NCERT PROBLEMS

Physics Class 12

Ch. 1 ELECTRIC CHARGES AND FIELDS

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ADDITIONAL EXERCISES

1.25 An oil drop of 12 excess electrons is held stationary under a constant electric field of $2.55 \times 10^4\ NC^{-1}$ (Millikan's oil drop experiment). The
density of the oil is $1.26\ g\ cm^{-3}$. Estimate the radius of the drop.
($g = 9.81\ ms^{-2}$; $e = 1.60 \times 10^{-19}$ C).

Ans. Given $|q|$ = Charge on 12 electrons = $12 \times 1.60 \times 10^{-19}$ C.

$E = 2.55 \times 10\ NC^{-1}$; $\sigma = 1.26\ g\ cm^{-3}$; $g = 9.81 ms^{-2}$, $r = ?$

For the drop to be stationary; the weight of the drop must be balanced by an equal upwards electric force i.e., $F_{grav} = mg = qE$

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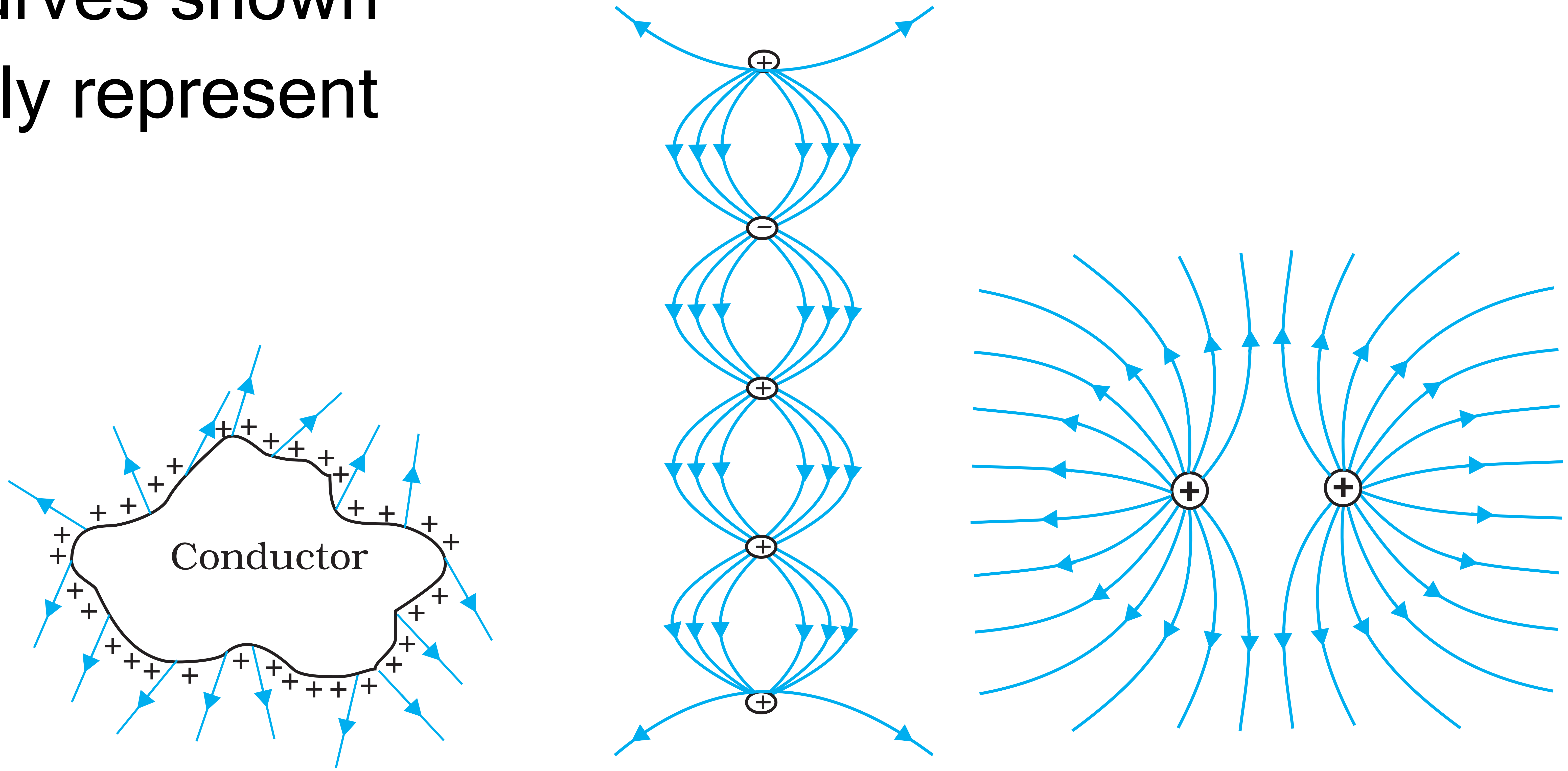
or $\frac{4}{3}\pi r^3 \rho g = qE.$

We get,

$$r = \left[\frac{3qE}{4\pi r\rho g}\right]^{1/3} = \left[\frac{3\times 12\times 1.60\times 10^{-19}\times 2.55\times 10^{4}}{4\times 3.14\times 1.26\times 10^{3}\times 9.81}\right]^{1/3}$$

$= 9.81 \times 10^{-7}$ m.

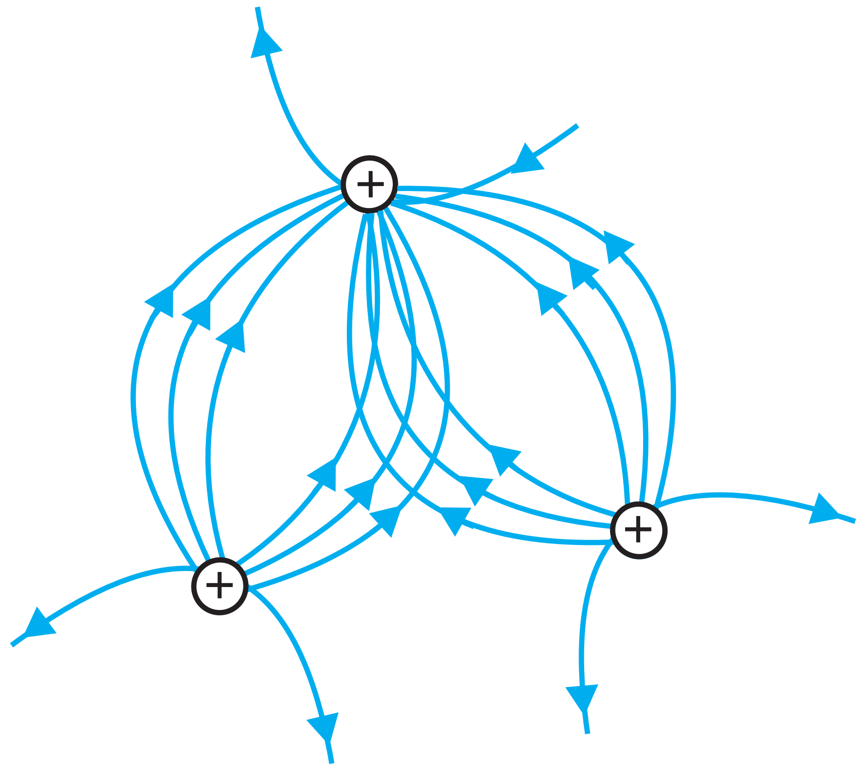
1.26 Which among the curves shown in Fig. 1.35 cannot possibly represent electrostatic field lines?



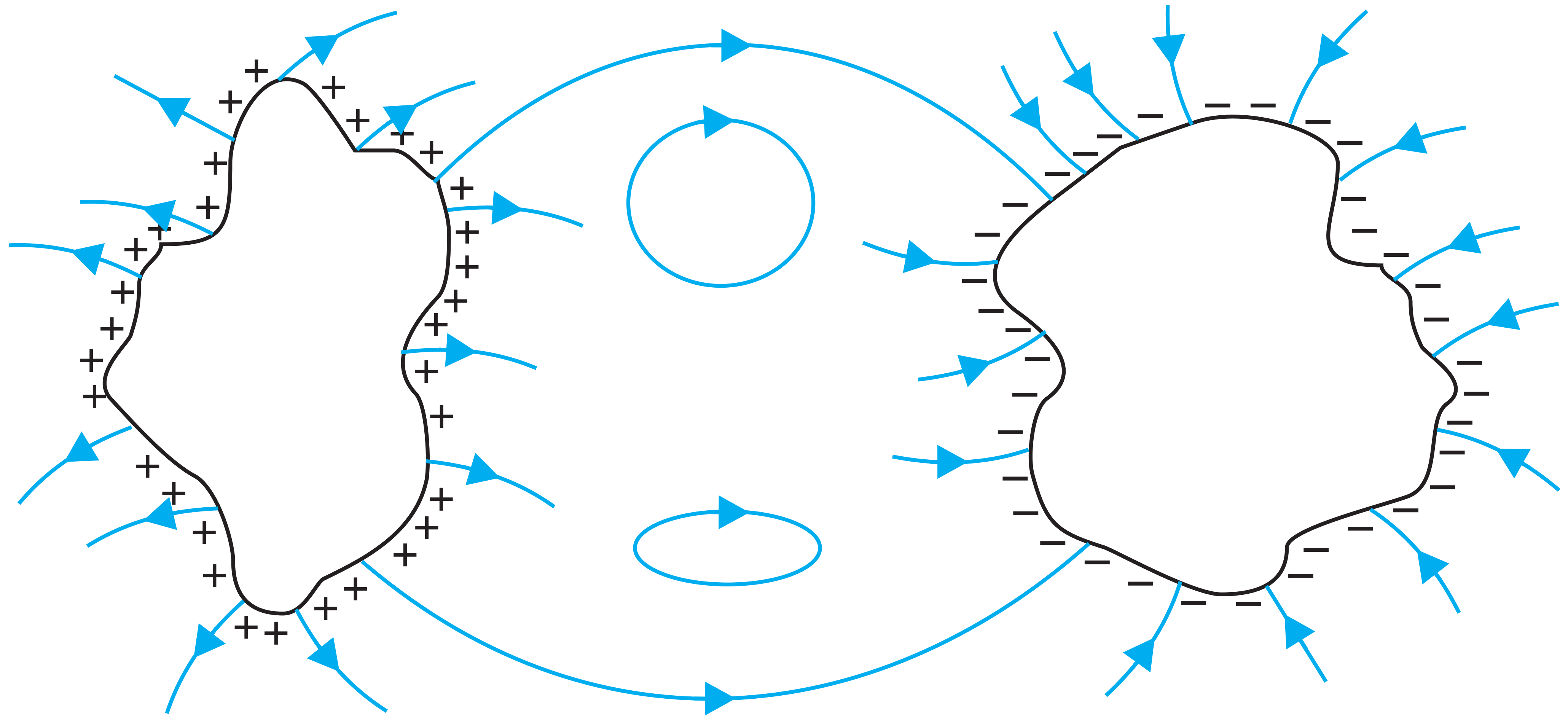
(a) (b) (c)

Ans. (i). Fig (a) No. As electrostatic field lines start normally from the surface.
(ii). Fig. (b) No. As the field lines do not terminate on positive charge.
(iii). Fig. (c) Yes. The pattern, further implies that the two charges are equal.

1.26 Which among the curves shown in Fig. 1.35 cannot possibly represent
electrostatic field lines?



(d)



(e)

(iv). Fig.(d) No. As the electrostatic field lines never intersect.

(v). Fig (e) No. As $\overrightarrow{E} \perp$ surface & the e.s. field lines never form closed loops.

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1.27 In a certain region of space, electric field is along the z-direction throughout. The magnitude of electric field is, however, not constant but increases uniformly along the positive z-direction, at the rate of 10^5 NC^{-1} per metre. What are the force and torque experienced by a system having a total dipole moment equal to 10^{-7} Cm in the negative z-direction ?

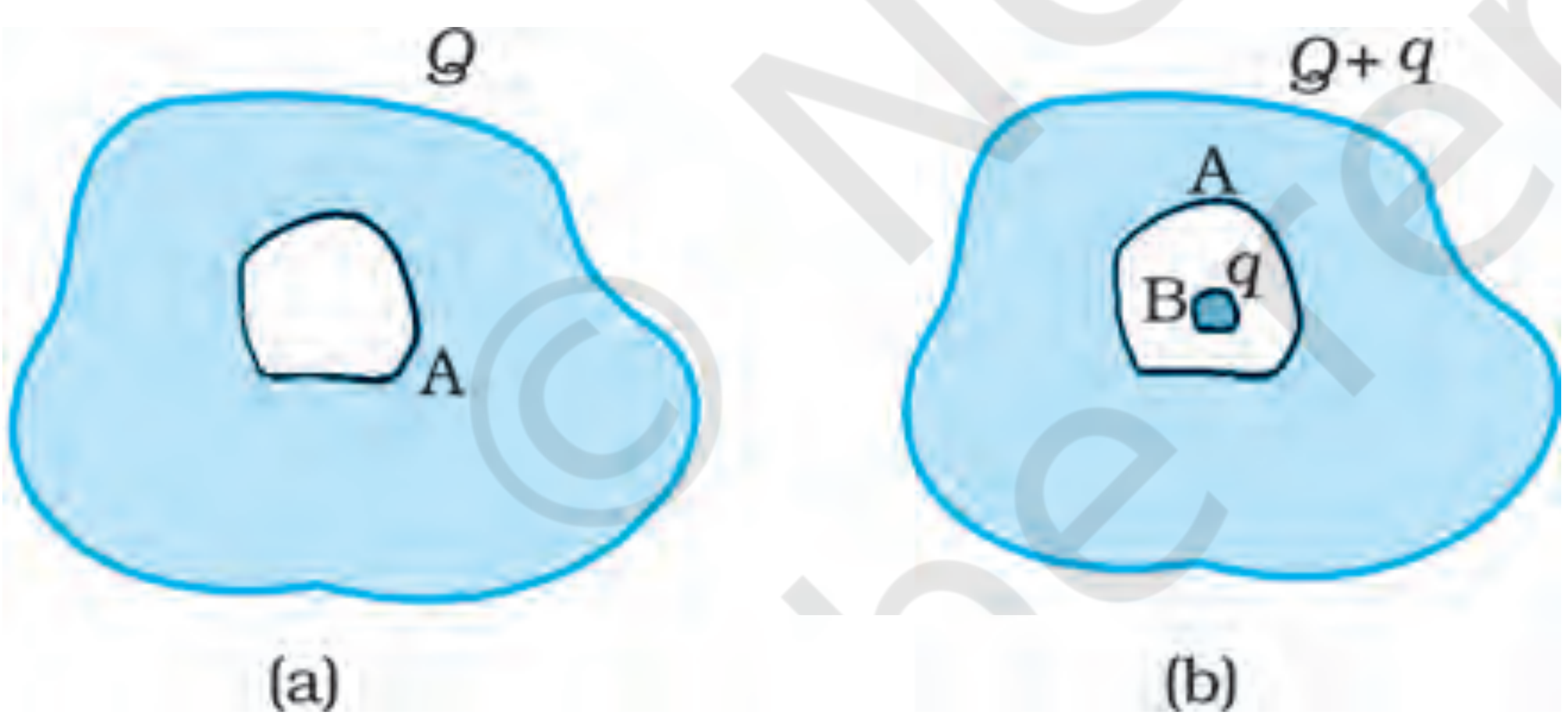
Ans. We have, $\overrightarrow{p} = -10^{-7}\hat{k}\ C.m$ and $\dfrac{\overrightarrow{dE}}{dz} = 10^5\ \hat{k}NC^{-1}m^{-1}$.

As the electric field is non-uniform, the dipole experiences a net force.

$$\overrightarrow{F} = p.\frac{dE}{dz} = (-10^{-7}).(10^{5}) = 10^{-2}\hat{k}\ N.$$

Torque $\vec{\tau} = [\overrightarrow{p} \times \overrightarrow{E}] = zero$ as $\theta = 180^0$.

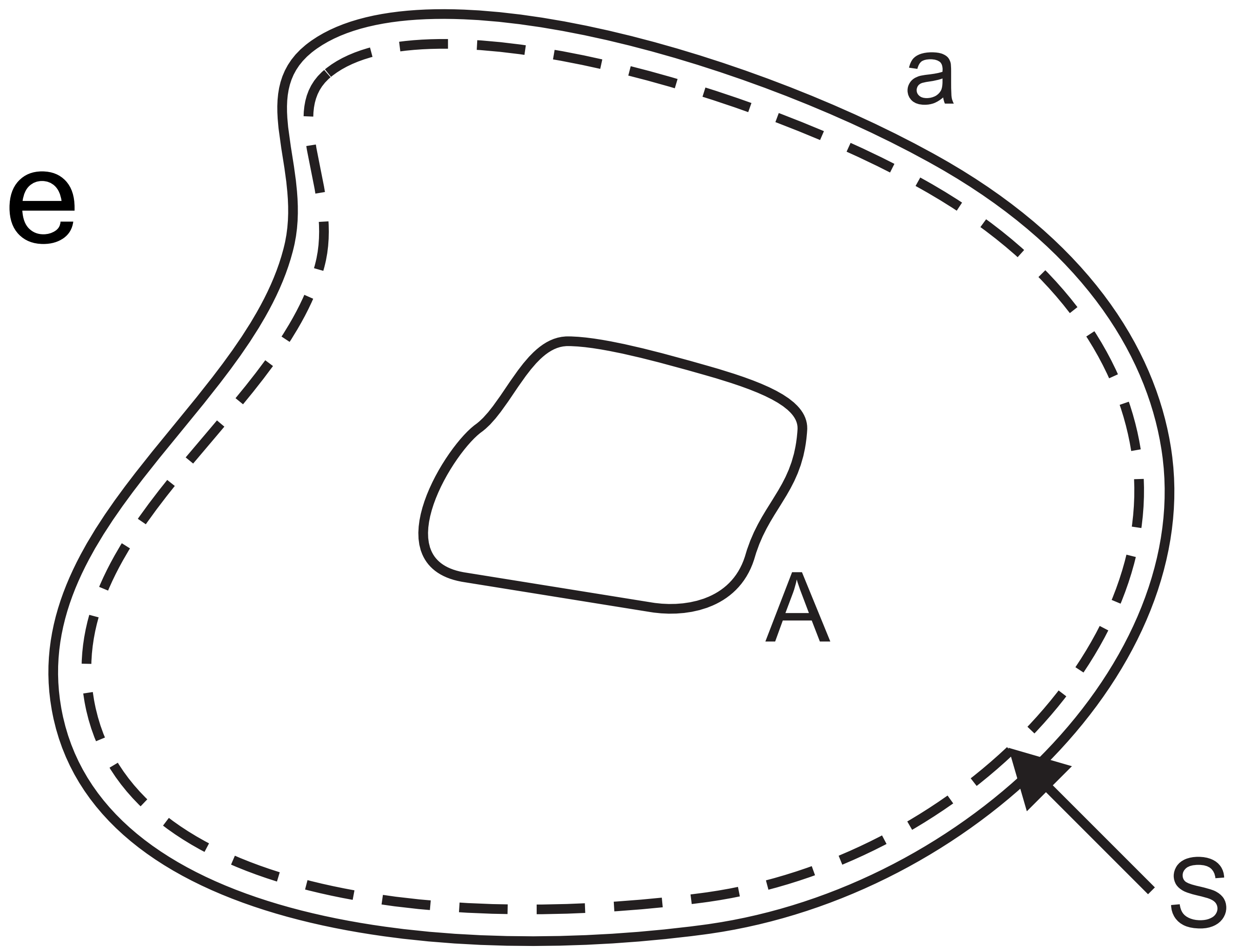
1.28 (a) A conductor A with a cavity as shown in Fig. 1.36(a) is given a charge Q. Show that the entire charge must appear on the outer surface of the conductor. (b) Another conductor B with charge q is inserted into the cavity keeping B insulated from A. Show that the total charge on the outside surface of A is Q + q [Fig. 1.36(b)]. (c) A sensitive instrument is to be shielded from the strong electrostatic fields in its environment. Suggest a possible way.



1.28 (a) A conductor A with a cavity as shown in Fig. is given a charge Q. Show that the entire charge must appear on the outer surface of the conductor.

(b) Another conductor B with charge q is inserted into the cavity keeping B insulated from A. Show that the total charge on the outside surface of A is Q + q .

(c) A sensitive instrument is to be shielded from the strong electrostatic fields in its environment. Suggest a possible way.



Ans. (a) Consider a gaussian surface S just inside the conductor as shown.

We have, $\phi_E = [\frac{\sum q}{\epsilon_0}] = \int_S \overrightarrow{E} \, . \, \overrightarrow{dS}$

= 0. [As E is zero inside a conductor.]

Hence Σq = 0 which implies that the entire charge must be on the outer surface of the conductor.

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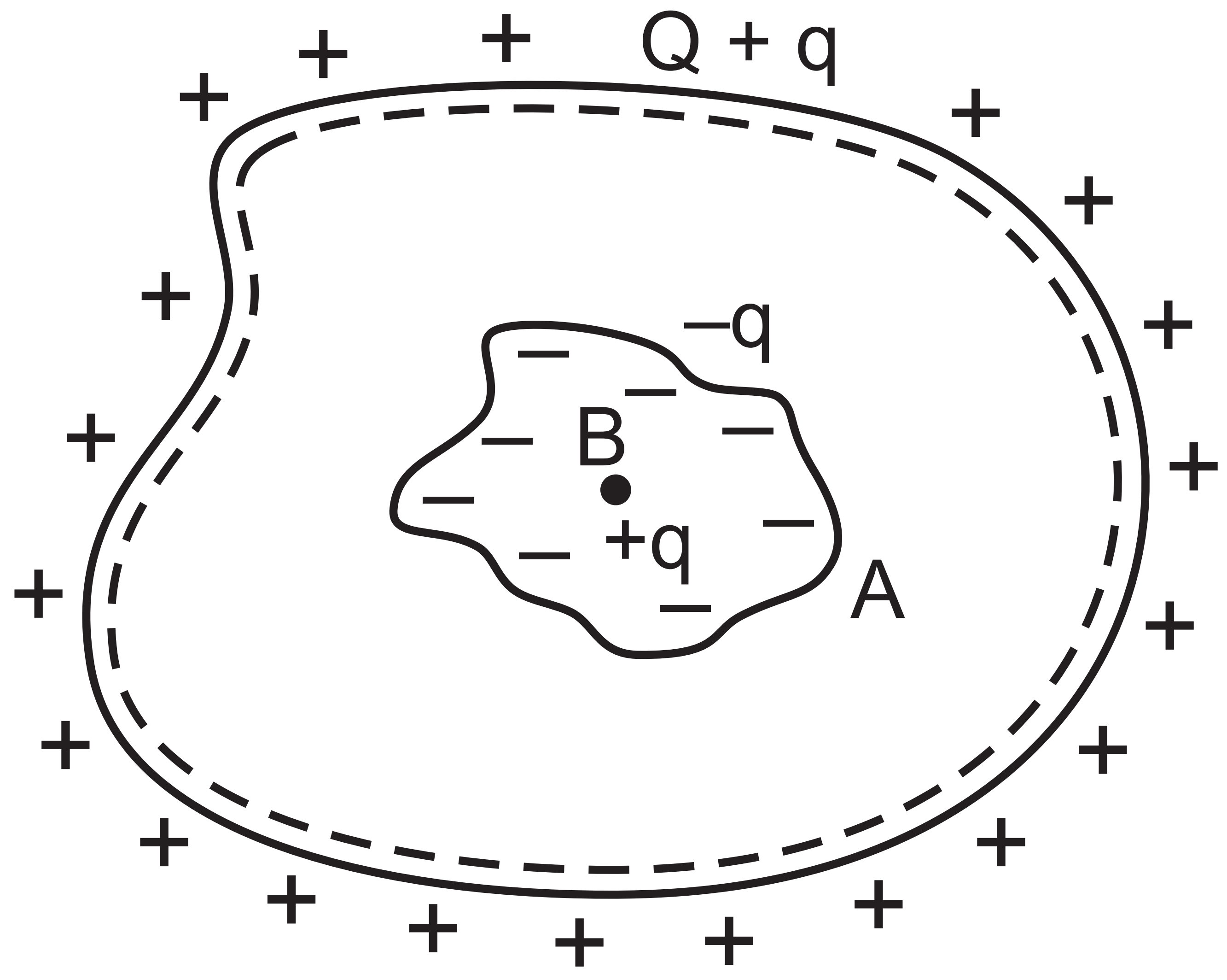
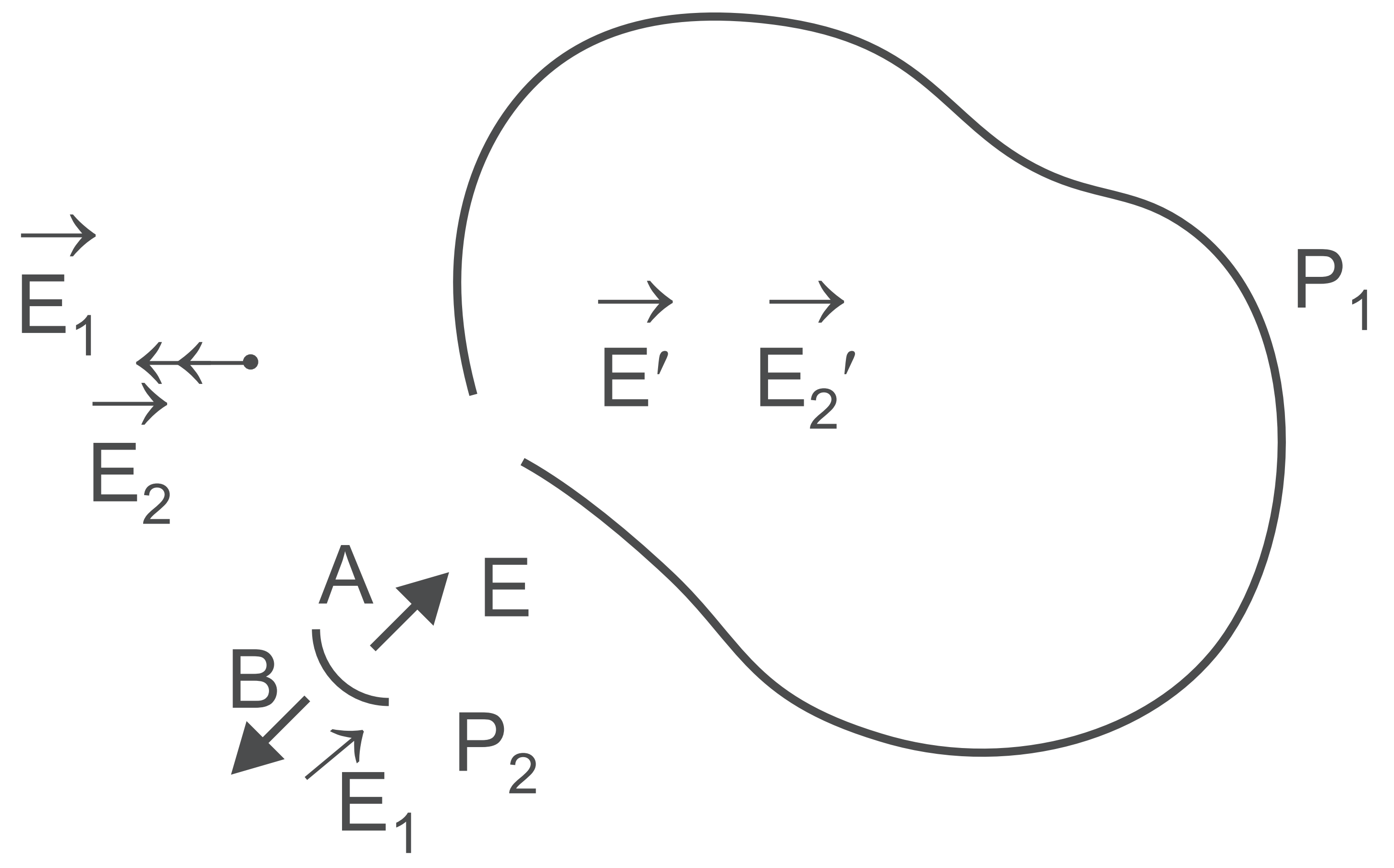
Ans. (b) A charge + q on B induces a charge –q on the inner surface of A and +q on its outer surface.



(c) Place the instrument in a hollow conductor as electric field intensity inside a hollow conductor is zero.

1.29 A hollow charged conductor has a tiny hole cut into its surface. Show that electric field in the hole is $(\sigma/2\varepsilon_0)\,\hat{n}$, where $\hat{n}$ is the unit vector in outward normal direction, and σ is surface charge density near the hole.

Ans. For convenience, let the two parts P_1 and P_2 of the conductor be shown separately.



P_2: The portion cut out of the hole

H : The hole

Net electric field intensity at A,

$$= \left| \vec{E}_1(\text{due to } P_1) + \vec{E}_2(\text{due to } P_2) \right|$$

$= E_1 - E_2 = 0$. [As E is zero inside a conductor.]

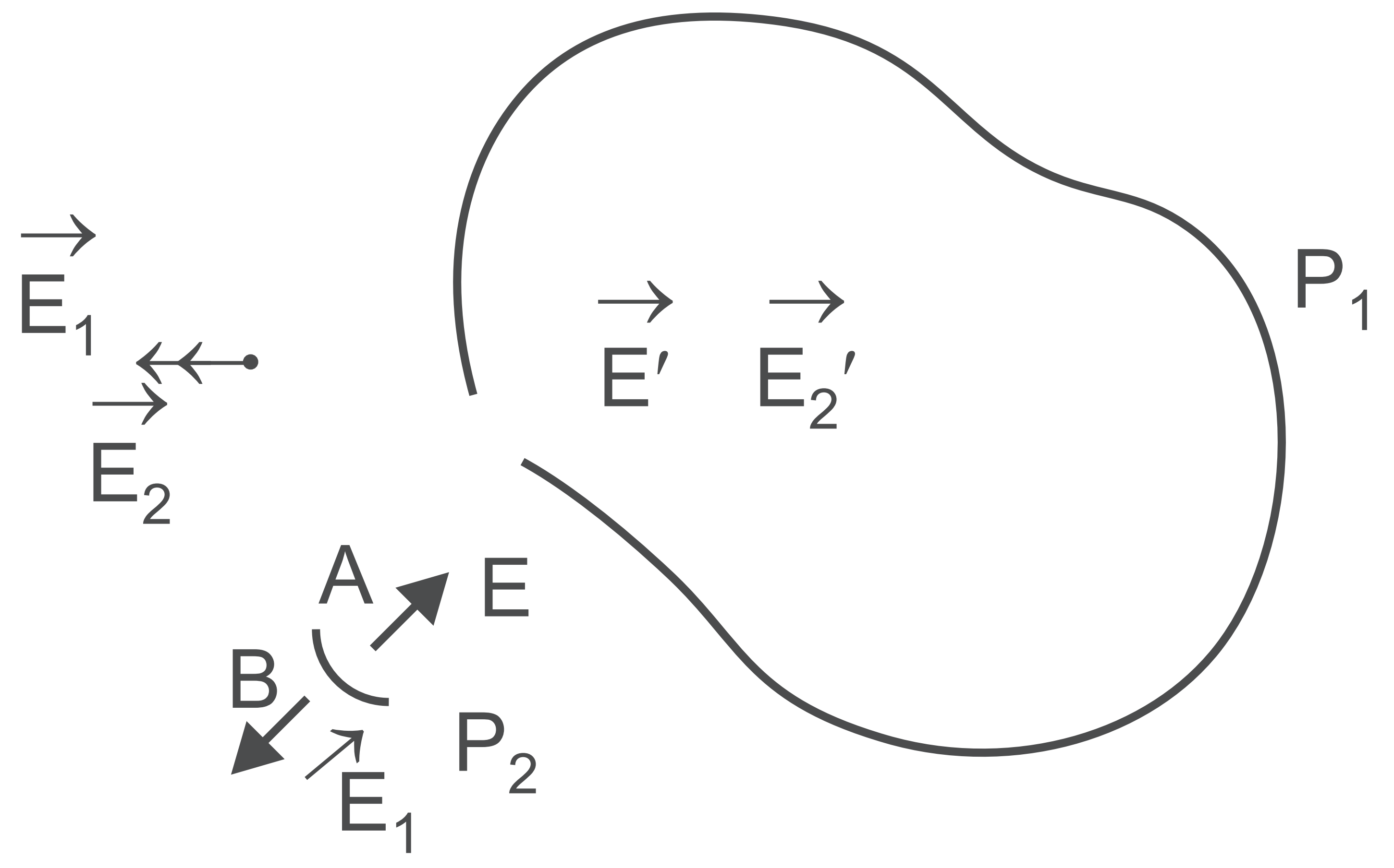
$$\Rightarrow \quad \left|\vec{E}_1\right| = \left|\vec{E}_2\right|.$$

1.29 A hollow charged conductor has a tiny hole cut into its surface. Show that the electric field in the hole is (σ/2ε0) nˆ , where nˆ is the unit vector in the outward normal direction, and σ is the surface charge density near the hole.

$$\text{At } B \left|\vec{E}\right| = \left|\vec{E'}_1 + \vec{E'}_2\right| = E_1 + E_2 = 2E_1 = \frac{\sigma}{\epsilon_0}$$

$$\Rightarrow \quad \vec{E}_1 = \frac{\sigma}{2\epsilon_0}\hat{n}$$

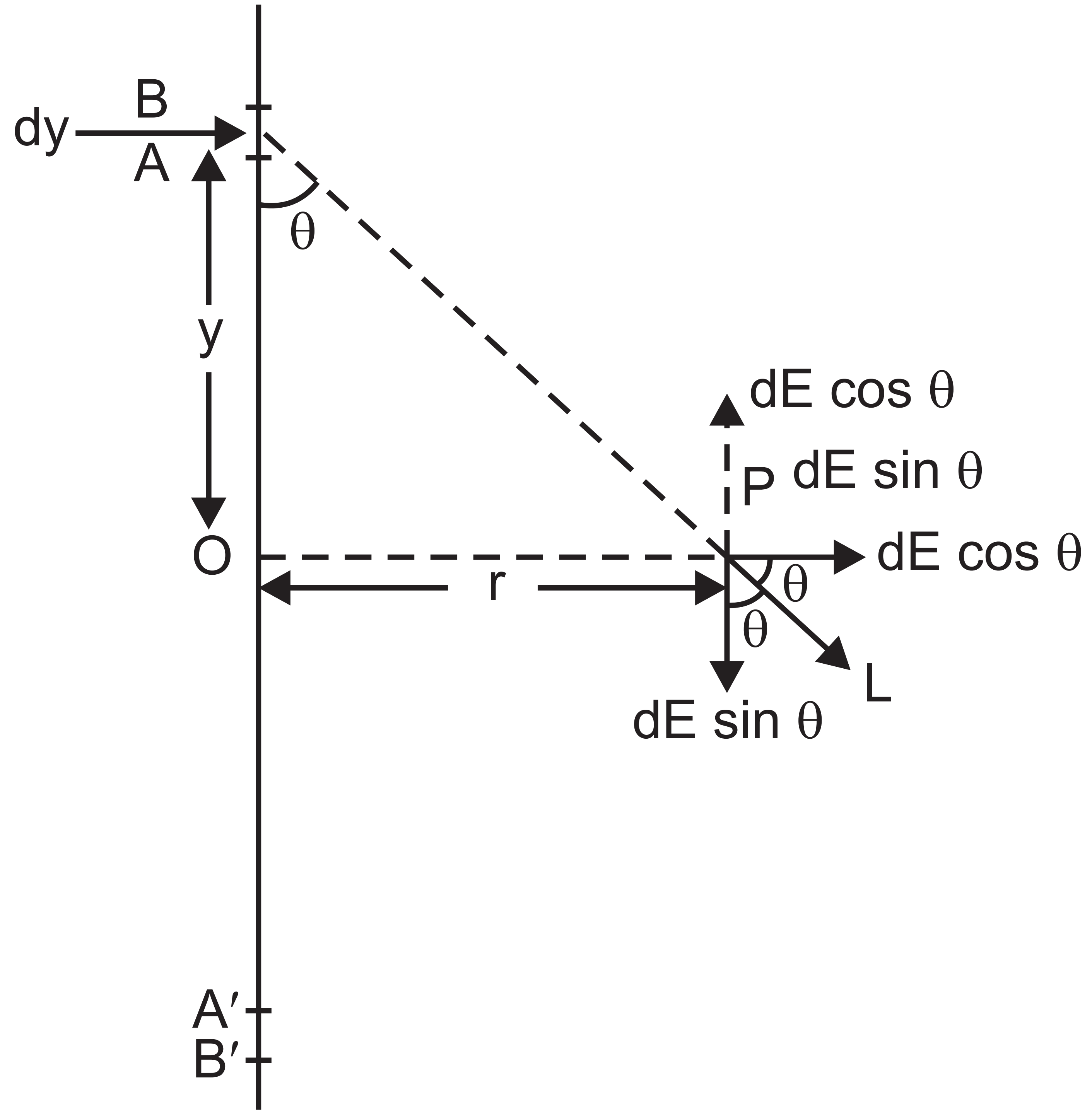
where $\hat{n}$ is a unit vector normal to the surface of the conductor directed outwards.



P_2: The portion cut out of the hole

H : The hole

1.30 Obtain the formula for the electric field due to a long thin wire of uniform linear charge density E without using Gauss's law. [Hint: Use Coulomb's law directly and evaluate the necessary integral.]



Ans. Let P be a point at a distance r from a long st. thin wire of length 'l' with uniform linear charge density λ.

Electric fled intensity at P due to AB

$$= \vec{dE} = \frac{1}{4\pi\epsilon_0} \frac{dq}{(r^2 + y^2)} \text{ along } \vec{PL}$$

where dq = λ dy is charge on AB.

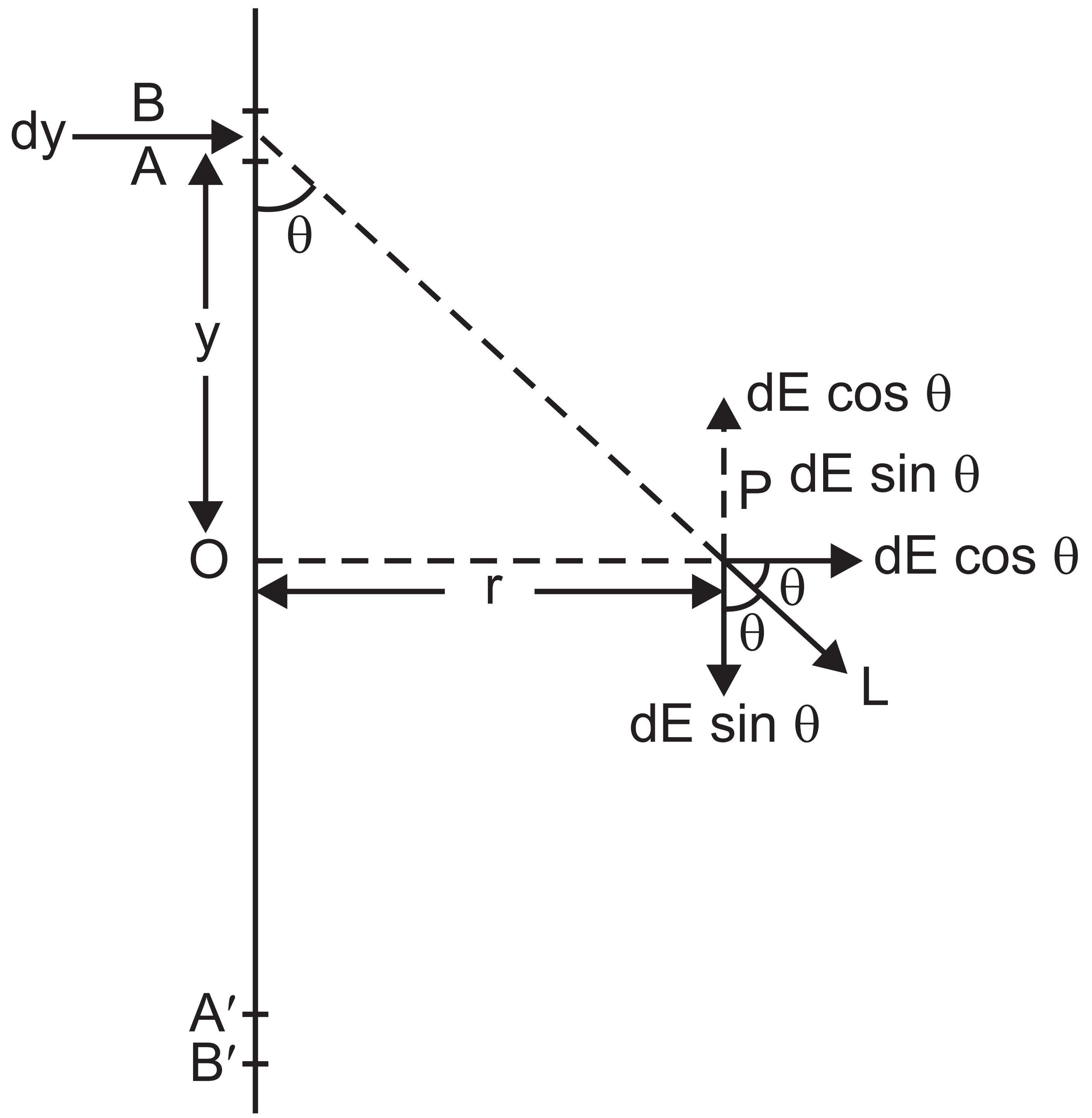
Resolving $\overrightarrow{dE}$; the components are dE sin $\theta \perp$ wire;

dE cos $\theta \downarrow$ along the wire.

Taking another identical part A′B′ of the wire symmetrically below O and resolving its field at P; the component

dE cos θ cancel out being equal and opposite where

components dE sin θ add up.



$$\therefore \qquad E = \int dE \sin\theta = \frac{\lambda}{4\pi\epsilon_0} \int \frac{dy \sin\theta}{r^2 + y^2}$$

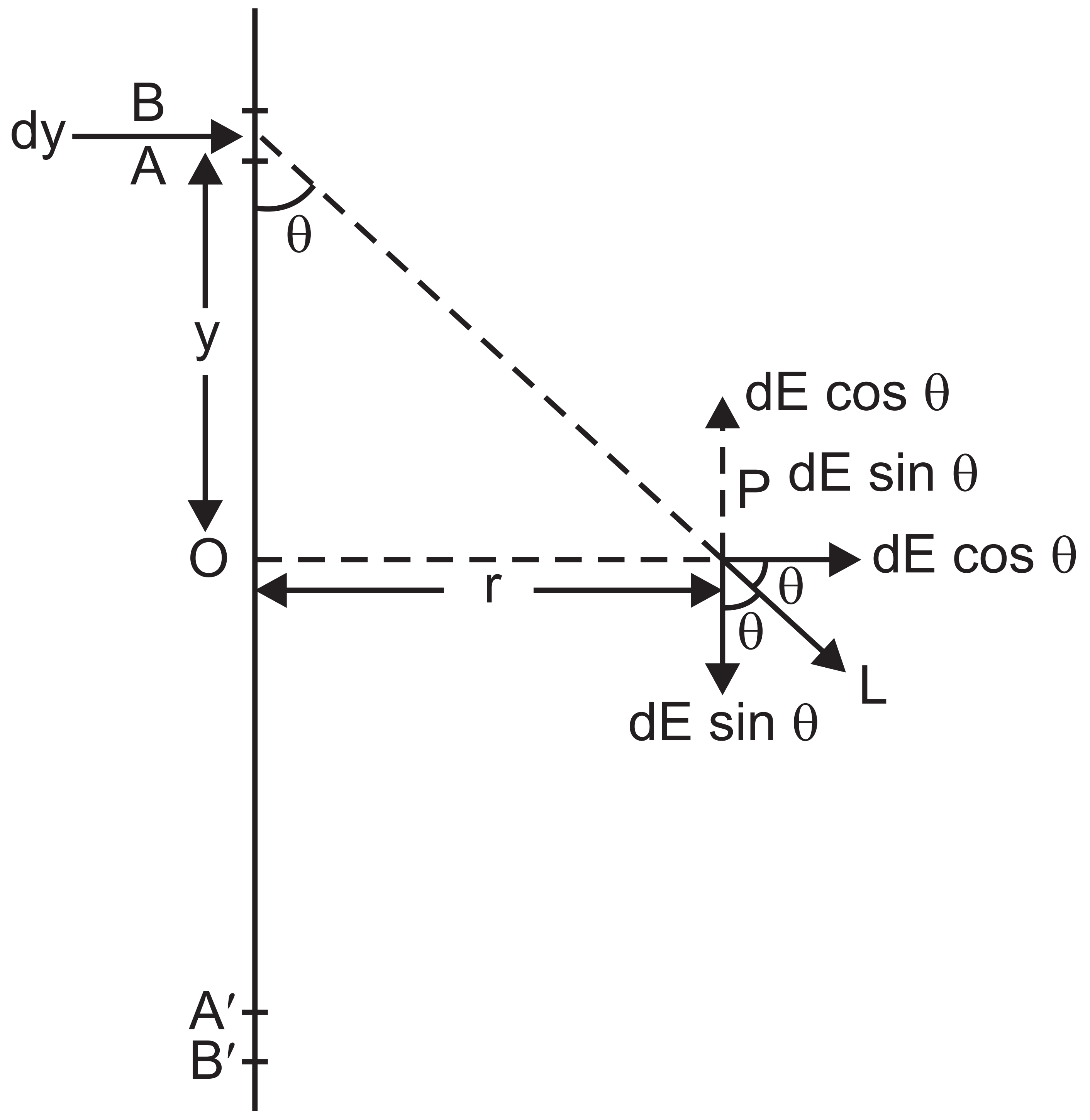
We have $\quad y = r \cot\theta \Rightarrow dy = -\, r \operatorname{cosec}^2\theta \, d\theta.$

$$\therefore \qquad E = \frac{\lambda}{4\pi \in_0} \int_{\theta=\pi}^{\theta=0} \frac{(-r\,\text{cosec}^2\,\theta\, d\,\theta)\sin\theta}{(r^2 + r^2\cot^2\theta)}$$

$$= \frac{\lambda}{4\pi\in_0} \int_{\pi}^{0} -\frac{1}{r}\sin\theta\, d\,\theta = \frac{\lambda}{4\pi\in_0 r} \left| \cos\theta \right|_{\pi}^{0}$$

$$= \frac{\lambda}{4\pi\in_0 r} [\cos 0 - \cos\pi]$$

$$= \frac{\lambda}{4\pi\in_0 r} [1 - (-1)] = \frac{\lambda}{2\pi\in_0 r}.$$



1.31 It is now established that protons and neutrons (which constitute nuclei of ordinary matter) are themselves built out of more elementary units called quarks. A proton and a neutron consist of three quarks each. Two types of quarks, the so called 'up' quark (denoted by u) of charge + (2/3) e, and the 'down' quark (denoted by d) of charge (–1/3) e, together with electrons build up ordinary matter. (Quarks of other types have also been found which give rise to different unusual varieties of matter.) Suggest a possible quark composition of a proton and neutron.

Ans. Proton may consist of two up quarks and one down quark.

Charge on proton = 2 u + 1 d = $2(\frac{2}{3}e) - \frac{1}{3}e = +e$ (Proton charge).

Charge on neutron = 1 u + 2 d = $+\frac{2}{3}e + 2(-\frac{1}{3}e) = 0.$

1.32 (a) Consider an arbitrary electrostatic field configuration. A small test charge is placed at a null point (i.e., where E = 0) of the configuration. Show that the equilibrium of the test charge is necessarily unstable.
(b) Verify this result for the simple configuration of two charges of the same magnitude and sign placed a certain distance apart.

Ans. (a) Let P be the null point. Then $\overrightarrow{E_P} = 0.$

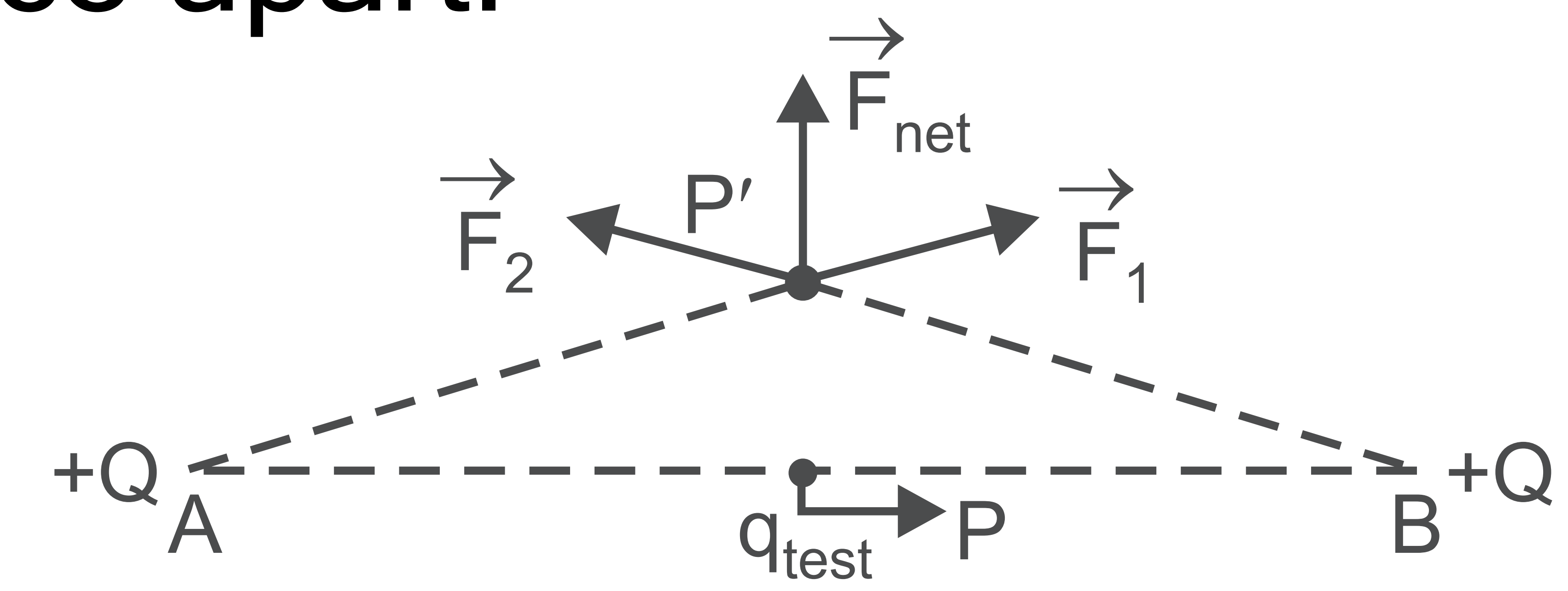
Suppose test charge q at P is stable. Displace the charge q to P′.

Net force an q should be along P′P for stable equilibrium.

So there should be a net field along P′P and have a net inward flay for a gaussian surface around P. But by Gauss theorem, the net flux through a surface around P must be zero. Hence our consideration is wrong.

Charge at P must be in unstable equilibrium.

1.32 (a) Consider an arbitrary electrostatic field configuration. A small test charge is placed at a null point (i.e., where E = 0) of the configuration. Show that the equilibrium of the test charge is necessarily unstable.
(b) Verify this result for the simple configuration of two charges of the same magnitude and sign placed a certain distance apart.

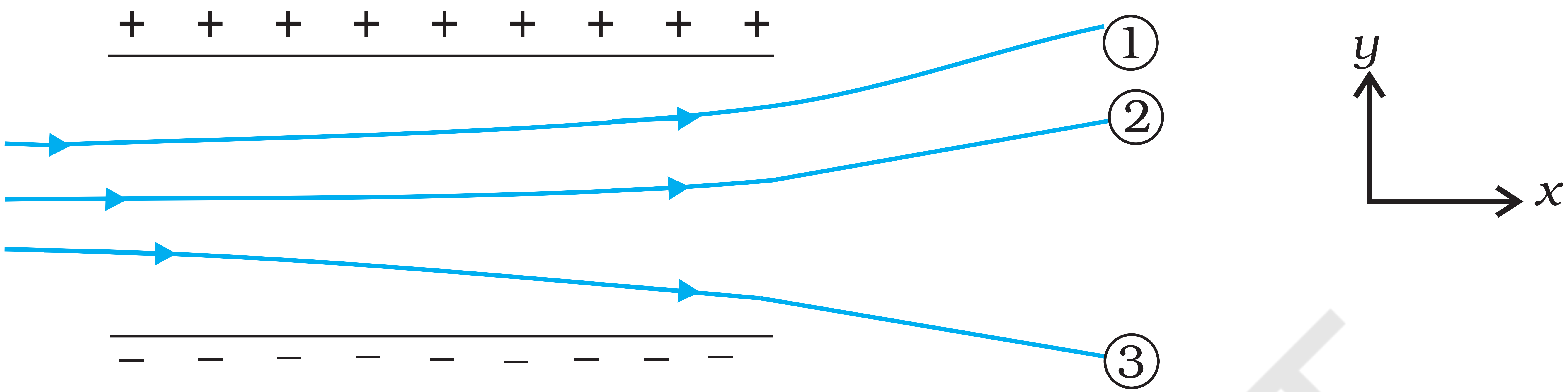


Ans. (b) Consider the arrangement shown in the figure with test charge at P in equilibrium.

If the charge is displaced to P’ with PP’ ⊥ AB; the test charge experiences a net force F_{net} away from P.

So the charge will not return to P indicating unstable equilibrium.

1.33 A particle of mass m and charge (-q) enters the region between the two charged plates initially moving along x-axis with speed v_x (like particle 1 in the Fig. below). The length of each plate is L and an uniform electric field E is maintained between the plates. Show that the vertical deflection of the particle at the far edge of the plate is $qEL^2/(2m\ v_x^2)$.



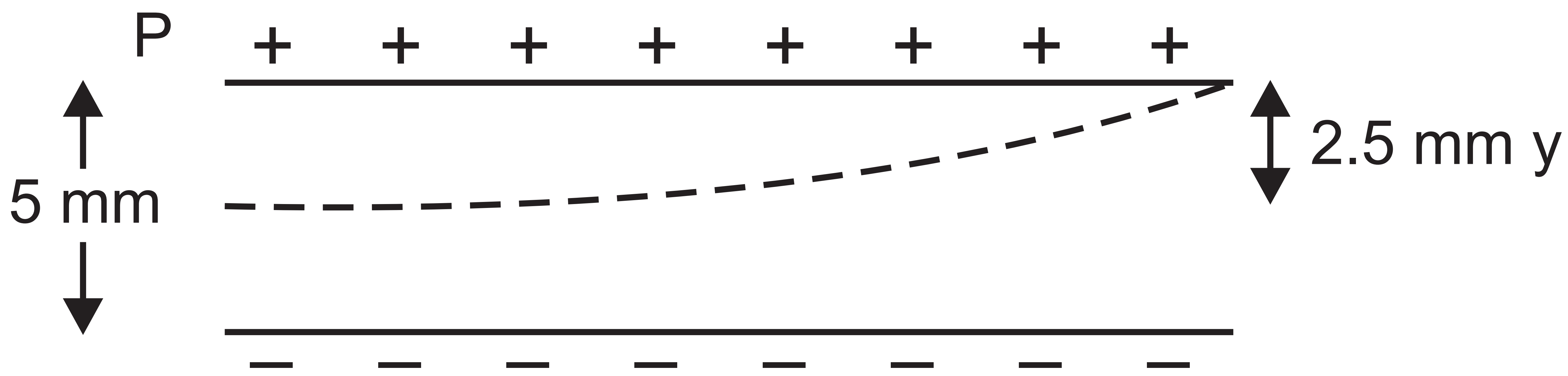
Ans. Solve as Q. 1.14 in NCERT Exercises.

1.34 Suppose that the particle in Exercise in 1.33 is an electron projected with velocity $v_x = 2.0 \times 10^6$ m s^{-1} . If E between the plates separated by 0.5 cm is 9.1×10^2 N/C, where will the electron strike the upper plate? ($|e| = 1.6 \times 10^{-19}$ C, $m = 9.1 \times 10^{-31}$ kg.)

Ans. From the diagram; the particle strikes plate P when y = 2.5mm = 2.5×10^{-3} m.

$$\therefore \quad y = \frac{qEL^2}{2mv_x^2} \Rightarrow L = v_x\sqrt{\frac{2my}{qE}}$$

$$= 2 \times 10^6 \sqrt{\frac{2 \times 9.1 \times 10^{-31} \times 2.5 \times 10^{-3}}{1.6 \times 10^{-19} \times 9.1 \times 10^{2}}}$$



= 1.1 cm.

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