Master Testing Agency
Practice papers, exam-standard · www.mastertestingagency.com

Electrostatics — 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 $1/(4\pi\varepsilon_0) = 9 \times 10^9$ N m²/C², $\varepsilon_0 = 8.85 \times 10^{-12}$ C²/N m², $e = 1.6 \times 10^{-19}$ C, $m_e = 9.1 \times 10^{-31}$ kg and $g = 10$ 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.

All questions are original and © Master Testing Agency. Free to download and use for personal practice; not for resale. Master Testing Agency is an independent test-prep publisher, not affiliated with, endorsed by or connected to the National Testing Agency (NTA), the IITs or any other exam-conducting body.

Topics covered: Electric charge and its conservation · Coulomb's law and superposition · Electric field and field lines · Electric field of continuous charge distributions · Electric dipole · Gauss's law and its applications · Electric potential and potential energy · Equipotential surfaces · Conductors and insulators · Capacitors and dielectrics · Combination of capacitors · Energy stored in a capacitor

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

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

1. Two identical small metal spheres with charges +9 μC and −3 μC attract each other with a force F when their centres are r apart. After being brought into contact, they are separated until their centres are r/2 apart. The force between them now is

(1) 4F/3, repulsive

(2) F/3, repulsive

(3) 4F/3, attractive

(4) 3F/4, repulsive

2. A charge −q is fixed at x = 0 and a charge +4q at x = L. A third charge placed on the x-axis feels no net electrostatic force when it is at

(1) x = L/3

(2) x = −L

(3) x = 2L

(4) x = −L/3

3. A charge Q is spread uniformly along a thin rod bent into a quarter of a circle of radius R. The magnitude of the electric field at the centre of the circle is

(1) $Q/(2\pi^2\varepsilon_0 R^2)$

(2) $\sqrt{2}Q/(\pi^2\varepsilon_0 R^2)$

(3) $Q/(\sqrt{2}\pi^2\varepsilon_0 R^2)$

(4) $Q/(4\sqrt{2}\pi\varepsilon_0 R^2)$

4. An electric dipole of moment 2×10^{-8} C m is in stable equilibrium in a uniform electric field of 5×10^4 N/C. The work needed to turn it through 60°, and the torque on it in that position, are

(1) 8.7×10^{-4} J and 5.0×10^{-4} N m

(2) 5.0×10^{-4} J and 5.0×10^{-4} N m

(3) 1.5×10^{-3} J and 8.7×10^{-4} N m

(4) 5.0×10^{-4} J and 8.7×10^{-4} N m

5. The electric field of a short dipole at a point on its equatorial line at a distance r from its centre has magnitude E. At a point on its axis at a distance r/2 from its centre, the field is

(1) 16E, in the same direction as the field at the first point

(2) 16E, opposite to the field at the first point

(3) 8E, opposite to the field at the first point

(4) 4E, in the same direction as the field at the first point

6. A point charge q is placed at the midpoint of one edge of a cube. The total electric flux through the surface of the cube is

(1) $q/(4\varepsilon_0)$

(2) $q/(8\varepsilon_0)$

(3) $q/(2\varepsilon_0)$

(4) $q/(24\varepsilon_0)$

7. Two large parallel plane sheets carry uniform surface charge densities $+\sigma$ and -2σ. The ratio of the magnitude of the electric field in the region between them to that in the region outside them is

(1) 1 : 3

(2) 2 : 1

(3) 1 : 1

(4) 3 : 1

8. Two concentric thin spherical shells of radii R and 2R carry charges +Q and −2Q respectively, spread uniformly. With $k = 1/(4\pi\varepsilon_0)$, the potential at their common centre and the electric field at a distance 3R from the centre are

(1) kQ/R, and $kQ/(9R^2)$ directed outward

(2) zero, and zero

(3) zero, and $kQ/(9R^2)$ directed towards the centre

(4) $-kQ/R$, and $kQ/(9R^2)$ directed outward

9. Four charges, each +q, are held fixed at the corners of a square of side a. With $k = 1/(4\pi\varepsilon_0)$, the work needed to bring a fifth charge +q from infinity to the centre of the square is

(1) $4\sqrt{2}\,kq^2/a$

(2) $2\sqrt{2}\,kq^2/a$

(3) $4kq^2/a$

(4) $(4 + \sqrt{2})\,kq^2/a$

10. The electric potential in a region is $V = (3x^2 - 2y)$ volt, with x and y in metre. The magnitude of the electric field at the point (1 m, 2 m) is

(1) 8 V/m

(2) $2\sqrt{5}$ V/m

(3) $2\sqrt{10}$ V/m

(4) $\sqrt{10}$ V/m

11. An electron enters the region between two parallel plates with a speed of 2×10^7 m/s, moving parallel to the plates. The plates are 10 cm long and the uniform field between them is 2×10^3 N/C. The sideways deflection of the electron when it leaves the plates is about

(1) 2.2 mm

(2) 8.8 mm

(3) 0.44 mm

(4) 4.4 mm

12. A solid conducting sphere of radius R carrying a charge Q is surrounded by an uncharged concentric conducting spherical shell of inner radius 2R and outer radius 3R. With $k = 1/(4\pi\varepsilon_0)$, the potential of the solid sphere is

(1) kQ/R

(2) $5kQ/(6R)$

(3) $kQ/(2R)$

(4) $kQ/(3R)$

13. A parallel-plate capacitor stays connected to a battery while a slab of dielectric constant K completely fills the space between its plates. Consider the statements:
(A) The charge on the plates becomes K times.
(B) The electric field between the plates is unchanged.
(C) The energy stored decreases.
(D) The potential difference between the plates is unchanged.
Choose the correct answer from the options given below:

(1) (A), (B) and (D) only
(2) (A) and (C) only
(3) (B), (C) and (D) only
(4) (A), (B), (C) and (D)

14. A parallel-plate capacitor with air between its plates (separation d) has capacitance C_0. A slab of dielectric constant 4 and thickness d/2, with the same area as the plates, is placed between them, parallel to the plates. The capacitance becomes

(1) $2.5C_0$
(2) $4C_0$
(3) $1.25C_0$
(4) $1.6C_0$

15. A 2 μF capacitor charged to 100 V and a 3 μF capacitor charged to 50 V are connected together with the positive plate of each joined to the negative plate of the other. The energy lost in the process is

(1) 1.5 mJ
(2) 13.5 mJ
(3) 11.0 mJ
(4) 7.5 mJ

16. The energy stored per unit volume in the electric field of air where the field is 3×10^6 V/m (close to the breakdown field of air) is about

(1) 80 J/m³
(2) 4.0 J/m³
(3) 40 J/m³
(4) 20 J/m³

17. Which of the following cannot be the net charge on an isolated body? ($e = 1.6 \times 10^{-19}$ C)

(1) 3.2×10^{-19} C
(2) 4.8×10^{-19} C
(3) 2.4×10^{-19} C
(4) -1.6×10^{-18} C

18. Which of the following statements about electrostatic field lines is NOT correct?

(1) They start on positive charges and end on negative charges or at infinity
(2) Two field lines never cross each other
(3) They meet the surface of a conductor in electrostatic equilibrium at right angles
(4) They can form closed loops in a region with no charges

19. An isolated charged parallel-plate capacitor stores energy U_0. The separation of its plates is slowly doubled. The work done by the external agent is

(1) U_0

(2) $2U_0$

(3) $U_0/2$

(4) zero

20. Charges +q, −2q and +q are fixed at x = −a, x = 0 and x = +a on the x-axis. With $k = 1/(4\pi\varepsilon_0)$, the electric potential at the point (0, a) is

(1) $(2 - \sqrt{2})kq/a$

(2) $-(2 - \sqrt{2})kq/a$

(3) zero

(4) $-2kq/a$

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.

---

21. A 10 μF capacitor is charged to 50 V and disconnected from the battery. It is then connected through a resistor across an uncharged 15 μF capacitor. The heat produced in the resistor (in μJ) is _____.

Answer: _____

22. A small ball of mass 2 g hangs from a silk thread in a uniform horizontal electric field of 2×10^4 N/C. In equilibrium the thread makes an angle of 37° with the vertical. The charge on the ball (in nC) is _____ (take tan 37° = 3/4).

Answer: _____

23. A sphere of radius R has charge density $\rho = \rho_0 r/R$, where r is the distance from its centre. The electric field at r = R/2 is x% of the field at the surface. The value of x is _____.

Answer: _____

24. Capacitors are connected as follows: 2 μF between A and P, 4 μF between P and B, 3 μF between A and Q, 6 μF between Q and B, and 5 μF between P and Q. A 30 V battery is connected between A and B. The charge (in μC) drawn from the battery is _____.

Answer: _____

25. A small particle of mass 1 g and charge +1 μC is released from rest at a distance of 0.2 m from a fixed point charge of +4 μC. Ignoring gravity, its speed (in m/s) when it is very far away is _____ (to the nearest integer).

Answer: _____

END OF THE QUESTION PAPER

ANSWER KEY

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

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

Q21	Q22	Q23	Q24	Q25
7500	750	25	100	19

WORKED SOLUTIONS

Q1. Answer (1). On contact the total charge +6 μC is shared equally: +3 μC each, so the force becomes repulsive. $F \propto q_1q_2/r^2$: originally $9 \times 3/r^2 = 27/r^2$; now $3 \times 3/(r/2)^2 = 36/r^2$. New force = 36F/27 = 4F/3. (F/3 would be the answer at the original distance.)

Q2. Answer (2). Between the charges the two forces point the same way, so the point lies outside, on the side of the smaller charge ($x < 0$). With d its distance from −q: $q/d^2 = 4q/(d + L)^2$, so $d + L = 2d$ and $d = L$. The point is $x = -L$.

Q3. Answer (3). $\lambda = Q/(\pi R/2) = 2Q/(\pi R)$. Taking the arc from $\theta = 0$ to $\pi/2$, each component is $\int k\lambda/R \cos\theta \, d\theta$ (or $\sin\theta \, d\theta$) $= k\lambda/R$. So $E = \sqrt{2}\, k\lambda/R = \sqrt{2} \times 2Q/(4\pi\varepsilon_0 \times \pi R^2) = Q/(\sqrt{2}\pi^2\varepsilon_0 R^2)$.

Q4. Answer (4). $W = pE(1 - \cos 60°) = 2 \times 10^{-8} \times 5 \times 10^4 \times 0.5 = 5.0 \times 10^{-4}$ J. Torque $\tau = pE \sin 60° = 10^{-3} \times 0.866 = 8.7 \times 10^{-4}$ N m.

Q5. Answer (2). Equatorial: $E = kp/r^3$, directed opposite to p. Axial at r/2: $2kp/(r/2)^3 = 16kp/r^3 = 16E$, directed along p. So it is 16E, opposite to the field at the first point.

Q6. Answer (1). Four cubes of the same size can be fitted round that edge so that together they enclose q completely. By symmetry each gets a quarter of the total flux q/ε_0, i.e. $q/(4\varepsilon_0)$. (The two faces that contain the edge get no flux: the field there lies in the face.)

Q7. Answer (4). Each sheet gives a field of $|\sigma|/(2\varepsilon_0)$ on both sides, away from a positive sheet and towards a negative one. Between them the two fields add: $(\sigma + 2\sigma)/(2\varepsilon_0) = 3\sigma/(2\varepsilon_0)$. Outside they oppose: $(2\sigma - \sigma)/(2\varepsilon_0) = \sigma/(2\varepsilon_0)$. Ratio 3 : 1.

Q8. Answer (3). Inside a shell its potential is constant and equal to its surface value: $V = kQ/R + k(-2Q)/(2R) = 0$. At 3R the enclosed charge is $Q - 2Q = -Q$, so by Gauss's law $E = kQ/(9R^2)$ directed towards the centre.

Q9. Answer (1). The centre is $a/\sqrt{2}$ from each corner, so the potential there is $4 \times kq/(a/\sqrt{2}) = 4\sqrt{2}\, kq/a$. The work is $qV = 4\sqrt{2}\, kq^2/a$. ($(4 + \sqrt{2})kq^2/a$ is the energy of the four charges themselves.)

Q10. Answer (3). $E = -\nabla V$: $E_x = -\partial V/\partial x = -6x = -6$ V/m at $x = 1$, and $E_y = -\partial V/\partial y = +2$ V/m. $|E| = \sqrt{(36 + 4)} = \sqrt{40} = 2\sqrt{10}$ V/m. The field is perpendicular to the equipotential curves $3x^2 - 2y =$ constant.

Q11. Answer (4). Time between the plates $t = L/v = 0.1/(2 \times 10^7) = 5 \times 10^{-9}$ s. Acceleration $a = eE/m = 1.6 \times 10^{-19} \times 2 \times 10^3/(9.1 \times 10^{-31}) = 3.52 \times 10^{14}$ m/s². $y = \tfrac{1}{2}at^2 = \tfrac{1}{2} \times 3.52 \times 10^{14} \times 2.5 \times 10^{-17} = 4.4 \times 10^{-3}$ m = 4.4 mm.

Q12. Answer (2). Induced charges: −Q on the inner surface (2R) and +Q on the outer surface (3R) of the shell. $V = kQ/R - kQ/(2R) + kQ/(3R) = 5kQ/(6R)$. Equivalently, integrate the field kQ/r^2 over $R < r < 2R$ and $r > 3R$; it is zero inside the shell's metal.

Q13. Answer (1). The battery holds V fixed (D true). C becomes KC_0, so $Q = KC_0V$ becomes K times (A true). $E = V/d$ is unchanged (B true): the extra free charge just cancels the bound charge on the slab. $U = \tfrac{1}{2}CV^2$ becomes K times, so it increases (C false).

Q14. Answer (4). The two layers act in series: $C = \varepsilon_0 A/(d/2 + (d/2)/4) = \varepsilon_0 A/(5d/8) = 8C_0/5 = 1.6C_0$.

Q15. Answer (2). Initial charges 200 μC and 150 μC; with opposite plates joined the net charge is 200 − 150 = 50 μC on 5 μF, so V = 10 V. Initial energy $\tfrac{1}{2} \times 2 \times 10^{-6} \times 100^2 + \tfrac{1}{2} \times 3 \times 10^{-6} \times 50^2 = 13.75$ mJ; final $\tfrac{1}{2} \times 5 \times 10^{-6} \times 10^2 = 0.25$ mJ. Loss = 13.5 mJ. (1.5 mJ is the loss if like plates are joined.)

Q16. Answer (3). $u = \tfrac{1}{2}\varepsilon_0 E^2 = \tfrac{1}{2} \times 8.85 \times 10^{-12} \times (3 \times 10^6)^2 = \tfrac{1}{2} \times 8.85 \times 10^{-12} \times 9 \times 10^{12} \approx 40$ J/m³.

Q17. Answer (3). Charge is quantised: q = ne with n an integer. $3.2 \times 10^{-19} = 2e$, $4.8 \times 10^{-19} = 3e$ and $-1.6 \times 10^{-18} = -10e$ are allowed, but 2.4×10^{-19} C = 1.5e is not.

Q18. Answer (4). The electrostatic field is conservative: its line integral round any closed path is zero, so a field line can never close on itself. The other three statements are true (a crossing would mean two directions of E at one point; a field along a conductor's surface would move its charges).

Q19. Answer (1). Isolated, so Q is fixed. Each plate is pulled by the other with the constant force $Q^2/(2\varepsilon_0 A)$, so the work over a further distance d is $Q^2 d/(2\varepsilon_0 A) = U_0$. Check: $U = Q^2/(2C)$ and C halves, so the energy rises from U_0 to $2U_0$.

Q20. Answer (2). Distances from (0, a): $a\sqrt{2}$ to each +q and a to −2q. $V = 2 \times kq/(a\sqrt{2}) - 2kq/a = (\sqrt{2} - 2)kq/a = -(2 - \sqrt{2})kq/a$.

Q21. Answer 7500. Q = 500 μC is shared over 25 μF: V = 20 V. Initial energy $\tfrac{1}{2} \times 10 \times 10^{-6} \times 50^2 = 12\,500$ μJ; final $\tfrac{1}{2} \times 25 \times 10^{-6} \times 20^2 = 5000$ μJ. Heat = 7500 μJ, whatever the resistance.

Q22. Answer 750. Horizontal: $T \sin\theta = qE$; vertical: $T \cos\theta = mg$. So $q = mg \tan\theta/E = 2 \times 10^{-3} \times 10 \times 0.75/(2 \times 10^4) = 7.5 \times 10^{-7}$ C = 750 nC.

Q23. Answer 25. Charge within r: $q(r) = \int \rho_0 (s/R) 4\pi s^2 \, ds = \pi\rho_0 r^4/R$. By Gauss's law $E = q/(4\pi\varepsilon_0 r^2) = \rho_0 r^2/(4\varepsilon_0 R) \propto r^2$. At R/2 it is $(1/2)^2 = 25\%$ of the surface value.

Q24. Answer 100. 2/4 = 3/6, so the bridge is balanced: P and Q are at the same potential and the 5 μF capacitor takes no charge. $C = (2 \times 4)/(2 + 4) + (3 \times 6)/(3 + 6) = 4/3 + 2 = 10/3$ μF, and $Q = (10/3) \times 30 = 100$ μC.

Q25. Answer 19. Energy conservation: $\tfrac{1}{2}mv^2 = kqQ/r = 9 \times 10^9 \times 10^{-6} \times 4 \times 10^{-6}/0.2 = 0.18$ J. $v = \sqrt{(2 \times 0.18/10^{-3})} = \sqrt{360} \approx 18.97$ m/s, i.e. 19.

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: fields and potentials by summing Coulomb's law over the charges, fluxes by integrating the field over each face, motions by step-by-step integration, and capacitor circuits by solving their charge equations.