Physics by fiziks

Learn Physics in Right Way

1. ELECTRIC CHARGES AND FIELDS

PGT Physics-Practice Set

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Summary

1. Electric and magnetic forces determine the properties of atoms, molecules and bulk matter.

2. From simple experiments on frictional electricity, one can infer that there are two types of charges in nature; and that like charges repel and unlike charges attract. By convention, the charge on a glass rod rubbed with silk is positive; that on a plastic rod rubbed with fur is then negative.

3. Conductors allow movement of electric charge through them, insulators do not. In metals, the mobile charges are electrons; in electrolytes both positive and negative ions are mobile.

4. Electric charge has three basic properties: quantization, additivity and conservation.

Quantization of electric charge means that total charge (q) of a body is always an integral multiple of a basic quantum of charge (e) i.e., $q = ne$, where $n = 0, \pm1, \pm2, \pm3, ...$ Proton and electron have charges $+e, -e$, respectively. For macroscopic charges for which n is a very large number, quantization of charge can be ignored.

Additivity of electric charges means that the total charge of a system is the algebraic sum (i.e., the sum taking into account proper signs) of all individual charges in the system.

Conservation of electric charges means that the total charge of an isolated system remains unchanged with time. This means that when bodies are charged through friction, there is a transfer of electric charge from one body to another, but no creation or destruction of charge.

5. ***Coulomb's Law***: The mutual electrostatic force between two point charges q_1 and q_2 is proportional to the product $q_1 q_2$ and inversely proportional to the square of the distance r_{21} separating them. Mathematically,

$\vec{F}_{21} =$ Force on q_2 due to $q_1 = \frac{k(q_1 q_2)}{r_{21}^2}\hat{r}_{21}$ where $\hat{r}_{21}$ is a unit vector in the direction from q_1 to q_2 and $k = \frac{1}{4\pi\varepsilon_0}$ is the constant of proportionality.

In SI units, the unit of charge is coulomb. The experimental value of the constant ε_0 is $\varepsilon_0 = 8.854 \times 10^{-12}\,\mathrm{C^2 N^{-1} m^{-2}}$ the approximate value of k is $k = 9 \times 10^9\ \mathrm{N\ m^2\ C^{-2}}$

6. The ratio of electric force and gravitational force between a proton and an electron is $\frac{ke^2}{Gm_e m_p} \cong 2.4 \times 10^{39}$

7. ***Superposition Principle***: The principle is based on the property that the forces with which two charges attract or repel each other are not affected by the presence of a third (or more) additional charge(s). For an assembly of charges $q_1, q_2, q_3, \ldots$, the force on any charge, say q_1, is the vector sum of the force on q_1 due to q_2, the force on q_1 due to q_3, and so on. For each pair, the force is given by the Coulomb's law for two charges stated earlier.

8. The electric field $\vec{E}$ at a point due to a charge configuration is the force on a small positive test charge *q* placed at the point divided by the magnitude of the charge. Electric field due to a point charge *q* has a magnitude $|q|/4\pi\varepsilon_0 r^2$; it is radially outwards from *q*, if *q* is positive, and radially inwards if *q* is negative. Like Coulomb force, electric field also satisfies superposition principle.

9. An electric field line is a curve drawn in such a way that the tangent at each point on the curve gives the direction of electric field at that point. The relative closeness of field lines indicates the relative strength of electric field at different points; they crowd near each other in regions of strong electric field and are far apart where the electric field is weak. In regions of constant electric field, the field lines are uniformly spaced parallel straight lines.

10. Some of the important properties of field lines are: (i) Field lines are continuous curves without any breaks. (ii) Two field lines cannot cross each other. (iii) Electrostatic field lines start at positive charges and end at negative charges- they cannot form closed loops.

11. An electric dipole is a pair of equal and opposite charges *q* and –*q* separated by some distance $2a$. Its dipole moment vector $\vec{p}$ has magnitude $2qa$ and is in the direction of the dipole axis from –*q* to *q*.

12. Field of an electric dipole in its equatorial plane (i.e., the plane perpendicular to its axis and passing through its center) at a distance *r* from the center:

$$\vec{E} = \frac{-\vec{p}}{4\pi\varepsilon_0}\frac{1}{\left(a^2+r^2\right)^{3/2}} \cong \frac{-\vec{p}}{4\pi\varepsilon_0 r^3}, \text{ for } r >> a$$

Dipole electric field on the axis at a distance *r* from the center:

$$\vec{E} = \frac{2\vec{p}r}{4\pi\varepsilon_0\left(r^2-a^2\right)^2} \cong \frac{2\vec{p}}{4\pi\varepsilon_0 r^3}, \text{ for } r >> a$$

The $1/r^3$ dependence of dipole electric fields should be noted in contrast to the $1/r^2$ dependence of electric field due to a point charge.

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13. In a uniform electric field $\vec{E}$, a dipole experiences a torque $\vec{\tau}$ given by $\vec{\tau} = \vec{p} \times \vec{E}$ but experiences no net force.

14. The flux $\Delta\phi$ of electric field $\vec{E}$ through a small area element $\Delta\vec{S}$ is given by

$$\Delta\phi = \vec{E} \cdot \Delta\vec{S}$$

The vector area element $\Delta\vec{S}$ is $\Delta\vec{S} = \Delta S\hat{n}$ where ΔS is the magnitude of the area element and $\hat{n}$ is normal to the area element, which can be considered planar for sufficiently small ΔS.

For an area element of a closed surface, $\hat{n}$ is taken to be the direction of outward normal, by convention.

15. ***Gauss's law***: The flux of electric field through any closed surface *S* is $1/\varepsilon_0$ times the total charge enclosed by *S*. The law is especially useful in determining electric field $\vec{E}$, when the source distribution has simple symmetry:

(i) Thin infinitely long straight wire of uniform linear charge density λ

$$\vec{E} = \frac{\lambda}{2\pi\varepsilon_0 r}\hat{n}$$

where *r* is the perpendicular distance of the point from the wire and $\hat{n}$ is the radial unit vector in the plane normal to the wire passing through the point.

(ii) *Infinite thin plane sheet of uniform surface charge density* σ

$$\vec{E} = \frac{\sigma}{2\varepsilon_0}\hat{n}$$

where $\hat{n}$ is a unit vector normal to the plane, outward on either side.

(iii) *Thin spherical shell of uniform surface charge density* σ

$$\vec{E} = \frac{q}{4\pi\varepsilon_0 r^2}\hat{r} \qquad (r \geq R)$$

$$\vec{E} = 0 \qquad (r < R)$$

where *r* is the distance of the point from the centre of the shell and R the radius of the shell. *q* is the total charge of the shell: $q = 4\pi R^2\sigma$.

The electric field outside the shell is as though the total charge is concentrated at the centre. The same result is true for a solid sphere of uniform volume charge density. The field is zero at all points inside the shell.

Physical quantity	Symbol	Dimensions	Unit	Remarks
Vector area element	$\Delta\vec{S}$	$\left[L^2\right]$	m^2	$\Delta\vec{S}=\Delta S\,\hat{n}$
Electric field	$\vec{E}$	$\left[MLT^{-3}A^{-1}\right]$	Vm^{-1}	
Electric flux	ϕ	$\left[ML^3T^{-3}A^{-1}\right]$	$V\,m$	$\Delta\phi=\vec{E}\cdot\Delta\vec{S}$
Dipole moment	$\vec{p}$	$[LTA]$	$C\,m$	Vector directed from negative to positive charge
Charge density:				
Linear	λ	$\left[L^{-1}TA\right]$	$C\,m^{-1}$	Charge/length
Surface	σ	$\left[L^{-2}TA\right]$	$C\,m^{-2}$	Charge/area
Volume	ρ	$\left[L^{-3}TA\right]$	$C\,m^{-3}$	Charge/volume

Question 1: If 10^9 electrons move out of a body to another body every second, how much time is required to get a total charge of $1C$ on the other body?

Question 2: The electrostatic force on a small sphere of charge $0.4\mu C$ due to another small sphere of charge $-0.8\mu C$ in air is $0.2N$.

(a) What is the distance between the two spheres?

(b) What is the force on the second sphere due to the first?

Question 3: How much positive and negative charge is there in a cup of $250\,g$ water?

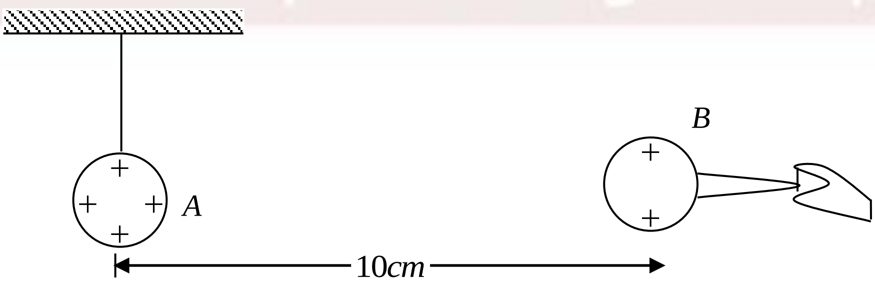
Question 4: Coulomb's law for electrostatic force between two-point charges and Newton's law for gravitational force between two stationary point masses, both have inverse-square dependence on the distance between the charges and masses respectively.

(a) Compare the strength of these forces by determining the ratio of their magnitudes

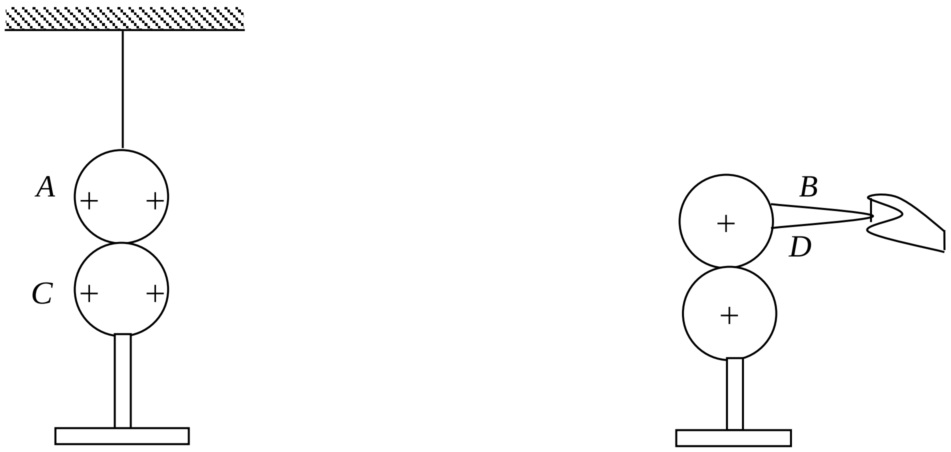
(i) for an electron and a proton and (ii) for two protons.

(b) Estimate the accelerations of electron and proton due to the electrical force of their mutual attraction when they are $1\overset{o}{A}\left(=10^{-10}m\right)$ apart? $\left(m_p=1.67\times10^{-27}kg, m_e=9.11\times10^{-31}kg\right)$

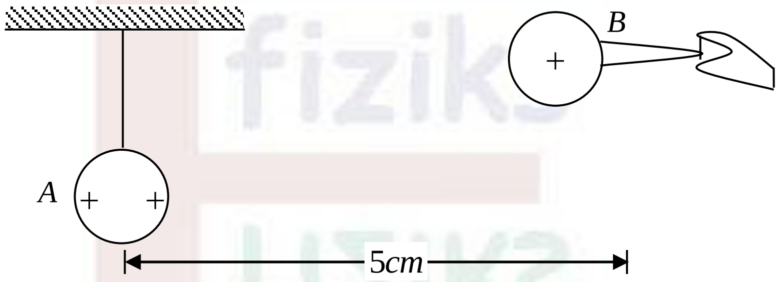
Question 5: A charged metallic sphere A is suspended by a nylon thread. Another charged metallic sphere B held by an insulating handle is brought close to A such that the distance between their centers is $10\,cm$, as shown in Fig. (a). The resulting repulsion of A is noted (for example, by shining a beam of light and measuring the deflection of its shadow on a screen). Spheres A and B are touched by uncharged spheres C and D respectively, as shown in Fig. (b). C and D are then removed and B is brought closer to A to a distance of $5\ cm$ between their centers, as shown in Fig. (c). What is the expected repulsion of A on the basis of Coulomb's law? Spheres A and C and spheres B and D have identical sizes. Ignore the sizes of A and B in comparison to the separation between their centers.



(a)



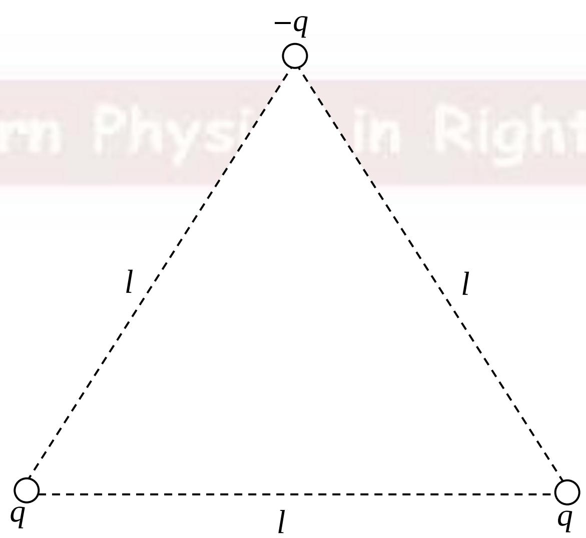
(b)



(c)

Question 6: Consider three charges q_1, q_2, q_3 each equal to q at the vertices of an equilateral triangle of side l. What is the force on a charge Q (with the same sign as q) placed at the centroid of the triangle, as shown in figure?

Question 7: Consider the charges q, q and $-q$ placed at the vertices of an equilateral triangle, as shown in figure. What is the force on each charge?



Question 8: Figure below shows tracks of three charged particles in a uniform electrostatic field. Give the signs of the three charges. Which particle has the highest charge to mass ratio?

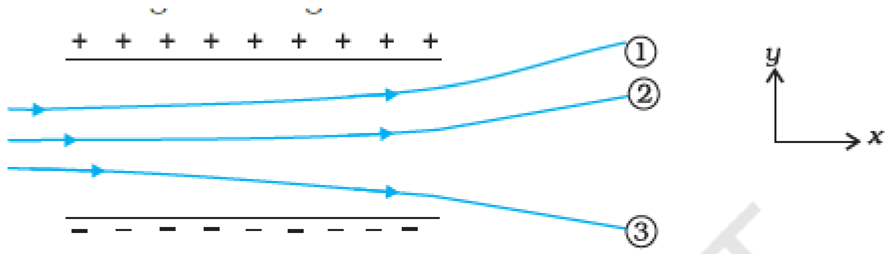
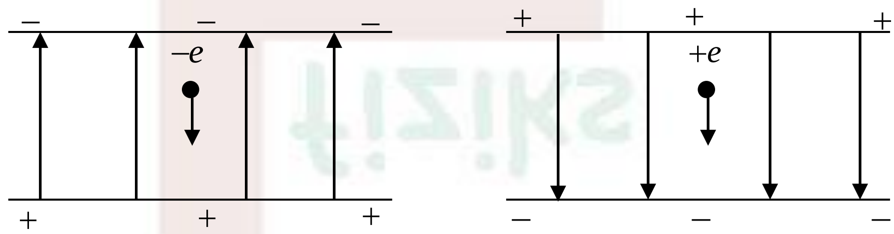
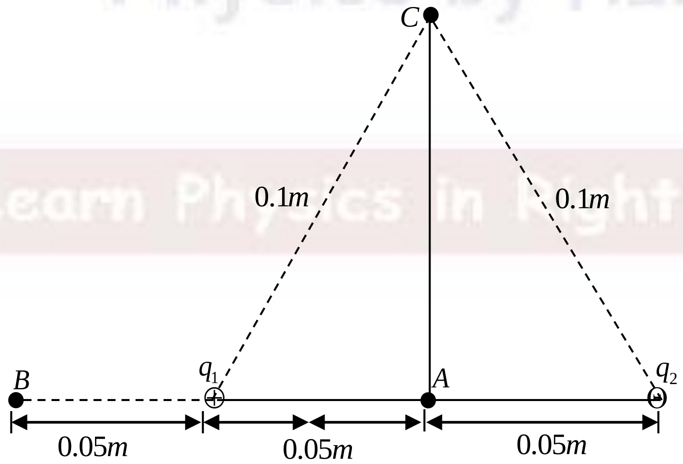


FIGURE 1.33

Question 9: An electron falls through a distance of $1.5\,cm$ in a uniform electric field of magnitude $2.0\times10^{4}\,NC^{-1}$ [figure (a)]. The direction of the field is reversed keeping its magnitude unchanged and a proton falls through the same distance [figure (b)]. Compute the time of fall in each case. Contrast the situation with that of 'free fall under gravity'.



Question 10: Two point charges q_1 and q_2, of magnitude $+10^{-8}C$ and $-10^{-8}C$, respectively, are placed $0.1m$ apart. Calculate the electric fields at points A, B and C shown in figure below.



Question 11: An oil drop of 12 excess electrons is held stationary under a constant electric field of $2.55\times10^{4}\,NC^{-1}$ in Millikan's oil drop experiment. The density of the oil is $1.26\,gcm^{-3}$. Estimate the radius of the drop. $\left(g = 9.81ms^{-2}; e = 1.60\times10^{-19}C\right)$.

Question 12: Which among the curves shown in figure cannot possibly represent electrostatic field lines?

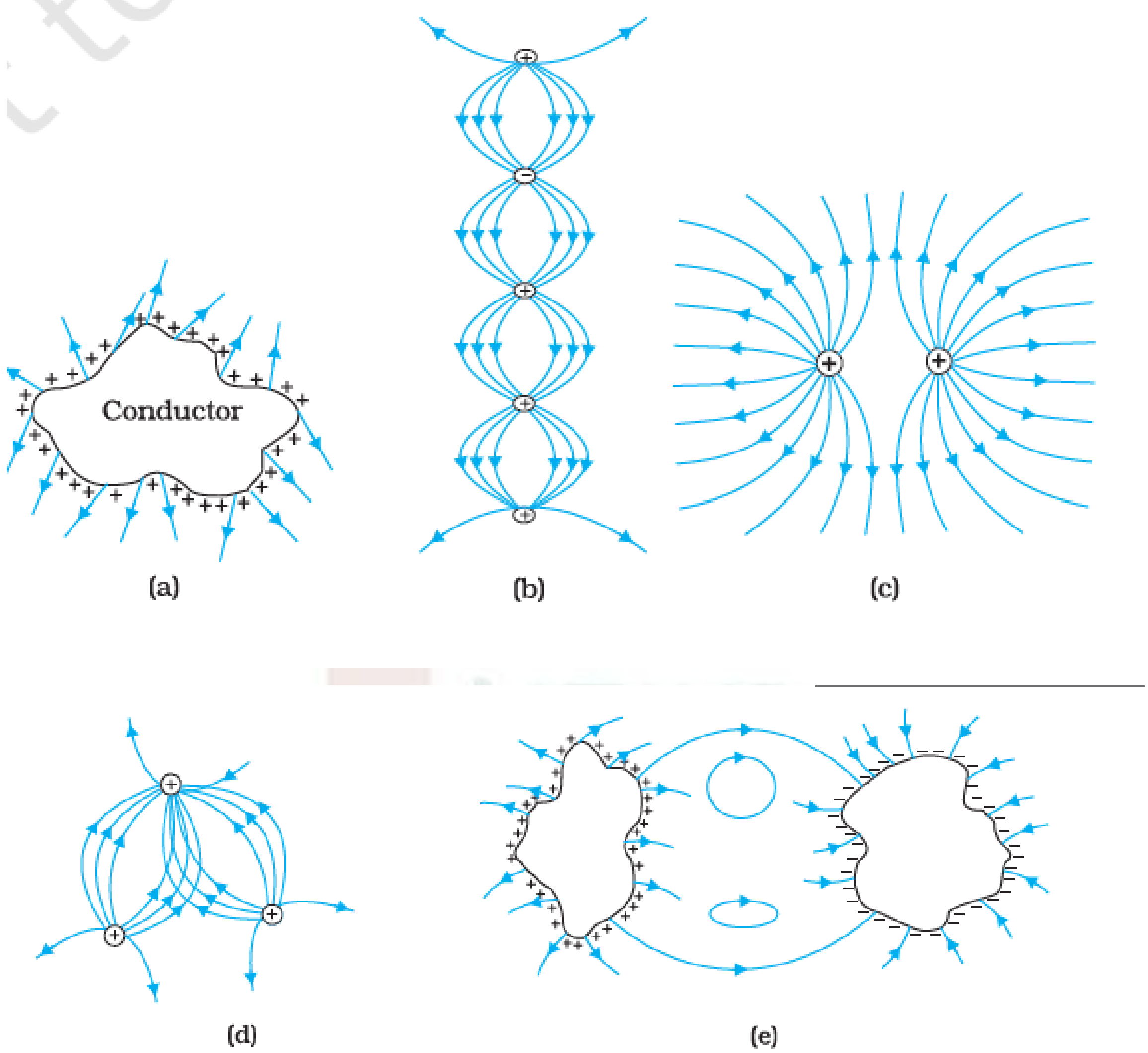
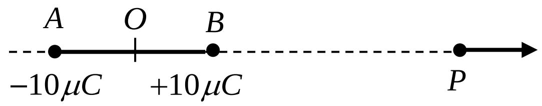
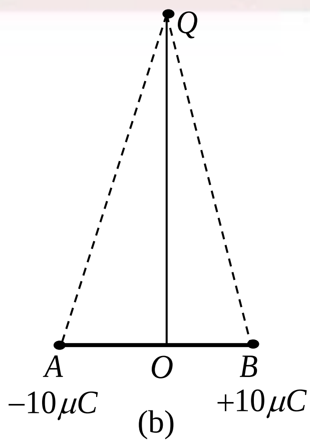


FIGURE 1.35

Question 13: Two charges $\pm 10\,\mu C$ are placed $5.0\,mm$ apart. Determine the electric field at (a) a point P on the axis of the dipole $15\,cm$ away from its center O on the side of the positive charge, as shown in figure (a), and (b) a point Q, $15\,cm$ away from O on a line passing through O and normal to the axis of the dipole, as shown in figure (b).



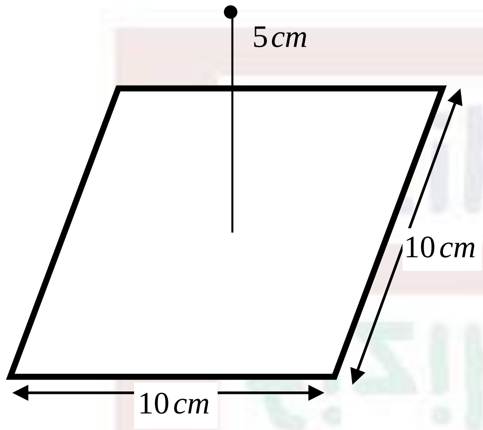
(a)



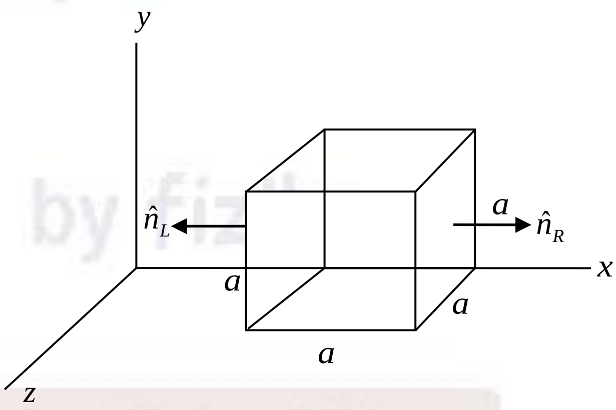
(b)

Question 14: 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 meter. What are the force and torque experienced by a system having total dipole moment equal to $10^{-7} Cm$ in the negative z-direction?

Question 15: A point charge $+10\mu C$ is a distance $5cm$ directly above the center of a square of side $10cm$ as shown in figure below. What is the magnitude of the electric flux through the square? (Hint: Think of the square as one face of a cube with edge $10cm$.)



Question 16: The electric field components in figure below are $E_x = \alpha x^{1/2}, E_y = E_z = 0$, in which $\alpha = 800 N/Cm^{1/2}$. Calculate (a) the flux through the cube, and (b) the charge within the cube. Assume that $a = 0.1m$.



Question 17: An electric field is uniform, and in the positive x direction for positive x, and uniform with the same magnitude but in the negative x, direction for negative x. It is given that $\vec{E} = 200\hat{i} N/C$ for $x > 0$ and $\vec{E} = -200\hat{i}\ N/C$ for $x < 0$. A right circular cylinder of length $20cm$ and radius $5cm$ has its center at the origin and its axis along the x-axis so that one face is at $x = +10cm$ and the other is at $x = -10cm$.

(a) What is the net outward flux through each flat face? (b) What is the flux through the side of the cylinder? (c) What is the net outward flux through the cylinder? (d) What is the net charge inside the cylinder?

Question 18: An early model for an atom considered it to have a positively charged point nucleus of charge Ze, surrounded by a uniform density of negative charge up to a radius R. The atom as a whole is neutral. For this model, what is the electric field at a distance r from the nucleus?

Question 19: An infinite line charge produces a field of $9\times10^4 N/C$ at a distance of $2cm$. Calculate the linear charge density.

Question 20: Two large, thin metal plates are parallel and close to each other. On their inner faces, the plates have surface charge densities of opposite signs and of magnitude $17.0\times10^{-22} C/m^2$. What is $\vec{E}$:

(a) In the outer region of the first plate, (b) In the outer region of the second plate, and

(c) Between the plates?

Question 21: Suppose that the particle in Exercise in 1.33 is an electron projected with velocity $v_x = 2.0\times10^6 ms^{-1}$. If E between the plates separated by $0.5cm$ is $9.1\times10^2 N/C$, where will the electron strike the upper plate? $\left(|e| = 1.6\times10^{-19} C, m_e = 9.1\times10^{-31} kg\right)$.

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