Announcements

- Midterm and the final will consist entirely of MCQ
- To get a passing grade letter you must obtain a weighted average of 50% or better for the midterm and the final.
- Please send me feedback on how the course is going for you and if there is a need to tweak the lecture notes.
- Please remember to take advantage of the office hours or contact me by email if you need help outside the office hours.

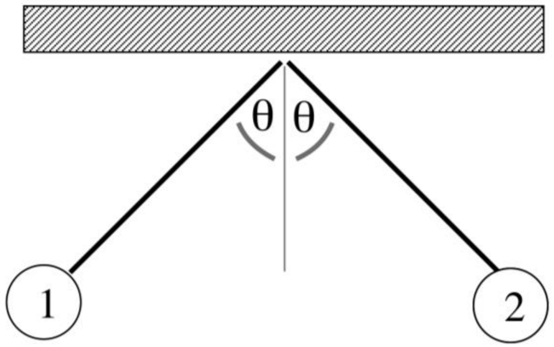
Last time

- Review of Coulomb's force due to a charged 90° arc of radius R at its center, constant charge density
- Coulomb's force due to a charged semi-circle of radius R at its center using superposition principle
- Coulomb's force due to a charged circle of radius R at its center using superposition principle
- Coulomb's force due to a charged semi-circle of radius R at its center with a twist using superposition principle
- Electric field

This time

- Top hat questions
- Electric field pattern due to point charges
- Electric field pattern for a dipole
- Electric field due to a charged 90° arc of radius R at its center, constant charge density
- Electric field due to a charged semi-circle of radius R at its center using superposition principle
- Electric field due to a charged circle of radius R at its center using superposition principle

Clarification on tophat questions



Should we worry about the mass of the charge that resides on the balls?

No!

Charging a ball even by 1 C, means transferring about 1.6×10^{19} electrons each with a mass of 9.1×10^{-31} Kg. This amounts to a change in mass of 1.5×10^{-11} kg which is negligibly small.

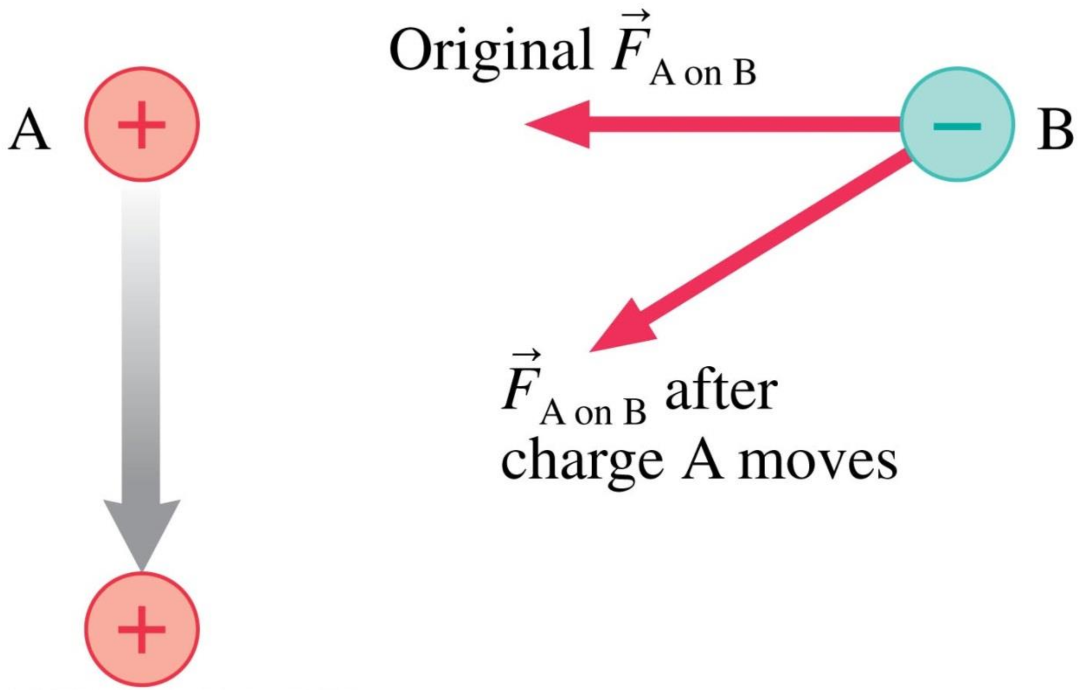
Action-at-a-Distance Forces
(Electric field)

A exerts a force on **B** through empty space.

- No contact.
- No apparent **mechanism**.

Action-at-a-Distance Forces
(Electric field)

If **A** suddenly moves to a new position, the force on **B** varies to match this new position. **How?**



What if B wasn't there?

If B is not there, charge A still "does something" to the **surrounding space**. We can quantify this by using the concept of an **electric field**. Start with a single positive charge:

Coulomb's Law rewritten:

$$\vec{F}_e = \left(\frac{k_e q}{r^2}\hat{r}\right) q' = \vec{E} q'$$

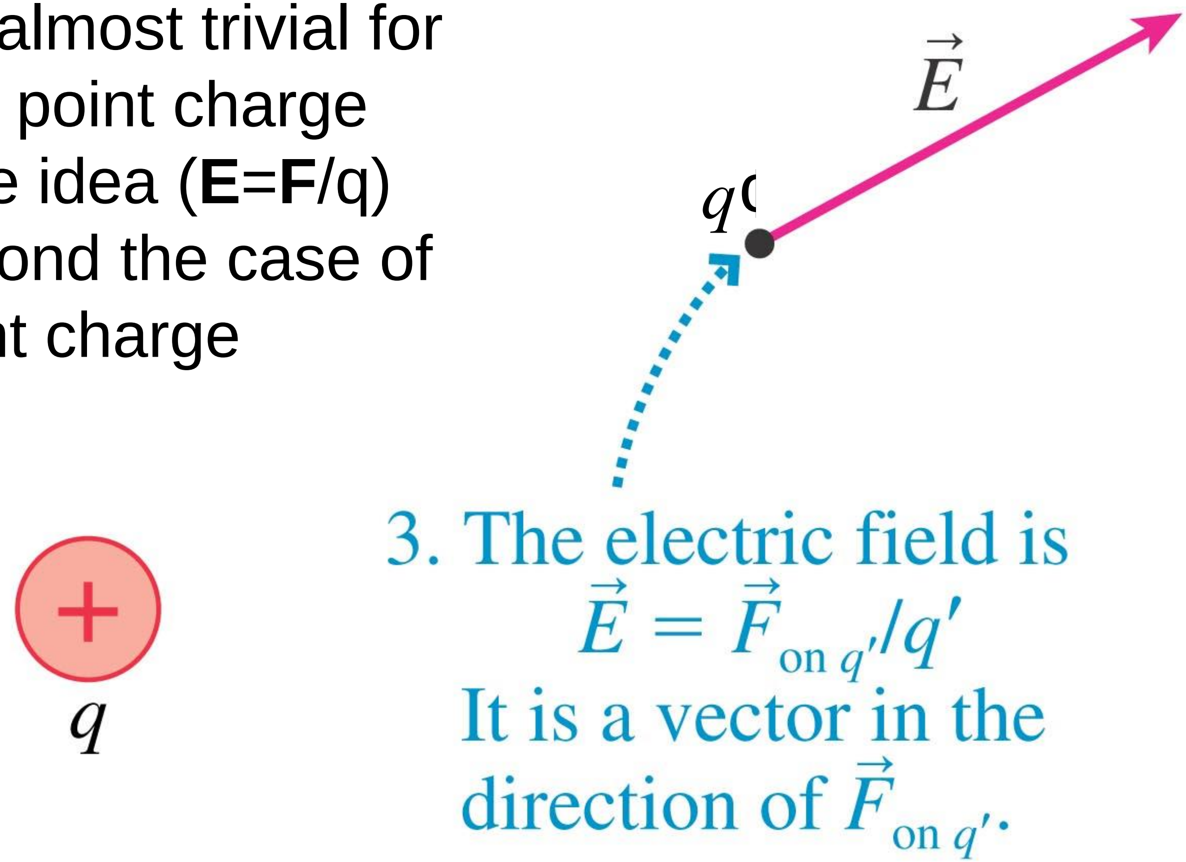
Electric field

$$\vec{E} = \frac{k_e q}{r^2}\hat{r}$$

Electric field is the mediator between q and q'!

How do we calculate Electric field?

This seems almost trivial for the field of a point charge but the same idea (**E**=**F**/q) extends beyond the case of a single point charge

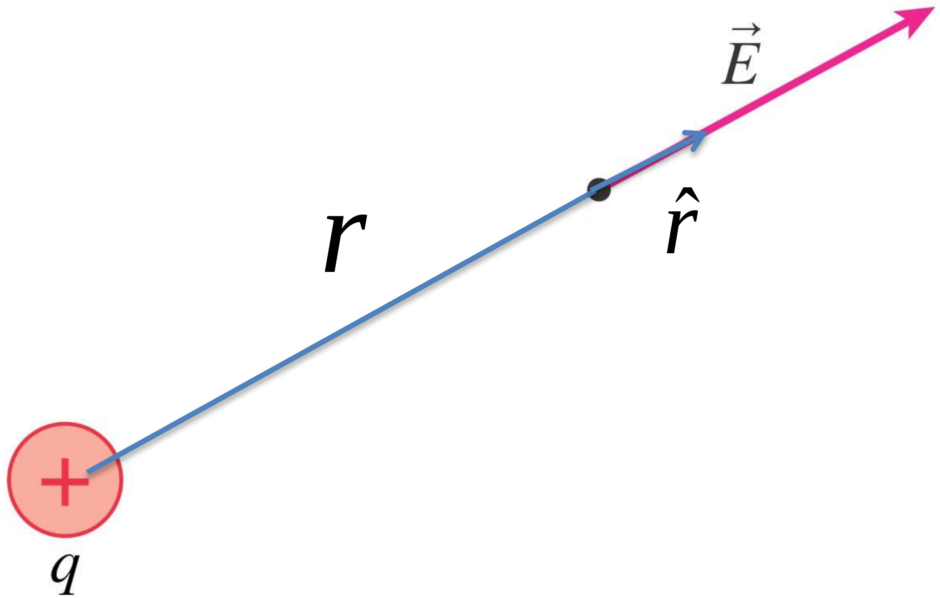


Charge q is the source of the field.

q' is a small + charge that we use to probe the field.

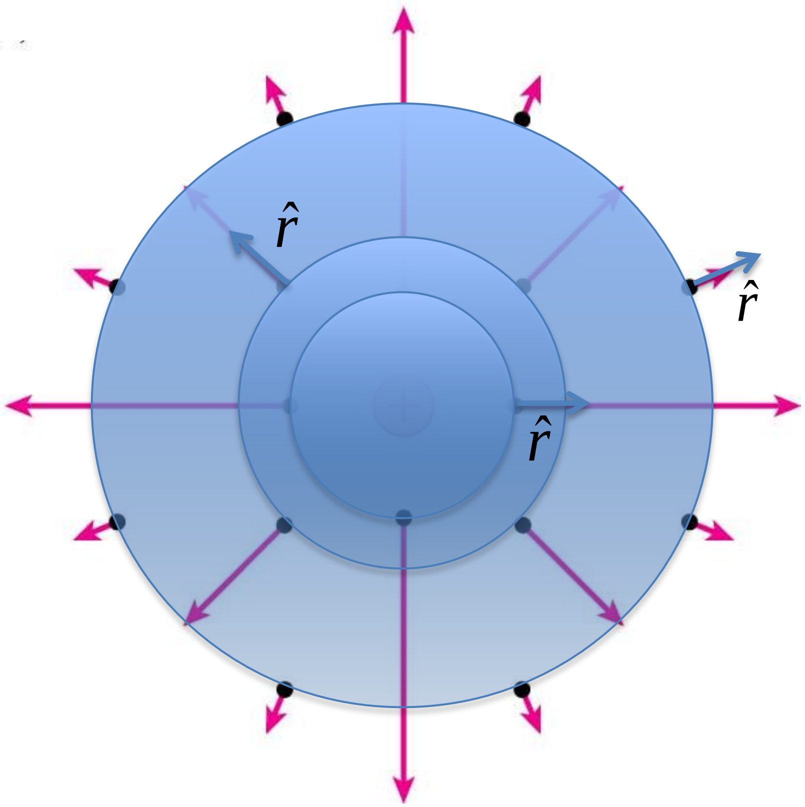
Electric field of a point charge at a distance r from the charge

$$\vec{E} = \frac{k_e\,|q|}{r^2}\,\hat{r}$$



Electric field due to a positive point charge

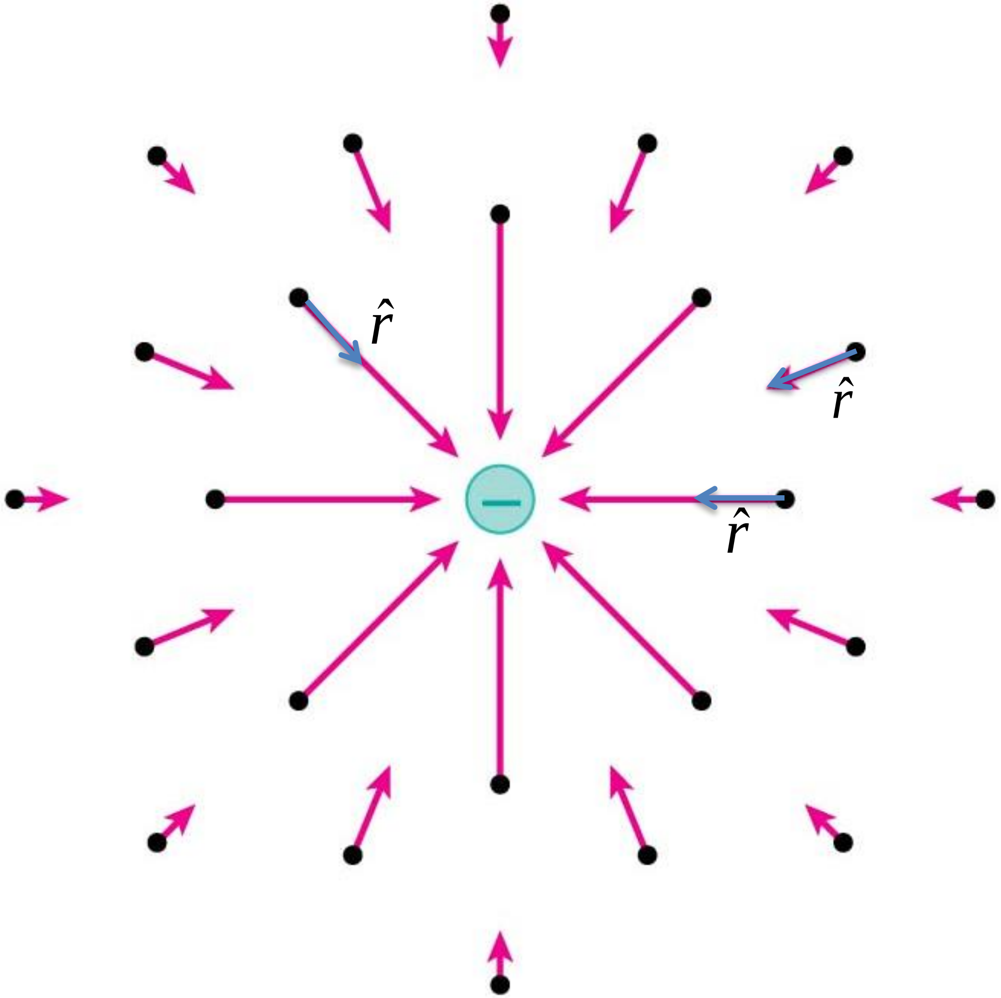
$$\vec{E} = \frac{k_e |q|}{r^2} \hat{r}$$



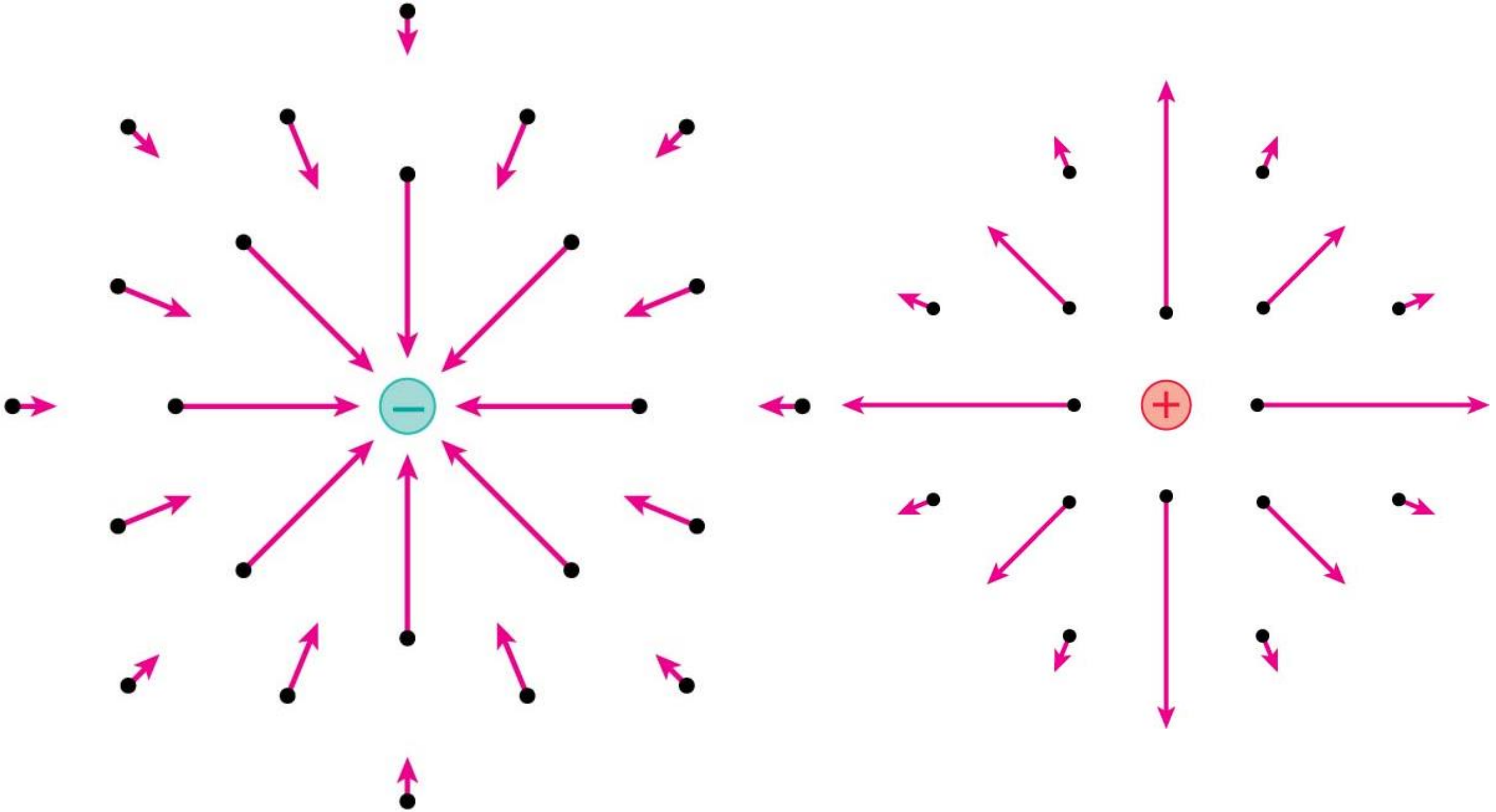
This is a three dimensional pattern.
We say that $\hat{r}$ is radial. The electric field pattern has spherical symmetry centered at the point charge. Electric field magnitude is a constant on a spherical surface of radius r centered at the point charge.

Electric field due to a negative point charge

$$\vec{E} = \frac{k_e |q|}{r^2}\hat{r}$$



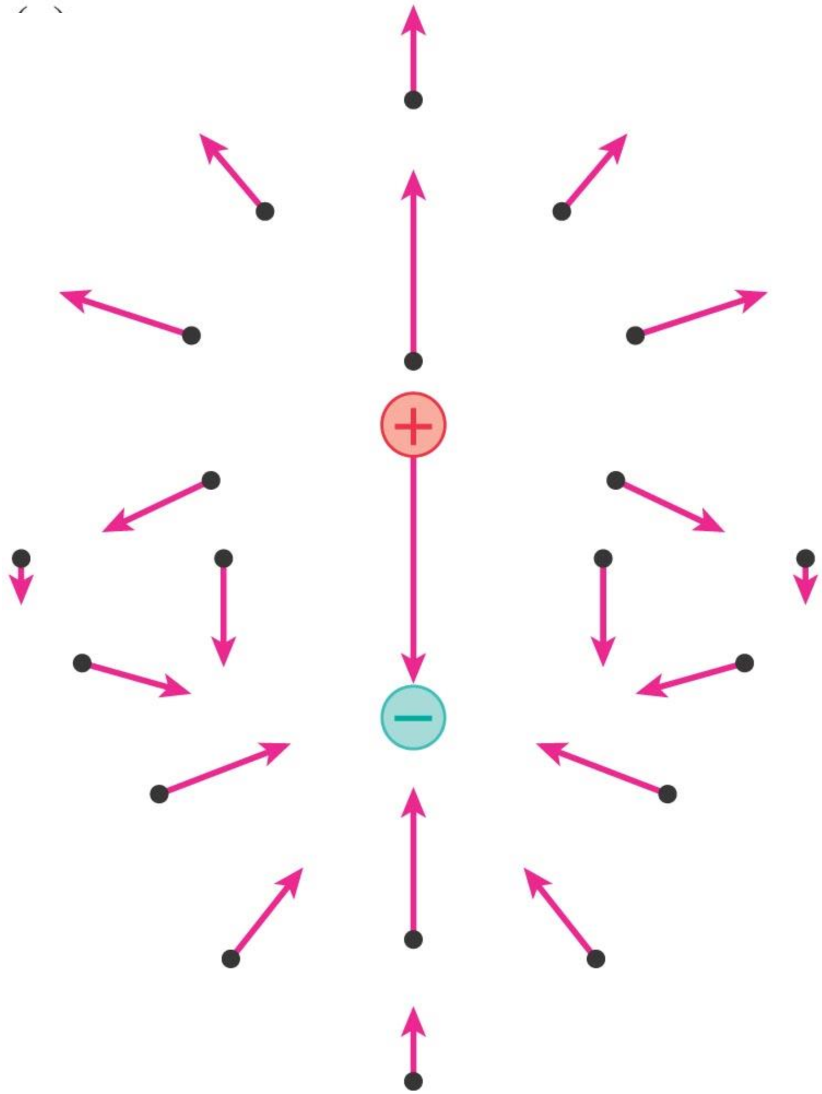
Superposition principle



Electric field vectors for a dipole

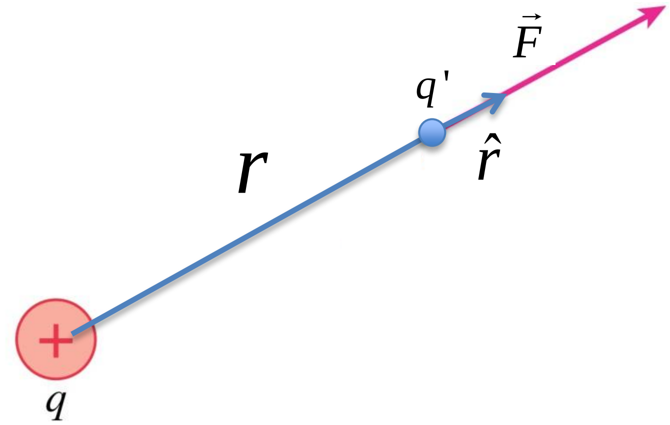
The vector represents the magnitude and direction of the electric field **at any point** using the superposition principle.

Electric field emanates from positive charges and terminates at negative charges.



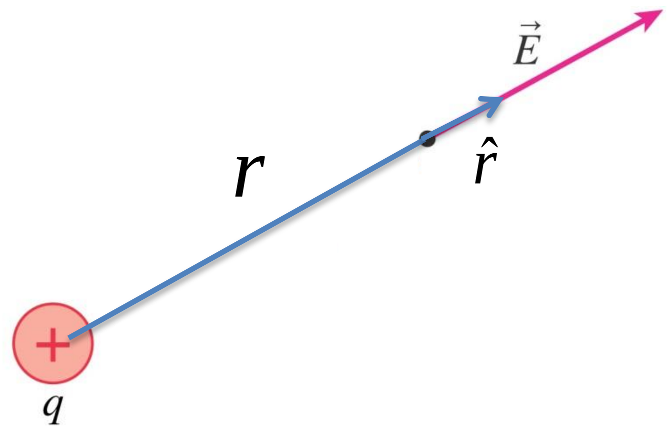
Electric field of a point charge at a distance r from the charge

$$\vec{F} = \frac{k_e |q||q'|}{r^2}\hat{r}$$



Divide the force by the test or the probe charge

$$\vec{E} = \frac{\vec{F}}{q'}$$



$$\vec{E} = \frac{k_e |q|}{r^2}\hat{r}$$

SI unit of Electric field: **Newton per coulomb** (N/C)

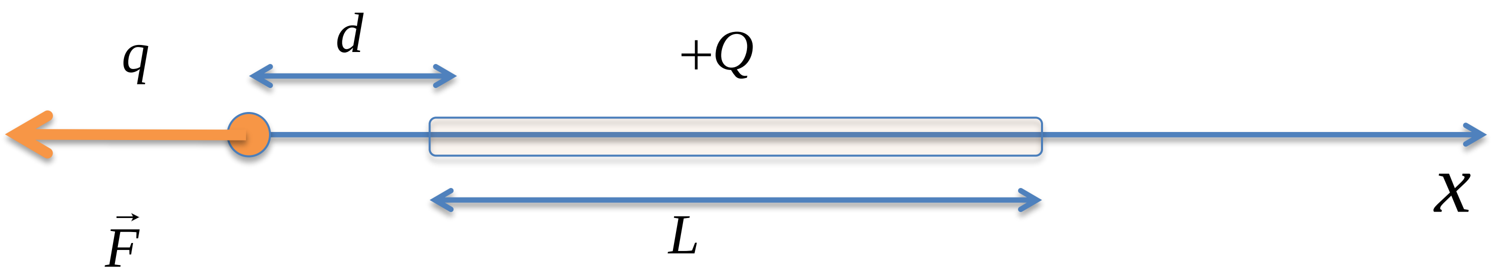
$$\vec{E} = \frac{\vec{F}}{q}$$

Thus force on a point charge (q) in an external electric field is

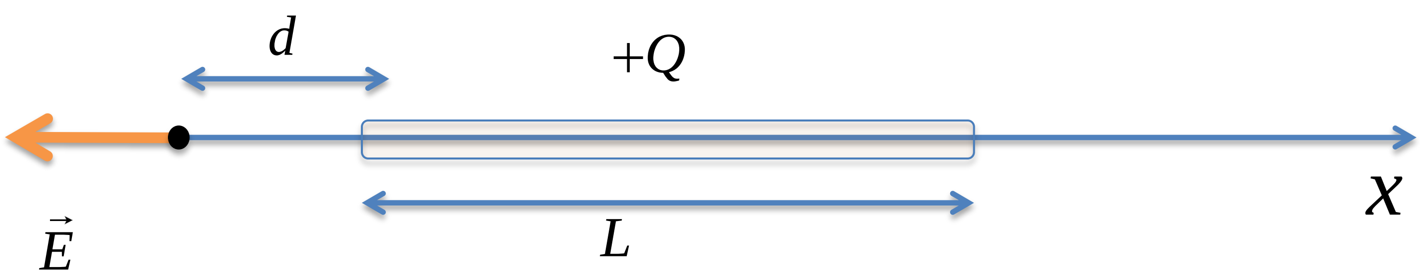
$$\vec{F} = q\vec{E}$$

Force on the charge is in the same direction as the electric field if $q>0$ and in opposite direction to the electric field if $q<0$.

Electric field for a charged rod at a point on the axis of the rod



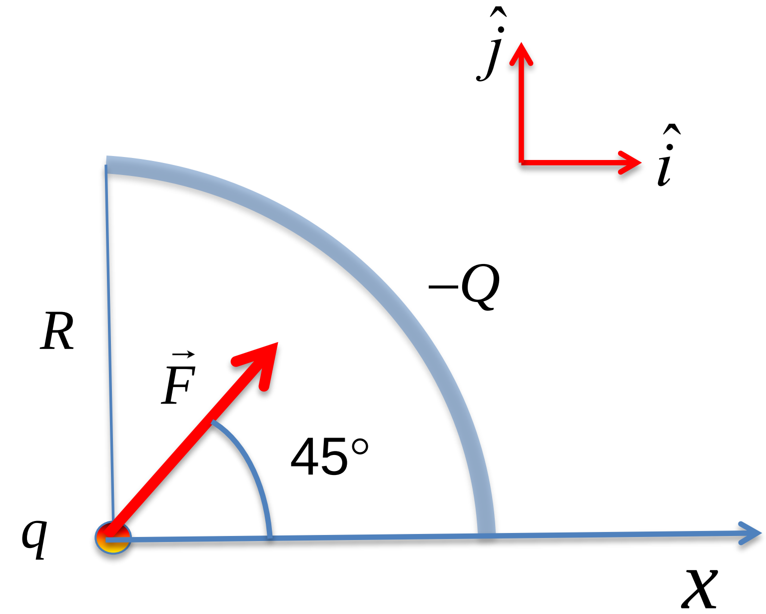
$$\vec{F} = -k_e \frac{qQ}{d\left(d+L\right)}\hat{i}$$

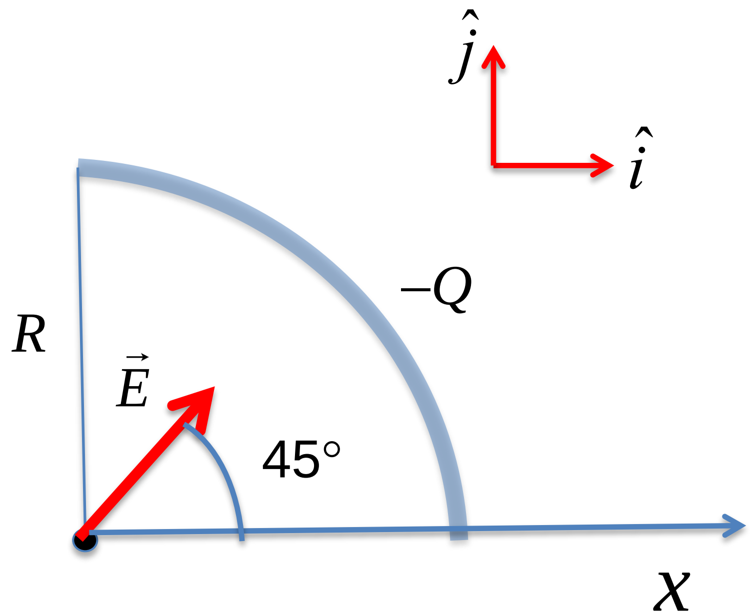


$$\vec{E} = -k_e \frac{Q}{d\left(d+L\right)}\hat{i}$$

Electric field due to a charged 90° arc at its center

$$\vec{F} = \frac{2}{\pi}\frac{k_e qQ}{R^2}\left(\hat{i} + \hat{j}\right)$$

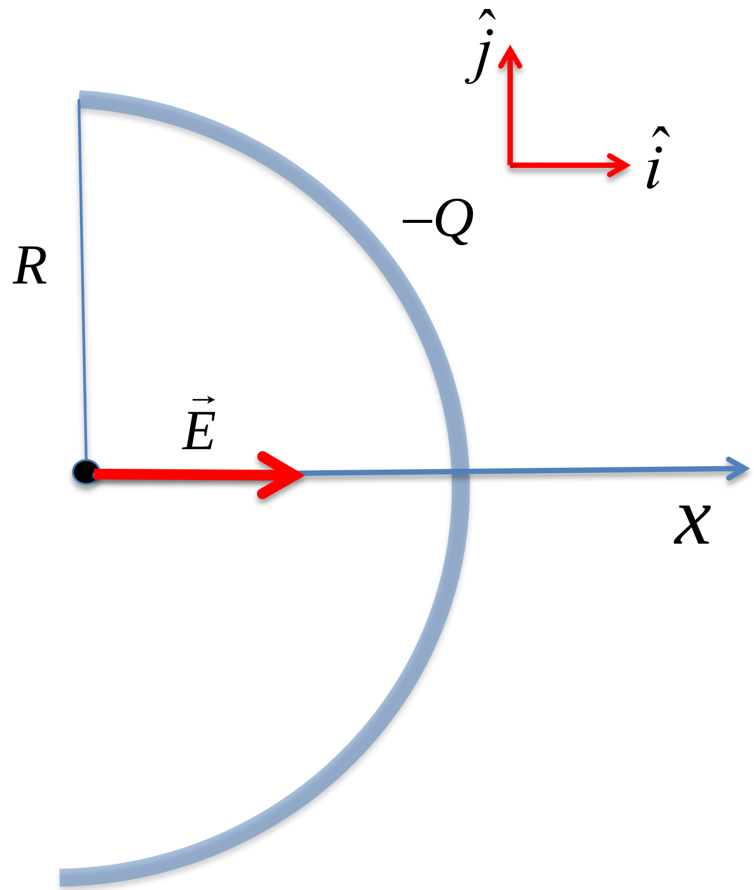


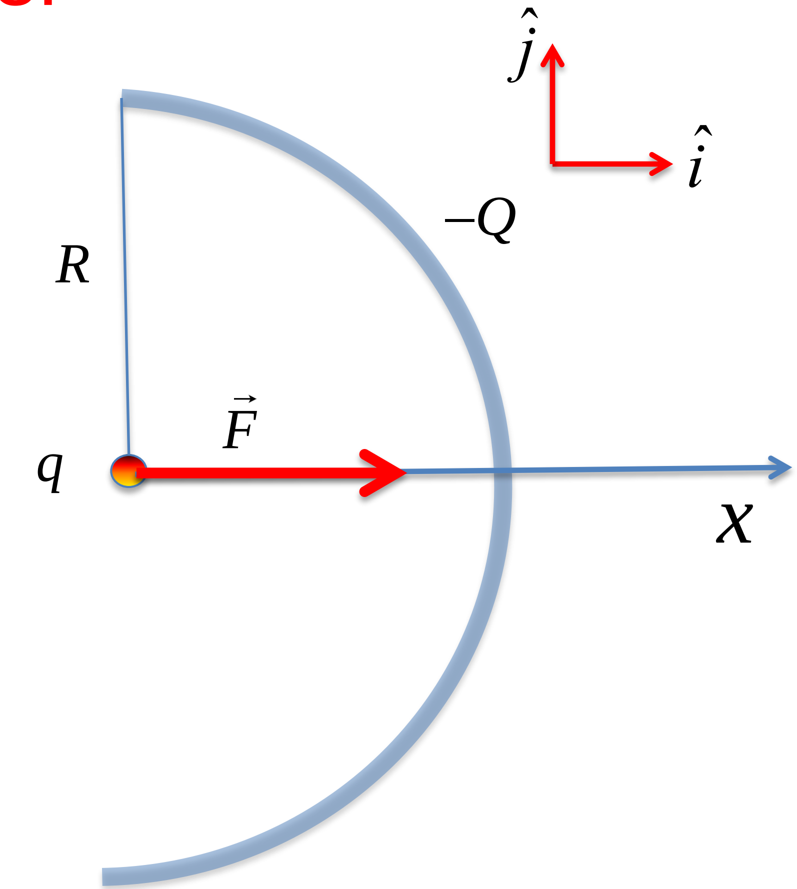


$$\vec{E} = \frac{2}{\pi}\frac{k_e Q}{R^2}\left(\hat{i} + \hat{j}\right)$$

Electric field due to a charged180° arc at its center

$$\vec{F} = \frac{2}{\pi}\frac{k_e q Q}{R^2}\hat{i}$$





$$\vec{E} = \frac{2}{\pi}\frac{k_e Q}{R^2}\hat{i}$$