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Properties of Solids and Liquids — JEE (Main) Pattern Topic Test

FREE SAMPLE TEST · PHYSICS · PATTERN OF JEE (MAIN)

DURATION	MAXIMUM MARKS	QUESTIONS	NAME / ROLL NO.
60 minutes	100	25 (20 + 5)	

GENERAL INSTRUCTIONS

1. This question paper has two sections, A and B. All 25 questions are compulsory.
2. Section A has TWENTY (20) multiple-choice questions. Each has FOUR options, (1), (2), (3) and (4), of which ONLY ONE is correct.
3. Section B has FIVE (05) questions whose answer is a numerical value. Enter the value rounded off to the nearest integer.
4. Marking scheme for both sections: +4 for a correct answer, −1 for an incorrect answer, 0 if the question is not attempted.
5. Take g = 10 m/s² unless stated otherwise. Use of a calculator, log tables or any other aid is not allowed.
6. The answer key and worked solutions are at the end of this booklet. Attempt the paper in 60 minutes before you look at them.

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Topics covered: Elasticity · Pressure in a fluid · Pascal's law · Viscosity and terminal velocity · Stokes' law · Streamline and turbulent flow · Bernoulli's principle · Surface energy and surface tension · Capillary rise · Thermal expansion · Calorimetry and latent heat · Heat transfer

SECTION A (Q1–20) · Multiple choice · +4 / 0 / −1

Each question has FOUR options. ONLY ONE of them is correct.

1. Wire A has length L and radius r; wire B, of the same material, has length 2L and radius 2r. The same load is hung from each. The ratio of the extension of A to that of B is

(1) 1 : 2

(2) 4 : 1

(3) 2 : 1

(4) 1 : 1

2. A steel wire of length 2 m and cross-sectional area 1 mm² (Young's modulus 2×10^{11} N/m²) is stretched slowly by a load that rises from zero to 100 N. The extension of the wire and the elastic potential energy stored in it are

(1) 1 mm and 0.1 J

(2) 1 mm and 0.05 J

(3) 0.5 mm and 0.025 J

(4) 2 mm and 0.1 J

3. A solid ball made of a material of bulk modulus 1.0×10^9 N/m² is lowered into a lake. At what depth below the surface does its volume decrease by 0.1%? (Density of water 1000 kg/m³, g = 10 m/s²; the volume at the surface is the reference.)

(1) 10 m

(2) 1000 m

(3) 50 m

(4) 100 m

4. Consider the following statements.
(A) The Young's modulus of a perfectly rigid body is infinite.
(B) Liquids and gases have a bulk modulus but no modulus of rigidity.
(C) Poisson's ratio is a pure number with no units.
(D) Rubber is more elastic than steel, since it stretches far more under the same stress.
(E) Stress has the same dimensions as energy.
Choose the correct answer from the options given below:

(1) (A), (B) and (C) only

(2) (A), (B), (C) and (D) only

(3) (B), (C) and (E) only

(4) (A), (C) and (D) only

5. In a hydraulic lift, the piston on which a car of mass 1500 kg rests has an area of 0.5 m², and the small piston has an area of 5 cm². The least force on the small piston that can raise the car, and the distance the car rises when the small piston moves down 1 m, are (g = 10 m/s²; ignore the weights of the pistons)

(1) 150 N and 1 cm

(2) 15 N and 1 cm

(3) 15 N and 1 mm

(4) 1.5 N and 1 mm

6. A U-tube of uniform cross-section contains mercury (relative density 13.6). Water is poured into one arm until the water column is 27.2 cm long. The mercury in the other arm rises above its original level by

(1) 2 cm

(2) 1 cm

(3) 0.5 cm

(4) 4 cm

7. An air bubble of radius 1 mm rises steadily through an oil of density 900 kg/m³ and viscosity 0.5 Pa s. Neglecting the mass of the air, its terminal speed is about ($g = 10\ m/s^2$)

(1) 2 mm/s

(2) 40 mm/s

(3) 4 mm/s

(4) 0.4 mm/s

8. Small spheres of the same material, of radius r, fall through a viscous liquid at their terminal speeds (Stokes' law holds). The rate at which heat is produced by the viscous force on one sphere is proportional to

(1) r^2

(2) r^3

(3) r^4

(4) r^5

9. Water flows steadily through a horizontal pipe whose cross-section narrows from 4 cm² to 1 cm². The speed of the water in the wide part is 1 m/s. The speed in the narrow part, and the difference between the pressures in the two parts, are

(1) 4 m/s and 7500 Pa

(2) 4 m/s and 8000 Pa

(3) 2 m/s and 1500 Pa

(4) 16 m/s and 127 500 Pa

10. A wide tank standing on level ground is filled with water to a height of 2 m. A small hole is made in its side 0.5 m below the water surface. The horizontal distance from the tank at which the jet first strikes the ground, and the depth below the surface of another hole whose jet strikes the ground at the same place, are

(1) $\sqrt{3}$ m and 1 m

(2) $\sqrt{3}$ m and 1.5 m

(3) 2 m and 1.5 m

(4) 1 m and 1.5 m

11. Water (viscosity 1.0×10^{-3} Pa s, density 1000 kg/m³) flows with an average speed of 0.2 m/s through a pipe of diameter 2 cm. The Reynolds number and the nature of the flow are

(1) 400; streamline

(2) 4000; turbulent

(3) 40; streamline

(4) 4000; streamline

12. The work needed to blow a soap bubble of radius 1 cm from a soap solution of surface tension 0.03 N/m (at constant temperature) is about

(1) 7.5×10^{-5} J

(2) 3.8×10^{-5} J

(3) 1.5×10^{-4} J

(4) 2.5×10^{-5} J

13. A drop of water of radius 1 mm is split into 1000 identical droplets at constant temperature. The surface tension of water is 0.07 N/m. The work needed is about

(1) 0.88 μJ

(2) 8.8 μJ

(3) 79 μJ

(4) 7.9 μJ

14. Water would rise 7.2 cm in a clean glass capillary tube of radius 0.2 mm (contact angle zero). The tube is dipped vertically in water with only 5 cm of it above the water surface. Then

(1) water overflows from the top of the tube in a jet

(2) water rises to the top and stays there, its meniscus having a radius of about 0.29 mm

(3) water rises to the top and stays there, its meniscus having a radius of 0.2 mm

(4) water rises only to 3.6 cm

15. A steel rod and a brass rod are to be cut so that the difference between their lengths stays 10 cm at all temperatures. The coefficients of linear expansion of steel and brass are $1.2 \times 10^{-5}\ K^{-1}$ and $1.8 \times 10^{-5}\ K^{-1}$. The lengths of the steel and brass rods must be

(1) 20 cm and 30 cm

(2) 30 cm and 20 cm

(3) 15 cm and 25 cm

(4) 30 cm and 40 cm

16. A steel rod is clamped rigidly between two walls at its ends with no stress in it, and its temperature is then raised by 50 K. For steel, $Y = 2 \times 10^{11}\ N/m^2$ and $\alpha = 1.2 \times 10^{-5}\ K^{-1}$. The thermal stress in the rod is

(1) $1.2 \times 10^{8}\ N/m^2$

(2) $1.2 \times 10^{6}\ N/m^2$

(3) $2.4 \times 10^{8}\ N/m^2$

(4) $6 \times 10^{7}\ N/m^2$

17. 100 g of ice at −10 °C is put into 200 g of water at 50 °C in a vessel of negligible heat capacity. The specific heat of ice is 0.5 cal/g °C, that of water 1 cal/g °C, and the latent heat of fusion of ice 80 cal/g. The final state of the mixture is

(1) all water at 5 °C

(2) all water at 0 °C

(3) water and some ice at 0 °C

(4) all water at 10 °C

18. Steam at 100 °C is passed into 1 kg of water at 20 °C in a vessel of negligible heat capacity until the temperature of the water becomes 80 °C. The mass of steam condensed is about (latent heat of vaporisation 540 cal/g; specific heat of water 1 cal/g °C)

(1) 111 g

(2) 100 g

(3) 107 g

(4) 120 g

19. Two slabs of equal thickness and equal area are placed face to face. The thermal conductivity of the first is 2K and of the second K. The outer face of the first is kept at 100 °C and that of the second at 0 °C. In the steady state, the temperature of the common face and the thermal conductivity of the combination (as a single slab of twice the thickness) are

(1) 50 °C and 3K/2

(2) 66.7 °C and 3K/2

(3) 33.3 °C and 4K/3

(4) 66.7 °C and 4K/3

20. A black sphere radiates as a black body. If its radius is doubled and its absolute temperature is halved, the total power it radiates, and the wavelength at which its emission is greatest, become

(1) 1/4 of the original, and half the original wavelength

(2) 1/4 of the original, and twice the original wavelength

(3) 1/8 of the original, and twice the original wavelength

(4) 4 times the original, and twice the original wavelength

SECTION B (Q21–25) · Numerical value · +4 / 0 / −1

The answer to each question is a NUMERICAL VALUE. Enter it rounded off to the nearest integer.

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21. A pendulum clock with a steel pendulum (coefficient of linear expansion $1.2 \times 10^{-5}\ K^{-1}$) keeps correct time at 20 °C. When the temperature is 40 °C, the time (in s) it loses in a day is _____ (to the nearest integer).

Answer: _____

22. A thin plate of area 0.1 m^2 is pulled at a steady speed of 5 cm/s midway between two large fixed parallel plates 4 mm apart. The space between them is filled with glycerine of viscosity 0.8 Pa s. The force (in N) needed to pull the plate is _____.

Answer: _____

23. An air bubble of radius 0.1 mm is 10 cm below the surface of water (surface tension 0.072 N/m, density 1000 kg/m^3). The pressure inside the bubble exceeds the atmospheric pressure by _____ Pa (to the nearest integer; g = 10 m/s^2).

Answer: _____

24. A copper rod of length 1 m and cross-sectional area 1 cm^2 (thermal conductivity 400 W/m K), lagged along its length, has one end in boiling water at 100 °C and the other in melting ice at 0 °C. The mass of ice (in g) melted in one hour in the steady state is _____ (to the nearest integer; latent heat of fusion of ice 3.36×10^5 J/kg).

Answer: _____

25. A lead bullet moving at 200 m/s strikes a wall and stops. Half of its kinetic energy is converted into heat in the bullet. The rise in temperature of the bullet (in °C) is _____ (to the nearest integer; specific heat of lead 128 J/kg K).

Answer: _____

END OF THE QUESTION PAPER

ANSWER KEY

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
(3)	(2)	(4)	(1)	(3)	(2)	(3)	(4)	(1)	(2)

Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
(2)	(1)	(4)	(2)	(2)	(1)	(1)	(3)	(4)	(2)

Q21	Q22	Q23	Q24	Q25
10	4	2440	43	78

WORKED SOLUTIONS

Q1. Answer (3). $\Delta L = FL/(\pi r^2 Y) \propto L/r^2$. A: L/r^2; B: $2L/(4r^2) = L/(2r^2)$. Ratio 2 : 1.

Q2. Answer (2). $\Delta L = FL/(AY) = 100 \times 2/(10^{-6} \times 2 \times 10^{11}) = 10^{-3}$ m = 1 mm. The force grows in proportion to the extension, so $U = \tfrac{1}{2} F\Delta L = \tfrac{1}{2} \times 100 \times 10^{-3} = 0.05$ J. $F \times \Delta L = 0.1$ J would be the work at a constant 100 N.

Q3. Answer (4). $\Delta P = B \times (\Delta V/V) = 10^9 \times 10^{-3} = 10^6$ Pa (the extra pressure above that at the surface). $\Delta P = \rho g h$ gives $h = 10^6/(1000 \times 10) = 100$ m.

Q4. Answer (1). (A) A perfectly rigid body has zero strain for any stress, so Y = stress/strain is infinite. (B) A fluid cannot resist a steady shear, so its modulus of rigidity is zero; it does resist compression. (C) It is a ratio of two strains. (D) is wrong: 'more elastic' means a larger modulus, and steel needs far more stress for the same strain. (E) is wrong: stress has the dimensions of pressure (energy per unit volume), not energy.

Q5. Answer (3). Pascal's law: the same pressure acts on both pistons, so $f = 15000 \times (5 \times 10^{-4}/0.5) = 15$ N. The liquid is incompressible, so $5 \times 10^{-4} \times 1 = 0.5 \times h$, $h = 10^{-3}$ m = 1 mm (the work done on each side is the same, 15 J).

Q6. Answer (2). 27.2 cm of water exerts the pressure of 27.2/13.6 = 2 cm of mercury, so at equilibrium the mercury surfaces differ by 2 cm. The mercury falls by x in one arm and rises by x in the other, so 2x = 2 cm and x = 1 cm.

Q7. Answer (3). At terminal speed the upthrust balances the weight (negligible) plus the viscous drag: $(4/3)\pi r^3 \rho g = 6\pi\eta r v$, so $v = 2r^2\rho g/(9\eta) = 2 \times 10^{-6} \times 900 \times 10/(9 \times 0.5) = 4 \times 10^{-3}$ m/s = 4 mm/s, upward.

Q8. Answer (4). At terminal speed the viscous force equals the net weight, $\propto r^3$, and $v \propto r^2$ ($v = 2r^2(\rho - \sigma)g/(9\eta)$). The power dissipated is $Fv \propto r^3 \times r^2 = r^5$.

Q9. Answer (1). Continuity: $A_1 v_1 = A_2 v_2$, so $v_2 = 4 \times 1 = 4$ m/s. Bernoulli (horizontal): $p_1 - p_2 = \tfrac{1}{2}\rho(v_2^2 - v_1^2) = \tfrac{1}{2} \times 1000 \times (16 - 1) = 7500$ Pa, the pressure being lower where the water is faster.

Q10. Answer (2). Torricelli: $v = \sqrt{(2gh)}$ with h = 0.5 m; the hole is H − h = 1.5 m above the ground, so the fall time is $\sqrt{(2(H - h)/g)}$. Range $= 2\sqrt{(h(H - h))} = 2\sqrt{(0.75)} = \sqrt{3}$ m ≈ 1.73 m. The expression is unchanged when h and H − h are interchanged, so a hole at a depth of 1.5 m gives the same range.

Q11. Answer (2). $Re = \rho v D/\eta = 1000 \times 0.2 \times 0.02/10^{-3} = 4000$. Flow in a pipe is streamline for Re below about 1000 and turbulent above about 2000, so this flow is turbulent.

Q12. Answer (1). A bubble has two surfaces, so the new surface area is $2 \times 4\pi r^2$. $W = S \times 8\pi r^2 = 0.03 \times 8\pi \times 10^{-4} \approx 7.5 \times 10^{-5}$ J. Counting one surface gives half this.

Q13. Answer (4). Volume is conserved, so each droplet has radius R/10 and the total area becomes $1000 \times 4\pi(R/10)^2 = 10 \times 4\pi R^2$. The increase is $9 \times 4\pi R^2 = 36\pi \times 10^{-6}$ m². $W = S\Delta A = 0.07 \times 1.131 \times 10^{-4} \approx 7.9 \times 10^{-6}$ J.

Q14. Answer (2). Water rises to the top of the tube and stops; it cannot overflow (that would make a fountain of energy). The meniscus flattens until its curvature supports only 5 cm: hR = constant, so R' = 7.2 × 0.2/5 ≈ 0.29 mm (and the contact angle at the rim is no longer zero).

Q15. Answer (2). The difference is constant if both rods expand by the same amount: L_s α_s = L_b α_b, so L_s/L_b = 1.8/1.2 = 3/2. With $L_s - L_b$ = 10 cm, L_b = 20 cm and L_s = 30 cm. The rod with the smaller α must be the longer.

Q16. Answer (1). The free expansion αΔT is prevented, so the strain is αΔT = 6 × 10^{-4} and the stress is YαΔT = 2 × 10^{11} × 6 × 10^{-4} = 1.2 × 10^{8} N/m² (compressive); it does not depend on the length or area.

Q17. Answer (1). Heat to warm the ice to 0 °C: 100 × 0.5 × 10 = 500 cal; to melt it: 8000 cal; together 8500 cal. Water cooling to 0 °C can give 200 × 50 = 10 000 cal, which is more, so all the ice melts. The 1500 cal left warms all 300 g: 1500/300 = 5 °C.

Q18. Answer (3). Each gram of steam gives 540 cal on condensing and 20 cal more cooling from 100 °C to 80 °C: 560 cal. The water needs 1000 × 60 = 60 000 cal. m = 60 000/560 ≈ 107 g. Forgetting the 20 cal per gram gives 111 g.

Q19. Answer (4). Steady state: the same heat current flows through both, 2K(100 − θ) = K(θ − 0), so θ = 200/3 ≈ 66.7 °C (the better conductor has the smaller temperature drop). In series the thermal resistances add: 2d/K_eq = d/(2K) + d/K, so K_eq = 4K/3, not the average 3K/2.

Q20. Answer (2). Stefan's law: P = σ(4πr²)T⁴ ∝ r²T⁴ = 4 × (1/16) = 1/4. Wien's law: λ_max T is constant, so halving T doubles λ_max.

Q21. Answer 10. T ∝ √L, so ΔT/T = ½αΔθ = ½ × 1.2 × 10^{-5} × 20 = 1.2 × 10^{-4}. The clock runs slow by this fraction: 1.2 × 10^{-4} × 86 400 ≈ 10.4 s a day, i.e. 10.

Q22. Answer 4. The plate is 2 mm from each fixed plate, and each layer of glycerine drags on one face: F = 2 × ηAv/d = 2 × 0.8 × 0.1 × 0.05/0.002 = 4 N. Counting only one face gives 2 N.

Q23. Answer 2440. The water at that depth is at atmospheric pressure + ρgh = +1000 Pa. An air bubble in a liquid has one surface, so its excess pressure is 2S/r = 2 × 0.072/10^{-4} = 1440 Pa. Total excess over atmospheric pressure: 2440 Pa.

Q24. Answer 43. Heat current = KAΔθ/L = 400 × 10^{-4} × 100/1 = 4 W. In an hour: 4 × 3600 = 14 400 J, which melts 14 400/3.36 × 10^{5} ≈ 0.0429 kg ≈ 43 g.

Q25. Answer 78. Per kilogram, heat = ½ × ½v² = 0.25 × 40 000 = 10 000 J, so Δθ = 10 000/128 ≈ 78.1 °C, i.e. 78 (independent of the mass).

All questions are original and © Master Testing Agency. Free to download and use for personal practice; not for resale. Every answer in this paper was checked independently by computer: elastic energy by integrating force over extension, the jet by integrating its flight, mixtures by a step-by-step heat balance through each change of state, and conduction by relaxing the temperature along the slabs to the steady state.