PHY-112

Principles of Physics-II

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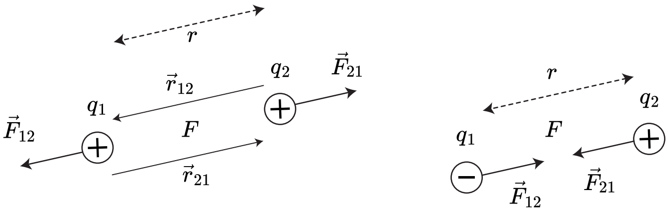
Spring-24 | Class-2



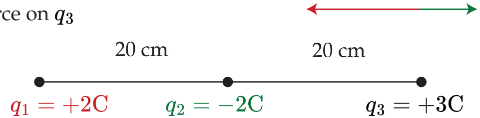
Like charges repel

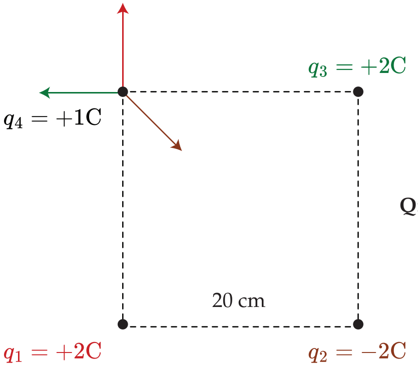
Opposite charges attract

$$\vec{F}_E = \left(\frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^3}\right)\vec{r}.$$
$$= \left(\frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}\right)\hat{r}$$

The Superposition Principle for $\vec{F}_E$

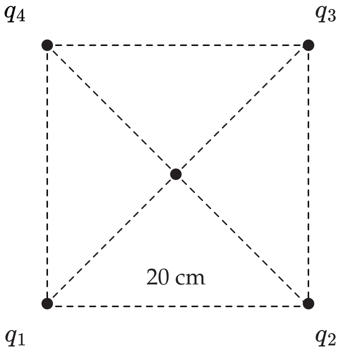
Q: Net Force on q_3



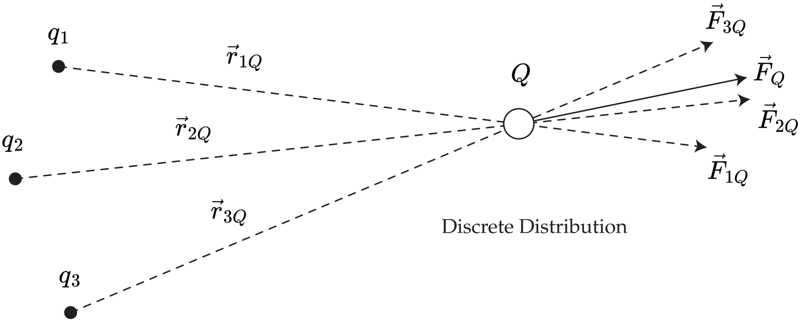


Q: Net Force on q_4

Q: Net Force at the center.



The Superposition Principle for $\vec{F}_E$: Discrete



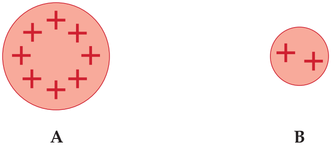
Discrete Distribution

The total force on Q is:

$$\begin{aligned}\vec{F}_Q &= \vec{F}_{1Q} + \vec{F}_{2Q} + \vec{F}_{3Q} + \dots \ \dots \vec{F}_{nQ} \\ &= \frac{Qq_1}{4\pi\epsilon_0 r_{1Q}^2}\hat{r}_{1Q} + \frac{Qq_2}{4\pi\epsilon_0 r_{2Q}^2}\hat{r}_{2Q} + \dots \ \dots \frac{Qq_n}{4\pi\epsilon_0 r_{nQ}^2}\hat{r}_{nQ} \\ &= \sum_i^N \frac{Qq_i}{4\pi\epsilon_0 r_{iQ}^2}\hat{r}_{iQ},\end{aligned}$$

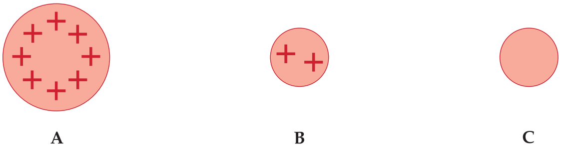
where $\vec{r}_{iQ} = \vec{r}_Q - \vec{r}_i$. $\vec{r}_Q$ is the position vector of the observer charge. $\vec{r}_i$ is the position vector of the i^{th} charge in the distribution, measured in the Cartesian coordinate system.

Q: Charged spheres A and B exert repulsive forces on each other. $q_A = 4q_B$. Which statement is true?

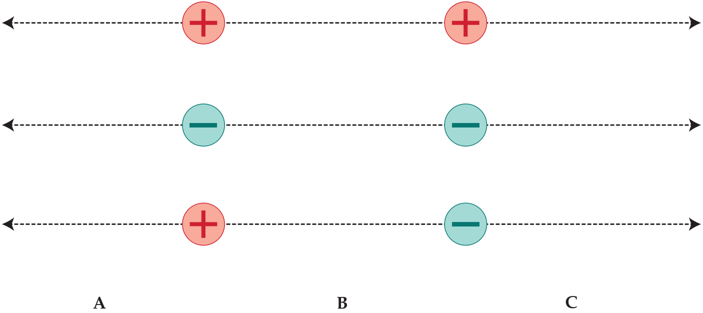


(a) $F_{A \text{ on } B} > F_{B \text{ on } A}$, (b) $F_{A \text{ on } B} = F_{B \text{ on } A}$, (c) $F_{A \text{ on } B} < F_{B \text{ on } A}$

Q: Charged spheres A and B exert repulsive forces on each other. $q_A = 5q_B$. They are brought together to make contact for a minute. F_{AB} is measured. Sphere B is then brought close to Sphere C for a minute. F_{BC} is measured. What is the $\vec{F}_E$ ratio in these 2 cases? Sphere C is initially uncharged. Take unit values for simplicity.



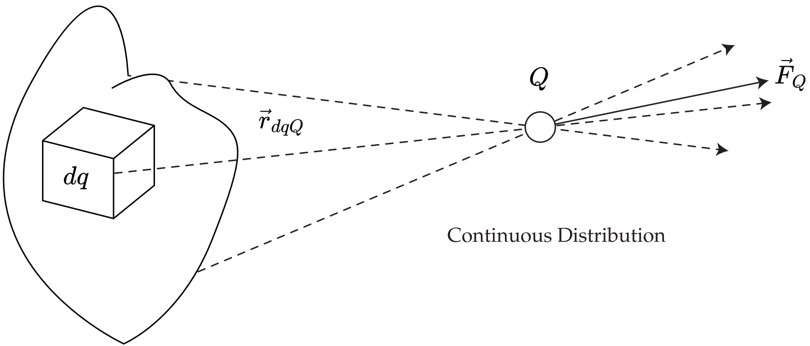
Q: Find the zero force location.



Discrete versus Continuous Charge Distribution

$$Q = \sum_{i}^{N} q_i \quad \text{(Discrete)}$$

$$Q = \int dq \quad \text{(Continuous)}$$



Continuous Distribution

The Superposition Principle for $\vec{F}_E$: Continuous

The total force on Q is:

$$\vec{F}_Q = \int \frac{Q dq}{4\pi\epsilon_0 r_{dqQ}^2}\hat{r}_{dqQ},$$

where $\vec{r}_{dqQ} = \vec{r}_Q - \vec{r}_{dq}$. $\vec{r}_Q$ is the position vector of the observer charge. $\vec{r}_{dq}$ is the position vector of the charge element dq in the distribution, measured in the Cartesian coordinate system.

Electric Charge Densities

A line charge λ [$\mathrm{C\,m^{-1}}$], is a charge per unit length:

$$\lambda = \frac{dq}{dl}$$

A surface charge σ [$\mathrm{C\,m^{-2}}$], is a charge per unit area:

$$\sigma = \frac{dq}{da}$$

A volume charge ρ [$\mathrm{C\,m^{-3}}$], is a charge per unit volume:

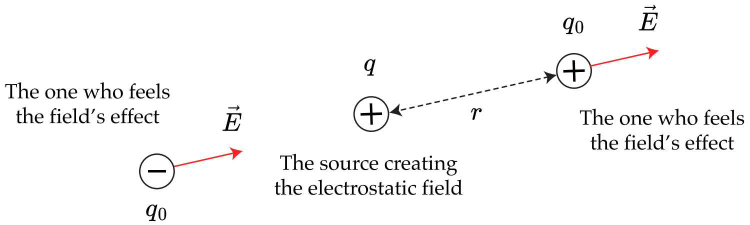
$$\rho = \frac{dq}{dV}$$

Electric Charge Densities

$$\text{distribution} \equiv \begin{cases} \dfrac{dq}{dl} & \text{in one dimension (1D)} \\ \dfrac{dq}{da} & \text{in two dimension (2D)} \\ \dfrac{dq}{dV} & \text{in three dimension (3D)} \end{cases}$$

$$Q = \int dq = \begin{cases} \lambda dl & \text{in one dimension (1D)} \\ \sigma da & \text{in two dimension (2D)} \\ \rho dV & \text{in three dimension (3D)} \end{cases}$$

Electric Field Definition



Electric Field Intensity

Electric Field $\vec{E}$ [$\mathrm{N\,C^{-1}}$ or $\mathrm{V\,m^{-1}}$] is defined as the force per unit positive charge exerted on the test charge.

$$\begin{aligned}\vec{E} &= \lim_{q_0 \to 0} \frac{\vec{F}}{q_0} \\ &= \left(\frac{1}{4\pi\epsilon_0} \frac{q}{r^3} \right) \vec{r} \\ &= \left(\frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \right) \hat{r},\end{aligned}$$

The limit is there to ensure the existence of the field even in the absence of Q.

Electric Field Direction

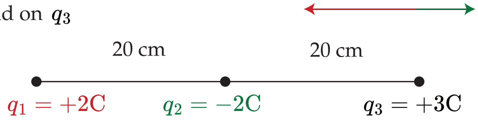
The direction of the electric field at a given point is **the direction in which a positive test charge would experience a force if placed at that point**.

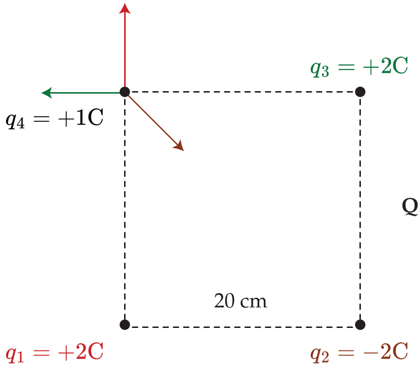
$$\vec{F}_E = q\vec{E},$$

where $\vec{F}_E \rightarrow$ Coulomb force felt by the charge q in presence of $\vec{E}$.

Testing Concepts (4)

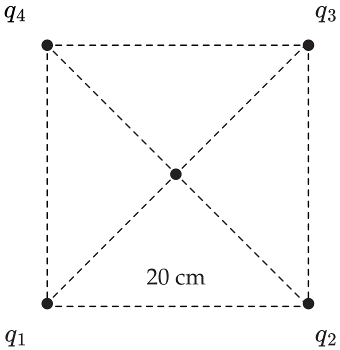
Q: Net Field on q_3





Q: Net Field on q_4

Q: Net Field at the center.



The Superposition Principle for $\vec{E}$: Discrete

The electric field experienced by a point charge Q due to a charge distribution q_i or dq is given by:

$$\begin{aligned}\vec{E} = \frac{\vec{F}}{Q} &= \frac{q_1}{4\pi\epsilon_0 r_{1r}^2}\hat{r}_{1r} + \frac{q_2}{4\pi\epsilon_0 r_{2r}^2}\hat{r}_{2r} + \dots \quad \dots \frac{q_n}{4\pi\epsilon_0 r_{nr}^2}\hat{r}_{nr} \\ &= \sum_i^N \frac{q_i}{4\pi\epsilon_0 r_{ir}^2}\hat{r}_{ir},\end{aligned}$$

where $\vec{r}_{ir} = \vec{r} - \vec{r}_i$ are the separation coordinates. $\vec{r}$ is the position vector of the point where the observation is being made. $\vec{r}_i$ is the position vector of the i^{th} source charge, measured in the Cartesian coordinate system.

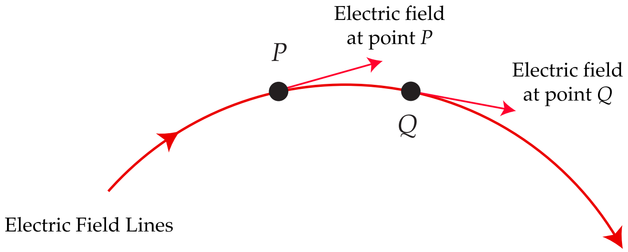
The Superposition Principle for $\vec{E}$: Continuous

The total field measured by Q is:

$$\vec{E} = \int \frac{dq}{4\pi\epsilon_0 r_{dqr}^2} \hat{r}_{dqr},$$

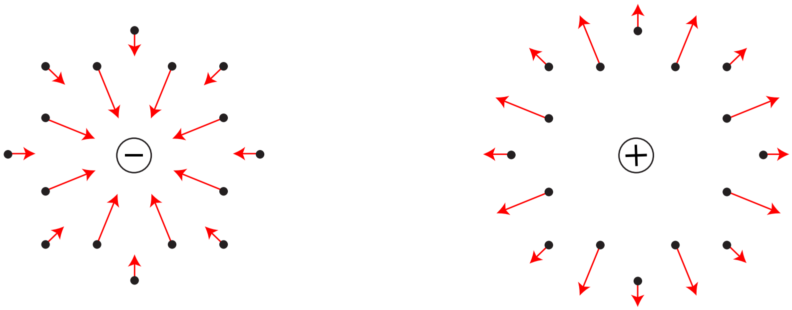
where $\vec{r}_{dqr} = \vec{r} - \vec{r}_{dq}$ are the separation coordinates. $\vec{r}$ is the position vector of the point where the observation is being made.

They are imaginary lines used to visualize and represent the direction and strength of an electric field.

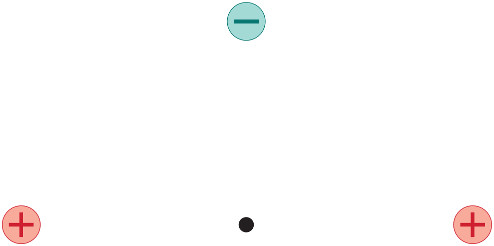


NOTE: **Electric field lines are not trajectories. No two electric field lines will intersect.**

Electric Field due to a Charged Particle



Q: Find the net Field direction at the dot.



Q: What magnitude charge creates a $1.0\,\mathrm{N\,C^{-1}}$ electric field at a point $1.0\,\mathrm{m}$ away?

Q: At an arbitrary point in space $\vec{E} = (400\hat{\imath} + 100\hat{\jmath})\,\mathrm{N\,C^{-1}}$ is found.

(a) What is the electric force on p^+ and e^- at this point? Give your answer in component form.

(b) What is the magnitude of the p^+ and e^-'s acceleration if placed from rest at this point?