CLASS XII – PHYSICS (042)
STEP-BY-STEP SOLUTIONS AND MARKING SCHEME

Chapter 1: Electric Charges and Fields – Practice Paper (35 Marks)

Answer key – Section A

Q.	1	2	3	4	5	6	7	8	9
Ans.	(c)	(b)	(d)	(a)	(c)	(b)	(d)	(a)	(d)

Marks are shown in square brackets. Equivalent correct methods are acceptable. Take $k = 1/(4\pi\varepsilon_0) = 9 \times 10^9$ N m^2 C^{-2}.

SECTION A

Q.1 (c)

Field lines must (i) never cross (a unique field direction at every point), (ii) never form closed loops (the electrostatic field is conservative), (iii) be continuous without breaks, and (iv) start on positive and end on negative charges. Sketch (a) shows crossing lines, (b) shows closed loops, (d) shows a broken line. Only (c), lines from + to −, is possible. **[1]**

Q.2 (b)

O is the midpoint of the diagonal AC. The equal charges +q at A and C produce fields of equal magnitude in opposite directions at O, so they cancel. Only the charge at B remains. OB = a/√2, so $E = kq/(a/\sqrt{2})^2 = 2kq/a^2$, directed away from B, i.e. towards the vacant corner D. **[1]**

Q.3 (d)

$F = kq^2/r^2$, so F versus $1/r^2$ is a straight line with slope kq^2. From the marked point, slope = $0.9/100 = 9 \times 10^{-3}$ N m^2. Then $q^2 = (9 \times 10^{-3})/(9 \times 10^9) = 10^{-12}$ C^2, so $q = 10^{-6}$ C = 1 μC. **[1]**

Q.4 (a)

The field is stronger on the right (lines are closer). The force +qE on the positive charge (towards the right) is larger than the force −qE on the negative charge (towards the left). The net force is therefore towards the region of stronger field, i.e. to the right. **[1]**

Q.5 (c)

C touches A: the +8 μC is shared equally, so A = +4 μC and C = +4 μC. C then touches B: +4 μC is shared equally, so B = +2 μC and C = +2 μC. Final charges: A = +4 μC, B = +2 μC. **[1]**

Q.6 (b)

Net flux = 12 − 3 + 6 − 2 + 4 − 7 = +10 N m^2 C^{-1}. By Gauss's law $q = \varepsilon_0\varphi = (8.854 \times 10^{-12})(10) = 8.854 \times 10^{-11}$ C. **[1]**

Q.7 (d)

The magnitude of the field is indicated by the closeness of field lines. Lines are most crowded at P, fewer at Q and sparsest at R. Hence $E_P > E_Q > E_R$. (On the bisector $E = kp/(r^2 + a^2)^{3/2}$, which decreases with distance.) **[1]**

Q.8 (a)

Both statements are true. The charged rod polarises the paper (induces a dipole moment), and because the rod's field is non-uniform the dipole feels a net force towards the rod. R correctly explains A. **[1]**

Q.9 (d)

A is false: zero net flux only means that the net enclosed charge is zero (for example an electric dipole inside the surface); the field on the surface need not be zero. R is true (Gauss's law). **[1]**

SECTION B

Q.10

Force on +1 μC due to +4 μC (repulsion, towards the right): $F_1 = (9 \times 10^9)(4 \times 10^{-6})(1 \times 10^{-6})/(0.1)^2 = 3.6$ N. **[½]**

Force on +1 μC due to −4 μC (attraction, also towards the right): $F_2 = 3.6$ N. **[½]**
Both forces act in the same direction, so F = 3.6 + 3.6 = 7.2 N, directed towards the −4 μC charge (to the right). **[1]**

Q.11

For suspension, the electric force balances the weight: $|q|E = mg$, so $|q| = mg/E = (4.8 \times 10^{-15})(10)/(3 \times 10^{4}) = 1.6 \times 10^{-18}$ C. The electric force must act upward while the field points downward, so the charge is negative. **[1]**
Number of excess electrons $n = q/e = (1.6 \times 10^{-18})/(1.6 \times 10^{-19}) = 10$ excess electrons. **[1]**

Q.12 (A)

$p = q \times 2a = (3 \times 10^{-6})(4 \times 10^{-3}) = 1.2 \times 10^{-8}$ C m. **[1]**
Maximum torque at θ = 90°: $\tau_{max} = pE = (1.2 \times 10^{-8})(5 \times 10^{3}) = 6 \times 10^{-5}$ N m. **[1]**

Q.12 (B)

Consider the closed surface formed by the curved surface and the flat circular rim (area πR^2). The bowl encloses no charge, so the net flux is zero: $\varphi_{curved} + \varphi_{flat} = 0$. **[1]**
The field lines are perpendicular to the flat face, so $|\varphi_{flat}| = E \times \pi R^2$. Hence the magnitude of the flux through the curved surface is $\pi R^2 E$. **[1]**

Q.13

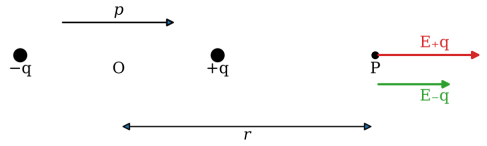
(i) Field lines start on positive and end on negative charges: q_1 is positive and q_2 is negative. The number of lines is proportional to the magnitude of charge: 12 lines leave q_1 and 4 end on q_2. So $|q_1| : |q_2| = 12 : 4 = 3 : 1$. **[1]**
(ii) 8 lines escape to infinity, i.e. more lines leave the system than enter it (net outward). The net charge is therefore positive ($+q_1$ outweighs $-q_2$). **[1]**

SECTION C

Q.14

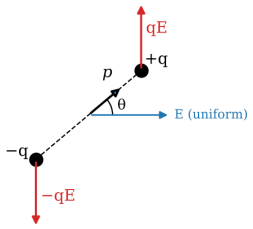
Distance of P from each charge = $\sqrt{(3^2 + 4^2)} = 5$ cm. $E_A = E_B = kq/r^2 = (9 \times 10^{9})(5 \times 10^{-6})/(0.05)^2 = 1.8 \times 10^{7}$ N C^{-1}. **[1]**
E_A points away from A and E_B points towards B. Each makes an angle θ with line AB where cos θ = 3/5 and sin θ = 4/5. The components perpendicular to AB (E sin θ each) are equal and opposite, so they cancel. **[1]**
The components parallel to AB add: $E = 2E \cos\theta = 2(1.8 \times 10^{7})(3/5) = 2.16 \times 10^{7}$ N C^{-1}, directed parallel to AB, from the positive charge A towards the negative charge B. **[1]**

Q.15 (A)



Let −q be at A and +q at B (separation 2a), O the centre and P on the axis at distance r from O on the side of +q. **[½]**
$E_{+q} = q/[4\pi\varepsilon_0(r - a)^2]$ along **p**; $E_{-q} = q/[4\pi\varepsilon_0(r + a)^2]$ opposite to **p**. **[½]**
$E = [q/(4\pi\varepsilon_0)][1/(r - a)^2 - 1/(r + a)^2]\ \hat{\mathbf{p}} = [q/(4\pi\varepsilon_0)] \cdot 4ar/(r^2 - a^2)^2\ \hat{\mathbf{p}}$. For r >> a: $E_{axial} = 2p/(4\pi\varepsilon_0 r^3)$ along **p**. **[1]**
On the equatorial plane, for r >> a: $E_{eq} = p/(4\pi\varepsilon_0 r^3)$ opposite to **p**. Hence $E_{axial} = 2E_{eq}$ at the same distance. **[1]**

Q.15 (B)



Let the dipole (charges ±q, separation 2a) make angle θ with a uniform field E. The force on +q is qE along E and on −q is qE opposite to E. The net force is zero but the two forces form a couple. **[1]**

Torque = force × perpendicular distance = qE × 2a sin θ = pE sin θ; in vector form $\boldsymbol{\tau} = \mathbf{p} \times \mathbf{E}$. **[1]**

In a non-uniform field with **p** parallel to **E**, the force on +q is greater than that on −q (field is stronger on the +q side), so the net force acts towards the region of stronger field. **[1]**

Q.16

For one infinite sheet, $E = \sigma/2\varepsilon_0$. $E_A = (17.7 \times 10^{-9})/(2 \times 8.854 \times 10^{-12}) \approx 1.0 \times 10^3$ N C^{-1} (directed away from A). $E_B = (35.4 \times 10^{-9})/(2 \times 8.854 \times 10^{-12}) \approx 2.0 \times 10^3$ N C^{-1} (directed towards B). **[1]**

Region I (left of A): E_A points left (1.0×10^3), E_B points right (2.0×10^3). Net = 1.0×10^3 N C^{-1}, towards the right (towards the sheets). Region III (right of B): E_A points right (1.0×10^3), E_B points left (2.0×10^3). Net = 1.0×10^3 N C^{-1}, towards the left. **[1]**

Region II (between A and B): both fields point right: net = $(1.0 + 2.0) \times 10^3 = 3.0 \times 10^3$ N C^{-1}, from A towards B. **[1]**

SECTION D

Q.17 (Case study)

(i) **(a)** Charge flows on to the leaves from the charged body, so both leaves acquire charge of the same sign and repel each other. **[1]**

(ii) **(b)** The greater the charge on the leaves, the greater the repulsion and the greater the divergence; divergence indicates the amount of charge. **[1]**

(iii) **(b)** Positive charge means a deficit of electrons. $n = q/e = (4.8 \times 10^{-9})/(1.6 \times 10^{-19}) = 3 \times 10^{10}$ electrons lost. **[1]**

(iv) **(b)** The metal rod and the human body are both conductors, so the charge produced by rubbing leaks through the body to the ground. **[1]**

OR (iv) (b) The wire is a conductor: the charge on the electroscope flows through it to the earth, discharging the leaves. Charge is never destroyed, only transferred. **[1]**

SECTION E

Q.18 (A)

Gauss's law: the net electric flux through any closed surface equals $1/\varepsilon_0$ times the total charge enclosed by it. **[½]**

By symmetry E is perpendicular to the sheet and has the same magnitude on both sides, so E is parallel to the area vectors of faces 1 and 2 and perpendicular to the side walls of the pillbox. Flux through the side walls = 0; flux through each face = EA. Total flux = 2EA. **[1]**

Charge enclosed = σA. Gauss's law: $2EA = \sigma A/\varepsilon_0 \Rightarrow E = \sigma/2\varepsilon_0$, directed away from the sheet if σ > 0 (towards it if σ < 0) and independent of the distance. **[1½]**

Numerical: $E = \sigma/2\varepsilon_0 = (17.7 \times 10^{-9})/(2 \times 8.854 \times 10^{-12}) \approx 1.0 \times 10^3$ N C^{-1}. **[1]**

Acceleration of the electron: $a = eE/m_e = (1.6 \times 10^{-19})(10^3)/(9.1 \times 10^{-31}) \approx 1.8 \times 10^{14}$ m s^{-2}. The sheet is positive and the electron is negative, so the acceleration is directed towards the sheet. **[1]**

Q.18 (B)

Gauss's law as stated above. **[½]**

(i) **Outside (r > R):** take a concentric spherical Gaussian surface of radius r. By symmetry E is radial and constant on it, so flux = $E \times 4\pi r^2$. The charge enclosed is the total charge $q = 4\pi R^2\sigma$. Hence $E \times 4\pi r^2 = q/\varepsilon_0 \Rightarrow E = q/(4\pi\varepsilon_0 r^2)\,\hat{\mathbf{r}}$: as if all the charge were at the centre. **[1]**

(ii) **Inside (r < R):** a concentric Gaussian sphere of radius $r < R$ encloses no charge, so $E \times 4\pi r^2 = 0 \Rightarrow E = 0$. **[1½]**

Numerical: P is 3 cm from O, inside the shell, so $E_P = 0$. **[½]**

Q is 15 cm from O, outside the shell: $E_Q = kq/r^2 = (9 \times 10^9)(6 \times 10^{-6})/(0.15)^2 = 2.4 \times 10^6$ N C^{-1}. The shell is negatively charged, so the field is directed radially inward (towards O). **[1½]**

— End of Solutions —