV

**Q24.** The same load cell (rated output $2$ mV/V, excitation $10$ V) has a rated capacity of $500$ kg. Assuming a linear response, its sensitivity expressed as output voltage per kilogram of applied load is: **[2 marks]**

(A) $40\ \mu$V/kg

(B) $4\ \mu$V/kg

(C) $400\ \mu$V/kg

(D) $20\ \mu$V/kg

**Q25.** The disposable transducer used for invasive (intra-arterial) blood-pressure monitoring most commonly senses the deflection of a diaphragm using a: **[2 marks]**

(A) thermocouple junction

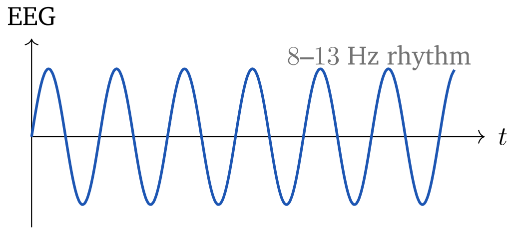
(B) linear variable differential transformer (LVDT)

(C) photodiode array

(D) piezoresistive (silicon strain-gauge) element bonded to the diaphragm

## Biomedical Signal Processing

**Q26.** The electroencephalogram (EEG) rhythm sketched below occupies the 8–13 Hz band and is most prominent over the occipital region during relaxed wakefulness with the eyes closed. This rhythm is the: **[2 marks]**




(A) delta rhythm

(B) beta rhythm

(C) theta rhythm

(D) alpha rhythm

**Q27.** An EEG channel is sampled at 256 samples per second. The highest signal frequency that can be represented without aliasing (the Nyquist frequency) is: **[2 marks]**

(A) 256 Hz

(B) 128 Hz

(C) 512 Hz

(D) 64 Hz

**Q28.** A 4-second epoch of EEG is analysed with a fast Fourier transform (FFT). The spacing between adjacent frequency bins of the resulting spectrum, $\Delta f = \frac{1}{T}$, is: **[2 marks]**

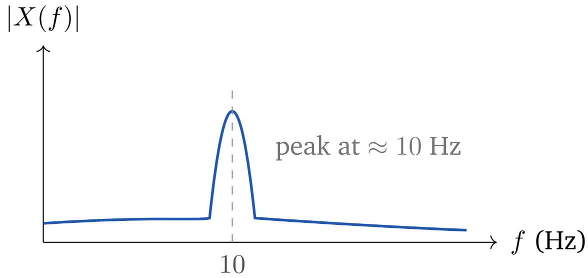
(A) 4 Hz

(B) 1 Hz

(C) 0.25 Hz

(D) 2 Hz

**Q29.** The single-sided FFT magnitude spectrum of an EEG segment is shown, with a single dominant peak near 10 Hz. This spectrum indicates that the recording is dominated by the: **[2 marks]**




(A) alpha rhythm (dominant peak at $\approx 10$ Hz)

(B) delta rhythm

(C) gamma rhythm

(D) beta rhythm

**Q30.** A 2-second EEG epoch sampled at 256 Hz is transformed with an FFT. Assuming no zero-padding, the number of samples in the epoch (the FFT length) is: **[2 marks]**

(A) 128

(B) 256

(C) 512

(D) 1024

## Medical Imaging Systems

**Q31.** In X-ray CT a voxel has linear attenuation coefficient $\mu = 0.21$ cm$^{-1}$, while water has $\mu_{\text{water}} = 0.20$ cm$^{-1}$. The CT number of the voxel, HU $= 1000 \cdot \dfrac{\mu - \mu_{\text{water}}}{\mu_{\text{water}}}$, is: **[2 marks]**

(A) 100 HU

(B) 50 HU

(C) 5 HU

(D) 500 HU

**Q32.** The standard analytic algorithm used to reconstruct a two-dimensional CT image from the set of one-dimensional projections (its Radon transform) is: [2 marks]

(A) direct display of the raw projections without processing

(B) simple (unfiltered) summation of back-projections

(C) filtered back-projection

(D) histogram equalisation of the detector data

**Q33.** On the Hounsfield (CT number) scale, water is defined as 0 HU and air as $-1000$ HU. Dense adult cortical bone has a CT number nearest to: [2 marks]

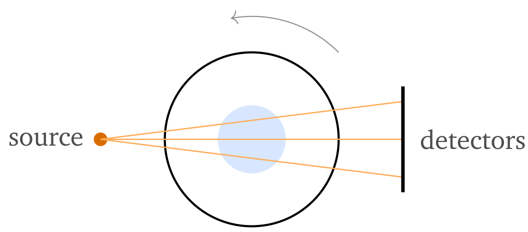
(A) $+1000$ HU

(B) 0 HU

(C) $-1000$ HU

(D) $-500$ HU

**Q34.** In CT, the raw data acquired by rotating the source–detector assembly around the patient are stored as a two-dimensional map of projection value versus projection angle, as suggested by the acquisition geometry shown. This raw-data image is called the: [2 marks]



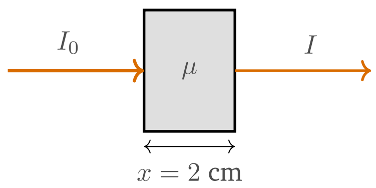

(A) histogram

(B) sinogram

(C) spectrogram

(D) dendrogram

**Q35.** A monoenergetic X-ray beam of incident intensity $I_0$ passes through a slab of tissue of thickness $x$ and linear attenuation coefficient $\mu$, as shown, following $I = I_0 e^{-\mu x}$. With $\mu = 0.15$ cm$^{-1}$ and $x = 2$ cm, the transmitted fraction $I/I_0$ is nearest to: **[2 marks]**




(A) 0.74

(B) 0.30

(C) 0.15

(D) 0.50

## Biomechanics and Biomaterials

**Q36.** The ultimate compressive strength of healthy adult cortical (compact) bone loaded along its long axis is nearest to: **[2 marks]**

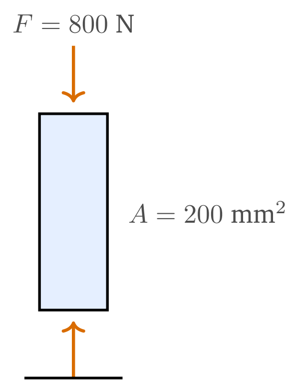
(A) 20 MPa

(B) 700 MPa

(C) 2 MPa

(D) 170 MPa

**Q37.** A short bone specimen of uniform cross-sectional area $A = 200$ mm$^2$ carries a purely axial compressive load of $F = 800$ N, as shown. The average normal (axial) stress in the specimen is: **[2 marks]**



(A) 4 MPa

(B) 40 MPa

(C) 0.4 MPa

(D) 16 MPa

**Q38.** A specimen of cortical bone (Young's modulus $E = 18$ GPa) is loaded so that the axial stress is $\sigma = 36$ MPa, within the linear-elastic range. The axial strain produced, $\varepsilon = \sigma/E$, is: **[2 marks]**

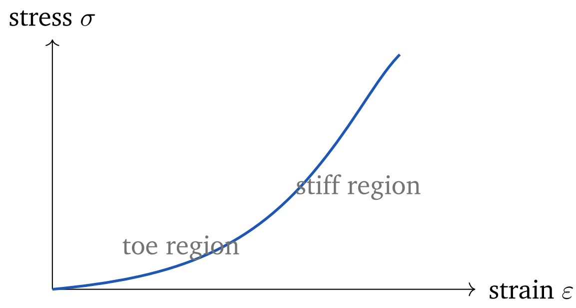
(A) 0.002

(B) 0.02

(C) 0.0002

(D) 0.2

**Q39.** Soft biological tissues such as tendon, ligament and skin show the non-linear "J-shaped" stress–strain curve sketched below: a compliant low-stiffness "toe" region followed by a much stiffer region. This behaviour is characteristic of a material that is: **[2 marks]**




(A) purely linear-elastic (Hookean) at all strains

(B) viscoelastic and nonlinear (J-shaped curve)

(C) perfectly plastic

(D) brittle with no toe region

**Q40.** A synthetic bone-graft material such as hydroxyapatite, to which the surrounding bone can chemically bond and which is gradually remodelled and replaced by new bone, is best described as: **[2 marks]**

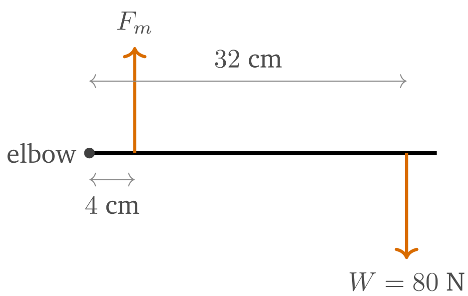
(A) bioinert and permanent

(B) toxic to surrounding tissue

(C) bioactive (osteoconductive)

(D) ferromagnetic

**Q41.** The forearm is modelled as a lever pivoted at the elbow, as shown. A weight $W = 80$ N is held in the hand at a horizontal distance of $32$ cm from the elbow, and the biceps muscle force $F_m$ acts vertically upward at $4$ cm from the elbow. Taking moments about the elbow for static equilibrium, the muscle force $F_m$ is: **[2 marks]**




(A) $80$ N

(B) $320$ N

(C) $640$ N

(D) $2560$ N

## Control Systems and Medical Instrumentation

**Q42.** A closed-loop control system has the characteristic equation $s^2 + 4s + 3 = 0$. Based on the locations of its closed-loop poles, the system is: **[2 marks]**

(A) unstable

(B) marginally stable

(C) oscillatory with constant amplitude

(D) stable (both poles in the left half of the $s$-plane)

**Q43.** A first-order physiological sensor has the transfer function $\dfrac{Y(s)}{X(s)} = \dfrac{1}{5s+1}$. The time constant of this system is: **[2 marks]**

(A) 5 s

(B) 0.2 s

(C) 1 s

(D) 10 s

**Q44.** A control system has the characteristic equation $s^3 + 2s^2 + s - 4 = 0$. Applying the Routh–Hurwitz criterion, the system is: **[2 marks]**

(A) stable

(B) unstable (a coefficient is negative, so at least one root lies in the right half-plane)

(C) critically damped

(D) marginally stable

**Q45.** A standard second-order control system has an undamped natural frequency $\omega_n = 10$ rad/s and a damping ratio $\zeta = 0.5$. Its damped natural frequency $\omega_d = \omega_n\sqrt{1-\zeta^2}$ is nearest to: **[2 marks]**

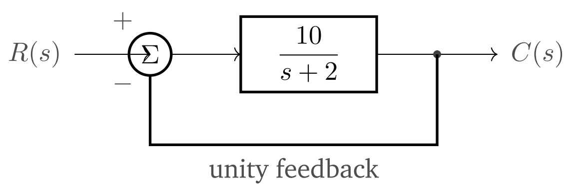
(A) 10 rad/s

(B) 5 rad/s

(C) 8.66 rad/s

(D) 7.5 rad/s

**Q46.** For the unity negative-feedback control system shown, the forward-path transfer function is $G(s) = \dfrac{10}{s+2}$. The steady-state (DC) closed-loop gain, $\dfrac{C}{R}\Big|_{s=0} = \dfrac{G(0)}{1+G(0)}$, is nearest to: **[2 marks]**




(A) 0.83

(B) 5

(C) 0.17

(D) 1

## Detailed Solutions

### Q1.

**Solution**

**Concept – oxygen partial pressures along the respiratory pathway:** As air moves from the atmosphere to the alveoli and into the blood, its oxygen partial pressure falls at each step.

**Step 1 – recall the standard values:** Inspired dry air $\approx 159$ mmHg; alveolar gas $\approx 100$ mmHg; systemic arterial blood $\approx 95$–$100$ mmHg; mixed venous blood $\approx 40$ mmHg.

**Step 2 – pick the arterial value:** Normal systemic arterial blood is very nearly equilibrated with alveolar gas, so $P_{O_2} \approx 100$ mmHg.

**Why the other options are wrong:**

- A, $40$ mmHg: is the oxygen tension of mixed *venous* blood.
- C, $159$ mmHg: is the oxygen tension of inspired atmospheric air, before it is diluted in the alveoli.
- D, $46$ mmHg: is the $CO_2$ tension of venous blood, not the arterial $P_{O_2}$.

**Final Answer:** $P_{O_2} \approx 100 \text{ mmHg} \Rightarrow \boxed{\text{B}}$

**Answer: (B)** Go Back to Q1

### Q2.

**Solution**

**Concept – residual volume:** The residual volume is the air that cannot be expelled from the lungs even by a maximal forced expiration; it keeps the alveoli open.

**Step 1 – recall the standard value:** For a healthy adult the residual volume is about $1200$ mL.

**Step 2 – distinguish it from neighbouring volumes:** Tidal volume ($\approx 500$ mL) and anatomical dead space ($\approx 150$ mL) are far smaller, while the vital capacity ($\approx 4800$ mL) is far larger.

**Why the other options are wrong:**

- A, $500$ mL: is the tidal volume.
- B, $3000$ mL: is closer to the inspiratory reserve volume.
- D, $150$ mL: is the anatomical dead space.

**Final Answer:** residual volume $\approx 1200$ mL $\Rightarrow \boxed{C}$

**Answer: (C)** Go Back to Q2

## Q3.

### Solution

**Concept – structure of the nephron:** Each nephron has a filtering unit (the renal corpuscle) followed by a tubule that processes the filtrate.

**Step 1 – locate the filtration site:** Plasma is filtered in the glomerulus, a knot of capillaries sitting inside Bowman's capsule, driven by the capillary hydrostatic pressure.

**Step 2 – trace what follows:** The filtrate then passes through the proximal tubule, loop of Henle, distal tubule and collecting duct, where it is modified into urine.

**Why the other options are wrong:**

- A, loop of Henle: sets up the concentration gradient but does not perform the initial filtration.
- C, collecting duct: adjusts final water content under ADH control, well downstream of filtration.
- D, distal convoluted tubule: fine-tunes ions and pH; it does not filter plasma.

**Final Answer:** glomerulus $\Rightarrow \boxed{B}$

**Answer: (B)** Go Back to Q3

## Q4.

### Solution

**Concept – tidal volume on a spirogram:** The tidal volume is the small, regular up-and-down swing of lung volume during quiet breathing.

**Step 1 – read the trace:** The small oscillations before the large excursion are quiet breaths; each swing is the tidal volume, marked TV.

**Step 2 – recall the standard value:** For a healthy adult at rest the tidal volume is about $500$ mL per breath.

**Why the other options are wrong:**

- A, $1200$ mL: is of the order of the residual volume.
- C, $2500$ mL: is closer to a deep inspiratory effort, matching the large excur-

sion, not the quiet swing.
- D, 4800 mL: is of the order of the vital capacity.

**Final Answer:** tidal volume $\approx 500$ mL $\Rightarrow \boxed{\text{B}}$

**Answer: (B)** Go Back to Q4

## Q5.

### Solution

**Concept – hormonal control of water reabsorption:** The final water content of urine is set in the collecting ducts, whose permeability to water is hormone-controlled.

**Step 1 – identify the controlling hormone:** Antidiuretic hormone (ADH, also called vasopressin), released by the posterior pituitary, inserts aquaporin water channels into the collecting-duct cells.

**Step 2 – describe the effect:** More water is reabsorbed back into the blood, so a smaller volume of concentrated urine is produced, conserving body water.

**Why the other options are wrong:**

- A, insulin: regulates blood glucose, not renal water handling.
- B, glucagon: raises blood glucose; it does not control collecting-duct water permeability.
- C, renin: is an enzyme that starts the renin–angiotensin cascade; it does not act directly on the collecting duct to move water.

**Final Answer:** antidiuretic hormone (ADH / vasopressin) $\Rightarrow \boxed{\text{D}}$

**Answer: (D)** Go Back to Q5

## Q6.

### Solution

**Concept – the Bohr effect and the oxygen–haemoglobin curve:** The position of the sigmoidal dissociation curve shows how tightly haemoglobin binds oxygen at a given $P_{O_2}$.

**Step 1 – interpret a rightward shift:** Shifting the curve to the right means that at any given $P_{O_2}$ the percentage saturation is lower, so oxygen is bound less tightly.

**Step 2 – state the consequence:** Lower binding affinity means haemoglobin unloads (releases) oxygen more readily to the tissues, which is exactly what active tissue (high $CO_2$, low pH) needs.

**Why the other options are wrong:**

- A, increased affinity: corresponds to a *leftward* shift, the opposite direction.
- B, independent of $P_{O_2}$: would flatten the curve, which the sketch does not show.
- C, doubled: affinity is not a simply doubled quantity here; the shift lowers affinity, it does not double it.

**Final Answer:** affinity decreased, oxygen released more readily $\Rightarrow \boxed{\text{D}}$

**Answer: (D)** **Go Back to Q6**

## Q7.

### Solution

**Concept – RMS value of a sinusoid:** For $v(t) = V_m \sin(\omega t)$, the RMS value is $V_{rms} = \dfrac{V_m}{\sqrt{2}}$.

**Step 1 – read the peak amplitude:** From $v(t) = 20\sin(100\pi t)$, the peak (amplitude) is $V_m = 20$ V.

**Step 2 – apply the RMS relation:** $V_{rms} = \dfrac{20}{\sqrt{2}}$

**Step 3 – evaluate the square root:** $\sqrt{2} = 1.414$

**Step 4 – divide:** $V_{rms} = \dfrac{20}{1.414} = 14.14\text{ V}$

**Why the other options are wrong:**

- A, 20 V: is the peak value, not the RMS value.
- C, 10 V: would be $V_m/2$, which is not the RMS of a sinusoid.
- D, 28.28 V: is $V_m\sqrt{2}$ (peak-to-RMS applied backwards).

**Final Answer:** $V_{rms} = 14.14\text{ V} \Rightarrow \boxed{\text{B}}$

**Answer: (B)** **Go Back to Q7**

## Q8.

**Solution**

**Concept – capacitive reactance:** $X_C = \frac{1}{2\pi f C}$.

**Step 1 – list the data in base units:** $f = 50$ Hz, $C = 1\ \mu\text{F} = 1 \times 10^{-6}$ F.

**Step 2 – form the product in the denominator:** $2\pi f C = 2\pi \times 50 \times 1 \times 10^{-6}$

**Step 3 – multiply the numbers:** $2\pi \times 50 = 314.16$

$314.16 \times 1 \times 10^{-6} = 3.1416 \times 10^{-4}$

**Step 4 – take the reciprocal:** $X_C = \frac{1}{3.1416 \times 10^{-4}}$

$X_C = 3183\ \Omega \approx 3.18\ \text{k}\Omega$

**Why the other options are wrong:**

- A, $318\ \Omega$: is a factor of ten too small.
- B, $31.8\ \text{k}\Omega$: is a factor of ten too large.
- D, $318\ \text{k}\Omega$: is off by a factor of one hundred.

**Final Answer:** $X_C \approx 3.18\ \text{k}\Omega \Rightarrow \boxed{\text{C}}$

**Answer: (C)** Go Back to Q8

## Q9.

**Solution**

**Concept – impedance magnitude of a series $RL$ circuit:** $|Z| = \sqrt{R^2 + X_L^2}$.

**Step 1 – list the data:** $R = 6\ \Omega$, $X_L = 8\ \Omega$.

**Step 2 – square each term:** $R^2 = 6^2 = 36$

$X_L^2 = 8^2 = 64$

**Step 3 – add:** $R^2 + X_L^2 = 36 + 64 = 100$

**Step 4 – take the square root:** $|Z| = \sqrt{100}$

$|Z| = 10\ \Omega$

**Why the other options are wrong:**

- B, $14\ \Omega$: is the simple sum $R + X_L$, which ignores the phasor addition.
- C, $2\ \Omega$: is the difference $X_L - R$, not the impedance.
- D, $48\ \Omega$: is the product $R\,X_L$, which has the wrong dimensions here.

**Final Answer:** $|Z| = 10\ \Omega \Rightarrow \boxed{\text{A}}$

Answer: (A) Go Back to Q9

## Q10.

### Solution

**Concept – phase angle of a series $RL$ impedance:** $\theta = \tan^{-1}\left(\frac{X_L}{R}\right)$.

**Step 1 – list the data:** $R = 10\ \Omega$, $X_L = 10\ \Omega$.

**Step 2 – form the ratio:** $\frac{X_L}{R} = \frac{10}{10} = 1$

**Step 3 – take the inverse tangent:** $\theta = \tan^{-1}(1)$

**Step 4 – evaluate:** $\theta = 45^\circ$

**Why the other options are wrong:**

- A, $0^\circ$: would need $X_L = 0$ (purely resistive).
- B, $90^\circ$: would need $R = 0$ (purely inductive).
- D, $30^\circ$: corresponds to $X_L/R = \tan 30^\circ = 0.577$, not $1$.

**Final Answer:** $\theta = 45^\circ \Rightarrow \boxed{\text{C}}$

Answer: (C) Go Back to Q10

## Q11.

### Solution

**Concept – resonant frequency of a series $RLC$ circuit:** $f_0 = \frac{1}{2\pi\sqrt{LC}}$.

**Step 1 – list the data in base units:** $L = 1\ \text{mH} = 1 \times 10^{-3}\ \text{H}$, $C = 1\ \mu\text{F} = 1 \times 10^{-6}$ F.

**Step 2 – form the product $LC$:** $LC = (1 \times 10^{-3})(1 \times 10^{-6}) = 1 \times 10^{-9}$

**Step 3 – take the square root:** $\sqrt{LC} = \sqrt{1 \times 10^{-9}} = 3.162 \times 10^{-5}$

**Step 4 – multiply by $2\pi$:** $2\pi\sqrt{LC} = 6.283 \times 3.162 \times 10^{-5} = 1.987 \times 10^{-4}$

**Step 5 – take the reciprocal:** $f_0 = \frac{1}{1.987 \times 10^{-4}} = 5033\ \text{Hz} \approx 5.03\ \text{kHz}$

**Why the other options are wrong:**

- B, $1$ kHz, and D, $503$ Hz: are an order of magnitude too small.
- C, $50$ kHz: is an order of magnitude too large.

**Final Answer:** $f_0 \approx 5.03\ \text{kHz} \Rightarrow \boxed{\text{A}}$

Answer: (A) Go Back to Q11

## Q12.

**Solution**

**Concept – real (average) power in an AC circuit:** $P = VI\cos\phi$, where $\cos\phi$ is the power factor.

**Step 1 – list the data:** $V = 100$ V, $I = 2$ A, $\cos\phi = 0.8$.

**Step 2 – form the apparent power:** $VI = 100 \times 2 = 200$ VA

**Step 3 – multiply by the power factor:** $P = 200 \times 0.8$

$P = 160$ W

**Why the other options are wrong:**

- A, 200 W: is the apparent power ($VA$), which ignores the power factor.
- C, 120 W: uses a power factor of 0.6, not 0.8.
- D, 256 W: has no consistent derivation from the data.

**Final Answer:** $P = 160$ W $\Rightarrow \boxed{\text{B}}$

Answer: (B) Go Back to Q12

## Q13.

**Solution**

**Concept – magnitude of a sum of two perpendicular phasors:** When two phasors are $90^\circ$ apart, the magnitude of their sum is $|V_R| = \sqrt{V_1^2 + V_2^2}$.

**Step 1 – list the data:** $V_1 = 3$ V at $0^\circ$ (along the real axis), $V_2 = 4$ V at $90^\circ$ (along the imaginary axis).

**Step 2 – square each magnitude:** $V_1^2 = 3^2 = 9$

$V_2^2 = 4^2 = 16$

**Step 3 – add:** $V_1^2 + V_2^2 = 9 + 16 = 25$

**Step 4 – take the square root:** $|V_R| = \sqrt{25}$

$|V_R| = 5$ V

**Why the other options are wrong:**

- A, 7 V: is the arithmetic sum $3 + 4$, valid only if the phasors were in phase.
- B, 1 V: is the difference $4 - 3$, valid only if they were exactly out of phase.

- C, 3.5 V: is the average of the two magnitudes, which has no physical basis here.

**Final Answer:** $|V_R| = 5$ V $\Rightarrow \boxed{\text{D}}$

**Answer: (D)** Go Back to Q13

## Q14.

**Solution**

**Concept – gain of an ideal inverting op-amp:** $\dfrac{V_{out}}{V_{in}} = -\dfrac{R_f}{R_{in}}$.

**Step 1 – list the data:** $R_{in} = 5$ kΩ, $R_f = 100$ kΩ.

**Step 2 – form the resistor ratio:** $\dfrac{R_f}{R_{in}} = \dfrac{100}{5} = 20$

**Step 3 – apply the negative sign of the inverting configuration:** $\dfrac{V_{out}}{V_{in}} = -20$

**Why the other options are wrong:**

- A, $+20$: drops the inversion; an inverting amplifier has a negative gain.
- B and C, $\pm 21$: use $1 + R_f/R_{in}$, which is the *non-inverting* formula.

**Final Answer:** gain $= -20 \Rightarrow \boxed{\text{D}}$

**Answer: (D)** Go Back to Q14

## Q15.

**Solution**

**Concept – gain of an ideal non-inverting op-amp:** $\dfrac{V_{out}}{V_{in}} = 1 + \dfrac{R_f}{R_1}$.

**Step 1 – list the data:** $R_1 = 10$ kΩ, $R_f = 40$ kΩ.

**Step 2 – form the resistor ratio:** $\dfrac{R_f}{R_1} = \dfrac{40}{10} = 4$

**Step 3 – add one:** $\dfrac{V_{out}}{V_{in}} = 1 + 4$

$$\frac{V_{out}}{V_{in}} = 5$$

**Why the other options are wrong:**

- A, 4: uses $R_f/R_1$ alone and forgets the $+1$.
- B and D, negative values: a non-inverting amplifier gives a positive gain.

**Final Answer:** gain $= +5 \Rightarrow \boxed{\text{C}}$

**Answer: (C)** Go Back to Q15

## Q16.

**Solution**

**Concept – why the instrumentation amplifier suits biopotentials:** Biopotentials such as the ECG are tiny differential signals riding on a large common-mode interference (mainly $50$ Hz mains) picked up by both electrodes.

**Step 1 – state the two key requirements:** The front end must (i) draw almost no current from the high-impedance electrode–skin interface, and (ii) amplify the difference while rejecting the common-mode interference.

**Step 2 – match to the instrumentation amplifier:** The three-op-amp instrumentation amplifier provides a very high input impedance (its inputs go to the non-inverting terminals of two buffers) together with a high common-mode rejection ratio.

**Why the other options are wrong:**

- A, low input impedance: would load the electrodes and distort the signal.
- B, high output impedance: is undesirable for driving the next stage.
- C, cannot reject common mode: is the opposite of its defining strength.

**Final Answer:** very high input impedance with high CMRR $\Rightarrow \boxed{\text{D}}$

**Answer: (D)** Go Back to Q16

## Q17.

**Solution**

**Concept – gain of a three-op-amp instrumentation amplifier:** $A = 1 + \dfrac{2R}{R_G}$, where $R_G$ is the single external gain-setting resistor and $R$ is each internal gain resistor.

**Step 1 – list the data:** $R = 25\ \text{k}\Omega$, $R_G = 1\ \text{k}\Omega$.

**Step 2 – form the numerator** $2R$**:** $2R = 2 \times 25\ \text{k}\Omega = 50\ \text{k}\Omega$

**Step 3 – divide by** $R_G$**:** $\dfrac{2R}{R_G} = \dfrac{50\ \text{k}\Omega}{1\ \text{k}\Omega} = 50$

**Step 4 – add one:** $A = 1 + 50$

$A = 51$

**Why the other options are wrong:**

- B, $50$: forgets the leading $+1$ in the gain formula.
- C, $101$: uses $2 \times 50 + 1$, doubling the ratio incorrectly.
- D, $26$: uses $R/R_G + 1$ and omits the factor of two.

**Final Answer:** $A = 51 \Rightarrow \boxed{\text{A}}$

**Answer: (A)** Go Back to Q17

## Q18.

**Solution**

**Concept – NOR truth table:** A NOR gate is an OR followed by inversion: $Y = \overline{A + B}$.

**Step 1 – form the OR of the inputs:** $A + B = 0 + 0 = 0$

**Step 2 – invert the result:** $Y = \overline{0} = 1$

**Step 3 – state the output level:** The output $Y$ is HIGH, i.e. logic $1$. (A NOR output is $1$ only when *all* inputs are $0$.)

**Why the other options are wrong:**

- A, $0$: would be the output of an OR gate, not a NOR, for these inputs.
- B and C, high impedance / undefined: a NOR gate always drives a defined logic level.

**Final Answer:** $Y = 1 \Rightarrow \boxed{\text{D}}$

**Answer: (D)** Go Back to Q18

## Q19.

**Solution**

**Concept – ADC resolution (step size):** resolution $= \dfrac{\text{full-scale range}}{2^n}$.

**Step 1 – list the data:** Full-scale range $= 10$ V, $n = 10$ bits.

**Step 2 – compute the number of steps:** $2^{10} = 1024$

**Step 3 – divide the range by the steps:** resolution $= \dfrac{10}{1024}$

**Step 4 – evaluate:** resolution $= 0.009766$ V

**Step 5 – convert to millivolts:** $0.009766$ V $= 9.77$ mV

**Why the other options are wrong:**

- A, $4.88$ mV: divides a $5$ V range by $1024$, but the range here is $10$ V.
- C, $19.5$ mV: divides $10$ V by $512$ (a $9$-bit converter).
- D, $1024$ mV: is the step count treated as a voltage, which is dimensionally wrong.

**Final Answer:** resolution $\approx 9.77$ mV $\Rightarrow \boxed{\text{B}}$

Answer: (B) Go Back to Q19

## Q20.

**Solution**

**Concept – transduction in a strain-gauge load cell:** A load cell measures force by measuring the strain it produces in a metal flexure to which foil gauges are bonded.

**Step 1 – identify the physical effect:** When the gauge is stretched, its wire grows longer and thinner, so its electrical resistance rises; when compressed, its resistance falls.

**Step 2 – relate to the force:** The fractional resistance change is proportional to strain through the gauge factor, and strain is proportional to the applied force, so resistance change maps directly to force.

**Why the other options are wrong:**

- A, capacitance change: is the mechanism of a capacitive sensor, not a foil gauge.
- B, piezoelectric charge: describes a piezo force sensor, which produces charge, not a resistance change.
- C, mutual inductance: is the mechanism of an LVDT.

**Final Answer:** change in electrical resistance produced by strain $\Rightarrow \boxed{\text{D}}$

Answer: (D) Go Back to Q20

## Q21.

**Solution**

**Concept – strain-gauge relation:** The gauge factor links fractional resistance change to strain: $\frac{\Delta R}{R} = \text{GF} \cdot \varepsilon$, so $\Delta R = \text{GF} \cdot \varepsilon \cdot R$.

**Step 1 – list the data:** $\text{GF} = 2.0$, $\varepsilon = 2000\ \mu\varepsilon = 2 \times 10^{-3}$, $R = 350\ \Omega$.

**Step 2 – form the fractional change:** $\frac{\Delta R}{R} = 2.0 \times 2 \times 10^{-3}$

$\frac{\Delta R}{R} = 4 \times 10^{-3}$

**Step 3 – multiply by the resistance:** $\Delta R = 4 \times 10^{-3} \times 350$

**Step 4 – evaluate:** $\Delta R = 1.4\ \Omega$

**Why the other options are wrong:**

- A, $0.7\ \Omega$: halves the strain or the gauge factor.
- C, $2.8\ \Omega$: doubles the correct value.
- D, $0.14\ \Omega$: is off by a factor of ten.

**Final Answer:** $\Delta R = 1.4\ \Omega \Rightarrow \boxed{\text{B}}$

**Answer: (B)** Go Back to Q21

## Q22.

**Solution**

**Concept – output of a full-bridge load cell:** With four active gauges the bridge output is $V_o = V_{ex} \cdot \text{GF} \cdot \varepsilon$ (four times the quarter-bridge output).

**Step 1 – list the data:** $V_{ex} = 10$ V, $\text{GF} = 2.0$, $\varepsilon = 500\ \mu\varepsilon = 5 \times 10^{-4}$.

**Step 2 – multiply the gauge factor by the strain:** $\text{GF} \cdot \varepsilon = 2.0 \times 5 \times 10^{-4}$

$\text{GF} \cdot \varepsilon = 1 \times 10^{-3}$

**Step 3 – multiply by the excitation voltage:** $V_o = 10 \times 1 \times 10^{-3}$

**Step 4 – evaluate:** $V_o = 1 \times 10^{-2}\ \text{V} = 10\ \text{mV}$

**Why the other options are wrong:**

- A, $2.5$ mV: is the quarter-bridge output, a factor of four smaller.
- B, $5$ mV: is the half-bridge output.
- D, $20$ mV: doubles the correct full-bridge value.

**Final Answer:** $V_o = 10\ \text{mV} \Rightarrow \boxed{\text{C}}$

Answer: (C) Go Back to Q22

## Q23.

### Solution

**Concept – rated output of a load cell:** The rated output (mV/V) is the full-scale bridge output per volt of excitation, so the full-scale output is $V_o$ = (rated output) $\times V_{ex}$.

**Step 1 – list the data:** Rated output $= 2$ mV/V, $V_{ex} = 10$ V.

**Step 2 – multiply:** $V_o = 2$ mV/V $\times$ 10 V

**Step 3 – evaluate:** $V_o = 20$ mV

**Why the other options are wrong:**

- B, 2 mV: forgets to multiply by the 10 V excitation.
- C, 12 mV: adds the two numbers instead of multiplying.
- D, 200 mV: is off by a factor of ten.

**Final Answer:** $V_o = 20$ mV $\Rightarrow \boxed{A}$

Answer: (A) Go Back to Q23

## Q24.

### Solution

**Concept – sensitivity as output per unit load:** Sensitivity $= \dfrac{\text{full-scale output voltage}}{\text{rated capacity}}$.

**Step 1 – find the full-scale output voltage:** From the previous result, full-scale output $= 2$ mV/V $\times$ 10 V $= 20$ mV.

**Step 2 – list the rated capacity:** Rated capacity $= 500$ kg.

**Step 3 – divide output by capacity:** sensitivity $= \dfrac{20 \text{ mV}}{500 \text{ kg}}$

**Step 4 – evaluate in millivolts per kg:** sensitivity $= 0.04$ mV/kg

**Step 5 – convert to microvolts per kg:** $0.04$ mV/kg $= 40\ \mu$V/kg

**Why the other options are wrong:**

- B, 4 $\mu$V/kg: is a factor of ten too small.
- C, 400 $\mu$V/kg: is a factor of ten too large.
- D, 20 $\mu$V/kg: divides only by 1000 kg, halving the true value.

**Final Answer:** sensitivity $= 40\ \mu\text{V/kg} \Rightarrow \boxed{\text{A}}$

**Answer: (A)** Go Back to Q24

## Q25.

### Solution

**Concept – disposable blood-pressure transducer:** Invasive blood pressure is sensed by a fluid-filled catheter that pushes on a thin diaphragm; the diaphragm's deflection is converted to a voltage.

**Step 1 – identify the sensing element:** Modern disposable dome transducers use a micromachined silicon diaphragm carrying diffused piezoresistors, so the diaphragm deflection changes their resistance in a bridge.

**Step 2 – relate to pressure:** The bridge unbalance is proportional to the diaphragm deflection, which is proportional to the applied blood pressure.

**Why the other options are wrong:**

- A, thermocouple: measures temperature, not pressure.
- B, LVDT: measures larger displacements and is bulky for a disposable dome.
- C, photodiode array: senses light, not diaphragm pressure.

**Final Answer:** piezoresistive (silicon strain-gauge) diaphragm $\Rightarrow \boxed{\text{D}}$

**Answer: (D)** Go Back to Q25

## Q26.

### Solution

**Concept – EEG frequency bands:** The EEG is classified into rhythms by frequency: delta ($< 4$ Hz), theta ($4$–$8$ Hz), alpha ($8$–$13$ Hz), beta ($13$–$30$ Hz) and gamma ($> 30$ Hz).

**Step 1 – read the band:** The rhythm shown lies in the $8$–$13$ Hz band.

**Step 2 – match the physiological context:** This band, prominent occipitally during relaxed wakefulness with eyes closed, is the alpha rhythm.

**Why the other options are wrong:**

- A, delta: is below $4$ Hz and appears in deep sleep.
- B, beta: is $13$–$30$ Hz and appears during active concentration.
- C, theta: is $4$–$8$ Hz and appears in drowsiness.

**Final Answer:** alpha rhythm $\Rightarrow \boxed{\text{D}}$

Answer: (D) Go Back to Q26

## Q27.

### Solution

**Concept – Nyquist frequency:** For a sampling rate $f_s$, the highest frequency that can be represented without aliasing is $f_N = \frac{f_s}{2}$.

**Step 1 – list the data:** $f_s = 256$ Hz.

**Step 2 – halve the sampling rate:** $f_N = \frac{256}{2}$

**Step 3 – evaluate:** $f_N = 128$ Hz

**Why the other options are wrong:**

- A, $256$ Hz: is the sampling rate itself, twice the Nyquist frequency.
- C, $512$ Hz: is twice the sampling rate.
- D, $64$ Hz: is one quarter of the sampling rate.

**Final Answer:** $f_N = 128$ Hz $\Rightarrow \boxed{\text{B}}$

Answer: (B) Go Back to Q27

## Q28.

### Solution

**Concept – FFT frequency resolution:** The bin spacing of an FFT equals the reciprocal of the record length: $\Delta f = \frac{1}{T}$.

**Step 1 – list the data:** $T = 4$ s.

**Step 2 – take the reciprocal:** $\Delta f = \frac{1}{4}$

**Step 3 – evaluate:** $\Delta f = 0.25$ Hz

**Why the other options are wrong:**

- A, $4$ Hz: uses $T$ directly instead of its reciprocal.
- B, $1$ Hz: would need a $1$-second record.
- D, $2$ Hz: would need a $0.5$-second record.

**Final Answer:** $\Delta f = 0.25$ Hz $\Rightarrow \boxed{\text{C}}$

Answer: (C) Go Back to Q28

## Q29.

### Solution

**Concept – reading a magnitude spectrum:** A dominant peak in the FFT magnitude spectrum locates the frequency at which most of the signal's energy sits.

**Step 1 – read the peak frequency:** The spectrum has a single strong peak near $10$ Hz.

**Step 2 – match to an EEG band:** A $10$ Hz peak lies in the $8$–$13$ Hz alpha band, so the recording is alpha-dominated (consistent with relaxed, eyes-closed EEG).

**Why the other options are wrong:**

- B, delta ($< 4$ Hz): the peak is not near DC.
- C, gamma ($> 30$ Hz): the peak is far below $30$ Hz.
- D, beta ($13$–$30$ Hz): the peak sits just below the beta band.

**Final Answer:** alpha rhythm (peak at $\approx 10$ Hz) $\Rightarrow \boxed{\text{A}}$

Answer: (A) Go Back to Q29

## Q30.

### Solution

**Concept – number of samples in a record:** The number of samples is the sampling rate times the record duration: $N = f_s \times T$.

**Step 1 – list the data:** $f_s = 256$ Hz, $T = 2$ s.

**Step 2 – multiply:** $N = 256 \times 2$

**Step 3 – evaluate:** $N = 512$

**Step 4 – note the FFT length:** With no zero-padding, the FFT length equals the number of samples, $512$ (already a power of two).

**Why the other options are wrong:**

- A, $128$, and B, $256$: are too few for a $2$-second record at $256$ Hz.
- D, $1024$: would correspond to a $4$-second record.

**Final Answer:** $N = 512$ samples $\Rightarrow \boxed{\text{C}}$

Answer: (C) Go Back to Q30

## Q31.

### Solution

**Concept – Hounsfield (CT number) scale:** $\text{HU} = 1000 \cdot \dfrac{\mu - \mu_{\text{water}}}{\mu_{\text{water}}}$.

**Step 1 – list the data:** $\mu = 0.21\ \text{cm}^{-1}$, $\mu_{\text{water}} = 0.20\ \text{cm}^{-1}$.

**Step 2 – form the difference in the numerator:** $\mu - \mu_{\text{water}} = 0.21 - 0.20 = 0.01\ \text{cm}^{-1}$

**Step 3 – divide by $\mu_{\text{water}}$:** $\dfrac{0.01}{0.20} = 0.05$

**Step 4 – multiply by** $1000$**:** $\text{HU} = 1000 \times 0.05$

$\text{HU} = 50\ \text{HU}$

**Why the other options are wrong:**

- A, $100$ HU: doubles the correct ratio.
- C, $5$ HU: drops a factor of ten in the division.
- D, $500$ HU: is off by a factor of ten too large.

**Final Answer:** $50\ \text{HU} \Rightarrow \boxed{\text{B}}$

**Answer: (B)** Go Back to Q31

## Q32.

### Solution

**Concept – analytic CT reconstruction:** A CT scan measures line integrals of attenuation (projections) at many angles; the image must be recovered from these projections.

**Step 1 – recall the reconstruction method:** Simple back-projection alone smears each projection back across the image and produces a blurred result.

**Step 2 – add the filtering step:** Filtering each projection with a ramp (high-pass) filter before back-projecting removes this blur; the method is filtered back-projection (FBP), the standard analytic inverse of the Radon transform.

**Why the other options are wrong:**

- A, raw projections: are a sinogram, not an image.
- B, unfiltered summation: gives a blurred reconstruction and is not used clinically on its own.
- D, histogram equalisation: is a contrast-adjustment technique, not a reconstruction algorithm.

**Final Answer:** filtered back-projection $\Rightarrow$ $\boxed{\text{C}}$

Answer: (C) Go Back to Q32

## Q33.

**Solution**

**Concept – Hounsfield values of common tissues:** On the CT scale, air $= -1000$ HU, water $= 0$ HU, and denser tissues take progressively larger positive values.

**Step 1 – place cortical bone on the scale:** Cortical bone attenuates X-rays far more strongly than water, so its CT number is large and positive, of the order of $+1000$ HU (often higher).

**Step 2 – confirm the trend:** Fat is slightly negative ($\approx -100$ HU) and soft tissue is a few tens of HU, so bone sitting near $+1000$ HU is consistent.

**Why the other options are wrong:**

- B, $0$ HU: is water by definition.
- C, $-1000$ HU: is air.
- D, $-500$ HU: is closer to lung (mostly air), not bone.

**Final Answer:** cortical bone $\approx +1000$ HU $\Rightarrow$ $\boxed{\text{A}}$

Answer: (A) Go Back to Q33

## Q34.

**Solution**

**Concept – the CT sinogram:** The projections acquired at every angle, stacked into a two-dimensional array of projection position versus angle, form the raw CT data set.

**Step 1 – describe the array:** Each horizontal line is one projection; stacking the projections for all angles gives an image whose axes are detector position and rotation angle.

**Step 2 – name it:** A single point in the object traces out a sinusoid in this array, which is why it is called a sinogram.

**Why the other options are wrong:**

- A, histogram: is a plot of value frequency, not raw projection data.
- C, spectrogram: is a time–frequency plot of a signal.

- D, dendrogram: is a tree diagram used in clustering.

**Final Answer:** sinogram $\Rightarrow \boxed{\text{B}}$

**Answer: (B)** Go Back to Q34

## Q35.

**Solution**

**Concept – Beer–Lambert attenuation of X-rays:** $\dfrac{I}{I_0} = e^{-\mu x}$.

**Step 1 – list the data:** $\mu = 0.15\ \text{cm}^{-1}$, $x = 2$ cm.

**Step 2 – form the exponent:** $\mu x = 0.15 \times 2 = 0.30$

**Step 3 – evaluate the exponential:** $\dfrac{I}{I_0} = e^{-0.30}$

**Step 4 – compute:** $e^{-0.30} = 0.741 \approx 0.74$

**Why the other options are wrong:**

- B, $0.30$: is the exponent $\mu x$, not $e^{-\mu x}$.
- C, $0.15$: is $\mu$ itself.
- D, $0.50$: would require $\mu x = 0.693$ (one half-value layer), which is not the case here.

**Final Answer:** $I/I_0 \approx 0.74 \Rightarrow \boxed{\text{A}}$

**Answer: (A)** Go Back to Q35

## Q36.

**Solution**

**Concept – strength of cortical bone:** The ultimate compressive strength is the maximum compressive stress the bone can bear before failure.

**Step 1 – recall the accepted range:** Adult cortical bone has an ultimate compressive strength of roughly $150$–$200$ MPa along its long axis.

**Step 2 – pick the representative value:** About $170$ MPa lies squarely in this range.

**Why the other options are wrong:**

- A, $20$ MPa: is an order of magnitude too weak (nearer to trabecular bone).
- B, $700$ MPa: is well above bone and closer to some metals.
- C, $2$ MPa: is far too low, in the range of soft tissue.

**Final Answer:** $\approx 170$ MPa $\Rightarrow \boxed{\text{D}}$

Answer: (D) Go Back to Q36

**Q37.**

**Solution**

**Concept – axial (normal) stress:** $\sigma = \dfrac{F}{A}$.

**Step 1 – list the data:** $F = 800$ N, $A = 200$ mm$^2$.

**Step 2 – substitute:** $\sigma = \dfrac{800}{200}$

**Step 3 – divide:** $\sigma = 4$ N/mm$^2$

**Step 4 – convert the unit:** $1$ N/mm$^2 = 1$ MPa, so $\sigma = 4$ MPa.

**Why the other options are wrong:**

- B, $40$ MPa: is off by a factor of ten.
- C, $0.4$ MPa: is off by a factor of ten the other way.
- D, $16$ MPa: squares nothing meaningful; it does not follow from $F/A$.

**Final Answer:** $\sigma = 4$ MPa $\Rightarrow \boxed{\text{A}}$

Answer: (A) Go Back to Q37

**Q38.**

**Solution**

**Concept – Hooke's law in the elastic range:** $\varepsilon = \dfrac{\sigma}{E}$.

**Step 1 – list the data in consistent units:** $\sigma = 36$ MPa $= 36 \times 10^6$ Pa, $E = 18$ GPa $= 18 \times 10^9$ Pa.

**Step 2 – substitute:** $\varepsilon = \dfrac{36 \times 10^6}{18 \times 10^9}$

**Step 3 – divide the coefficients:** $\dfrac{36}{18} = 2$

**Step 4 – combine the powers of ten:** $\dfrac{10^6}{10^9} = 10^{-3}$

**Step 5 – assemble:** $\varepsilon = 2 \times 10^{-3} = 0.002$

**Why the other options are wrong:**

- B, $0.02$: is off by a factor of ten too large.
- C, $0.0002$: is off by a factor of ten too small.

- D, $0.2$: is off by a factor of one hundred.

**Final Answer:** $\varepsilon = 0.002 \Rightarrow \boxed{A}$

**Answer: (A)** Go Back to Q38

## Q39.

**Solution**

**Concept – mechanical behaviour of soft tissue:** Unlike metals, soft tissues such as tendon and skin do not follow a single straight-line (Hookean) law.

**Step 1 – read the curve:** The sketch shows a compliant "toe" region at low strain (crimped collagen fibres straightening) followed by a stiff region (aligned fibres bearing load), giving a J-shaped, upward-curving response.

**Step 2 – add the time dependence:** Soft tissues also show rate dependence, hysteresis and stress relaxation, i.e. viscoelasticity.

**Step 3 – classify:** A nonlinear, J-shaped, rate-dependent response is best described as viscoelastic and nonlinear.

**Why the other options are wrong:**

- A, purely linear-elastic: contradicts the curved (nonlinear) plot.
- C, perfectly plastic: would show a flat plateau, not a stiffening curve.
- D, brittle with no toe region: the plot clearly has a toe region and no sudden brittle fracture at low strain.

**Final Answer:** viscoelastic and nonlinear (J-shaped) $\Rightarrow \boxed{B}$

**Answer: (B)** Go Back to Q39

## Q40.

**Solution**

**Concept – classifying biomaterials by tissue response:** Biomaterials are grouped as bioinert (no bonding), bioactive (chemically bond to tissue) or bioresorbable (dissolve and are replaced).

**Step 1 – identify hydroxyapatite's behaviour:** Hydroxyapatite is chemically similar to the mineral of bone; new bone bonds directly to it and grows along it, and it is gradually remodelled.

**Step 2 – classify:** A material to which bone bonds and which guides new bone growth is bioactive (specifically osteoconductive).

**Why the other options are wrong:**

- A, bioinert and permanent: describes materials like alumina that do not bond chemically to bone.
- B, toxic: is false; hydroxyapatite is highly biocompatible.
- D, ferromagnetic: is irrelevant to bone bonding and untrue for hydroxyapatite.

**Final Answer:** bioactive (osteoconductive) $\Rightarrow \boxed{\text{C}}$

Answer: (C) Go Back to Q40

## Q41.

**Solution**

**Concept – moment (torque) balance of the forearm lever:** For static equilibrium the muscle moment about the elbow equals the load moment: $F_m \cdot d_m = W \cdot d_W$.

**Step 1 – list the data:** $W = 80$ N at $d_W = 32$ cm; muscle acts at $d_m = 4$ cm.

**Step 2 – write the moment balance about the elbow:** $F_m \times 4 = 80 \times 32$

**Step 3 – evaluate the right-hand side:** $80 \times 32 = 2560$

**Step 4 – solve for $F_m$:** $F_m = \dfrac{2560}{4}$

$F_m = 640$ N

**Step 5 – sanity check:** The muscle's lever arm ($4$ cm) is eight times shorter than the load's ($32$ cm), so it must supply eight times the weight: $8 \times 80 = 640$ N, which agrees.

**Why the other options are wrong:**

- A, $80$ N: forgets the lever-arm ratio and just equals the weight.
- B, $320$ N: uses a lever-arm ratio of four instead of eight.
- D, $2560$ N: is the moment $W\,d_W$ (in N·cm), not the force.

**Final Answer:** $F_m = 640$ N $\Rightarrow \boxed{\text{C}}$

Answer: (C) Go Back to Q41

## Q42.

**Solution**

**Concept – stability from closed-loop pole locations:** A linear system is stable when every root of its characteristic equation has a negative real part (lies in the left half of the $s$-plane).

**Step 1 – read the characteristic equation:** $s^2 + 4s + 3 = 0$.

**Step 2 – factor it:** $s^2 + 4s + 3 = (s + 1)(s + 3)$

**Step 3 – find the roots:** $s = -1$ and $s = -3$.

**Step 4 – check their location:** Both roots are real and negative, so both poles lie in the left half-plane.

**Step 5 – conclude:** With all poles in the left half-plane the system is stable.

**Why the other options are wrong:**

- A, unstable: would require a pole with a positive real part.
- B and C, marginal / constant-amplitude oscillation: would require poles on the imaginary axis.

**Final Answer:** stable (poles at $-1$ and $-3$) $\Rightarrow \boxed{\text{D}}$

Answer: (D) Go Back to Q42

## Q43.

**Solution**

**Concept – standard form of a first-order transfer function:** $\dfrac{1}{\tau s + 1}$, where $\tau$ is the time constant.

**Step 1 – compare with the given function:** $\dfrac{1}{5s + 1}$ has the form $\dfrac{1}{\tau s + 1}$ with the coefficient of $s$ equal to 5.

**Step 2 – identify the time constant:** $\tau = 5$ s.

**Step 3 – interpret:** The step response reaches $63.2\%$ of its final value after one time constant, i.e. after 5 s.

**Why the other options are wrong:**

- B, 0.2 s: is the reciprocal $1/\tau$ (the pole magnitude), not the time constant.
- C, 1 s: ignores the coefficient of $s$.
- D, 10 s: is about the settling time ($\approx 2\tau$), not $\tau$ itself.

**Final Answer:** $\tau = 5\text{ s} \Rightarrow \boxed{\text{A}}$

Answer: (A) Go Back to Q43

## Q44.

### Solution

**Concept – Routh–Hurwitz necessary condition:** For a stable system all coefficients of the characteristic polynomial must be present and of the *same sign*. A missing or opposite-sign coefficient guarantees at least one root in the right half-plane.

**Step 1 – read the characteristic equation:** $s^3 + 2s^2 + s - 4 = 0$.

**Step 2 – inspect the signs of the coefficients:** The coefficients are $+1$, $+2$, $+1$ and $-4$. The last coefficient is negative while the others are positive.

**Step 3 – apply the necessary condition:** A sign change among the coefficients violates the necessary condition for stability, so the Routh first column must change sign and at least one root lies in the right half-plane.

**Step 4 – conclude:** The system is unstable.

**Why the other options are wrong:**

- A, stable: is impossible once a coefficient is negative.
- C, critically damped: is a description of a second-order damping case, not applicable to this sign test.
- D, marginally stable: would require purely imaginary roots (a row of zeros in the Routh array), not a negative coefficient.

**Final Answer:** unstable (negative coefficient $\Rightarrow$ right-half-plane root) $\Rightarrow \boxed{\text{B}}$

Answer: (B) Go Back to Q44

## Q45.

### Solution

**Concept – damped natural frequency:** $\omega_d = \omega_n\sqrt{1-\zeta^2}$.

**Step 1 – list the data:** $\omega_n = 10$ rad/s, $\zeta = 0.5$.

**Step 2 – square the damping ratio:** $\zeta^2 = 0.5^2 = 0.25$

**Step 3 – subtract from one:** $1 - \zeta^2 = 1 - 0.25 = 0.75$

**Step 4 – take the square root:** $\sqrt{0.75} = 0.866$

**Step 5 – multiply by $\omega_n$:** $\omega_d = 10 \times 0.866$

$\omega_d = 8.66$ rad/s

**Why the other options are wrong:**

- A, 10 rad/s: is $\omega_n$, ignoring the damping factor.
- B, 5 rad/s: is $\zeta\omega_n$ (the decay rate), not the damped frequency.
- D, 7.5 rad/s: uses $(1 - \zeta^2)$ without the square root.

**Final Answer:** $\omega_d = 8.66$ rad/s $\Rightarrow \boxed{\text{C}}$

**Answer: (C)** Go Back to Q45

## Q46.

**Solution**

**Concept – steady-state gain of a unity-feedback loop:** For unity negative feedback the closed-loop transfer function is $\frac{C}{R} = \frac{G(s)}{1+G(s)}$; the DC gain is its value at $s = 0$.

**Step 1 – evaluate the forward gain at DC:** $G(0) = \frac{10}{0+2} = \frac{10}{2} = 5$

**Step 2 – form the closed-loop DC gain:** $\left.\frac{C}{R}\right|_{s=0} = \frac{G(0)}{1+G(0)} = \frac{5}{1+5}$

**Step 3 – add the denominator:** $1 + 5 = 6$

**Step 4 – divide:** $\left.\frac{C}{R}\right|_{s=0} = \frac{5}{6} = 0.833 \approx 0.83$

**Why the other options are wrong:**

- B, 5: is the open-loop DC gain $G(0)$, before closing the loop.
- C, 0.17: is $\frac{1}{1+G(0)}$, the error transfer function, not the output gain.
- D, 1: is the ideal high-gain limit; here $G(0)$ is only 5, so the gain stays below 1.

**Final Answer:** closed-loop DC gain $\approx 0.83 \Rightarrow \boxed{\text{A}}$

**Answer: (A)** Go Back to Q46

# Answer Key

| Q | Ans | Q | Ans | Q | Ans | Q | Ans | Q | Ans |
|---|---|---|---|---|---|---|---|---|---|
| 1 | B | 2 | C | 3 | B | 4 | B | 5 | D |
| 6 | D | 7 | B | 8 | C | 9 | A | 10 | C |
| 11 | A | 12 | B | 13 | D | 14 | D | 15 | C |
| 16 | D | 17 | A | 18 | D | 19 | B | 20 | D |
| 21 | B | 22 | C | 23 | A | 24 | A | 25 | D |
| 26 | D | 27 | B | 28 | C | 29 | A | 30 | C |
| 31 | B | 32 | C | 33 | A | 34 | B | 35 | A |
| 36 | D | 37 | A | 38 | A | 39 | B | 40 | C |
| 41 | C | 42 | D | 43 | A | 44 | B | 45 | C |
| 46 | A | | | | | | | | |