PHY-112 | Principles of Physics-2

Akiful Islam (AZW)
Summer 2025 | Class #1

Department of Mathematics & Natural Sciences

Enter Electrostatics

Electric Charge

It is a fundamental property of matter that determines how it interacts with other matter through electromagnetic force. Electrons carry a negative charge, while protons carry a positive charge.

Important Properties!

- **Conservation of electric charge**: You cannot create/destroy them
- **Quantization of electric charge**: At microscopic scale
- **Additivity of charges**: Charge is Scalar
- **Charge interactions**: Like charges repel, opposites attract
- **Coulomb's Law of *electrostatics***: Measures Electrostatic force

Note: The magnitude of the charge of the electron or proton is a natural unit of charge, called the *electron number*, $e = 1.602 \times 10^{-19}$ C.

Incepting Ideas (1)

Hint: Conservation and Quantization of charge

Q1: You rub a neutral woolen sweater and neutral a balloon for 10 seconds. The balloon gains 10 electrons in the process. Does the balloon stick to the sweater or not?

Q2: You collect 1 kg of protons. How many protons are there? What is the total charge of 1 kg of protons? Is the amount quantized at this scale? Find proton's charge-to-mass ratio.

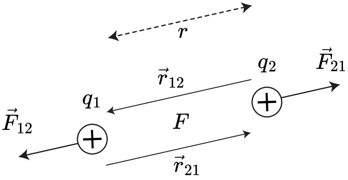
Homework Practice Problem: Try it Yourself

Do the same problem for 1 kg of electrons and neutrons. How do their charge-to-mass ratio changes?

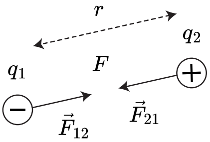
Enter Electrostatic/Coulomb Force

Electrostatic Force and Coulomb's Law

Force is observer dependent!



Like charges repel



Opposite charges attract

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

This forms an *inverse square law* and an action-reaction pair.

Incepting Ideas (2)

Hint: Gravity is weak!!!

Q: Find the ratio of the Electrostatic force and the Gravitational force in action between a proton and electron separated by 10^{-10} m.

Gravity is weak at this scale!

Important Conclusion: Gravitational force can be safely ignored in this course since it is *miniscule* compared to the Electrostatic force. E.g., $F_G : F_E \sim 10^{-39}$ in the case of a proton and electron.

Limitations of Coulomb's Law

Not Sunshine and Rainbows all the time!

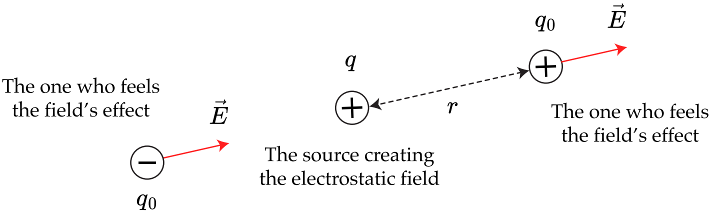
What does it require to work?

- **Point Charge Assumption**: Derived for only pointlike charges. But in real-world scenarios, charges are often distributed over volumes, surfaces, or along lines. The law needs to be integrated over these distributions for accurate results.
- **Static Charges**: Works well when charges are not moving. For moving charges, magnetic forces and relativistic effects need to be considered, which are not accounted for by Coulomb's Law.
- **Cannot deal with 3D charges**: Cannot measure field inside an extended charge. The law starts working from the surface.
- **Distance Constraints**: Accurate for charges that are sufficiently far apart. When charges are very close, quantum effects and other forces (like nuclear forces) become significant, and Coulomb's Law no longer provides an accurate description.

Enter Electric Field

Electric Field Definition

Field is observer independent



Electric Field Intensity
Just the magnitude part

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.

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

Note: The limit is there to ensure the existence of the field even in the absence of q_0. The field (or, in this case, the ratio $\frac{\vec{F}_E}{q_0}$) remains the same if the sources remain the same.

Electric Field Direction
Just the direction part

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 same point** around the source charge that made the field.

$$\vec{F}_E = q_0 \vec{E},$$

where $\vec{F}_E \rightarrow$ Coulomb force felt by the observer charge q_0 in presence of $\vec{E}$. The field is produced by charge q.

Remember, q_0 did not make this $\vec{E}$. q_0 only measures its effect.

Coulomb Forces for Charge Distribution

The Superposition Principle for $\vec{F}_E$: Discrete
Do Pairwise vector sum

The total force on Q is:

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

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.

Electric Fields for Charge Distribution

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

Do Pairwise vector sum

The electric field experienced by a point charge q_0 due to a charge distribution q_i is given by:

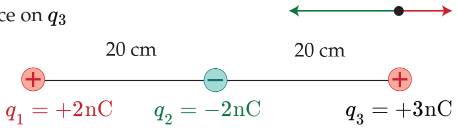
$$\begin{aligned}\vec{E} = \frac{\vec{F}}{q_0} &= \frac{\vec{F}_1}{q_0} + \frac{\vec{F}_2}{q_0} + \dots \dots \frac{\vec{F}_n}{q_0} \\ &= \frac{|q_1|}{4\pi\epsilon_0 r_{1r}^2}\hat{r}_{1r} + \frac{|q_2|}{4\pi\epsilon_0 r_{2r}^2}\hat{r}_{2r} + \dots \dots \frac{|q_n|}{4\pi\epsilon_0 r_{nr}^2}\hat{r}_{nr} \\ &= \sum_i^N \frac{|q_i|}{4\pi\epsilon_0 r_{ir}^2}\hat{r}_{ir},\end{aligned}$$

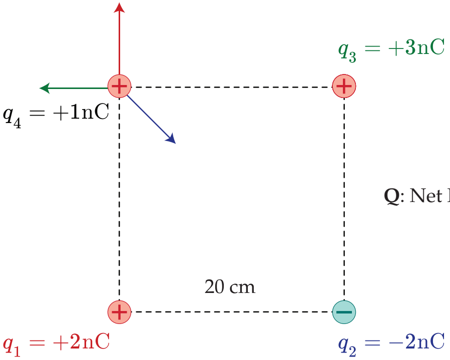
where $\vec{r}_{ir} = \vec{r} - \vec{r}_i$ are the separation coordinates. $\vec{r}$ is the position vector of the point where the observation is being made. $\vec{r}_i$ is the position vector of the i^{th} source charge, measured in the Cartesian coordinate system.

Incepting Ideas (3)

Hint: Pair the charges, and think vectorially

Q: Net Force on q_3





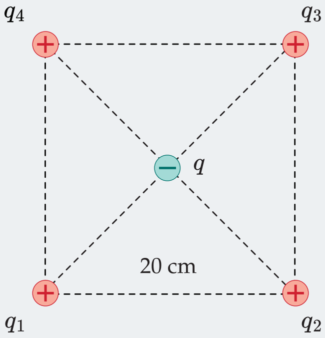
Q: Net Force on q_4

Incepting Ideas (4)

Hint: Pair the charges, and think vectorially

Homework Practice Problem: Try it Yourself

Q: Calculate the net Force $q = -2$ nC experiences at the center. Take $q_1 = q_2 = q_3 = q_4 = +2$ nC.

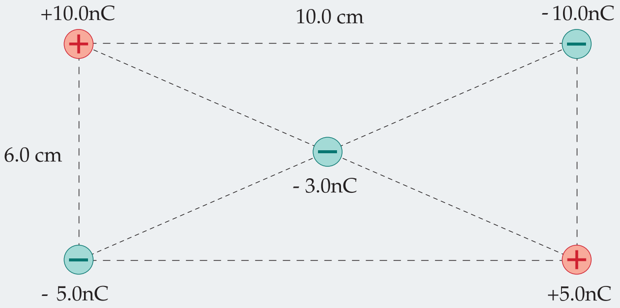


Incepting Ideas (5)

Hint: Pair the charges, and think vectorially

Homework Practice Problem: Try it Yourself

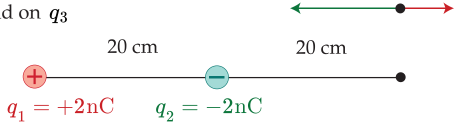
Q: Find $\vec{F}$ on the -3.0 nC charge. Give your answer in component and magnitude form. Measure the direction with respect to $+x$-axis.



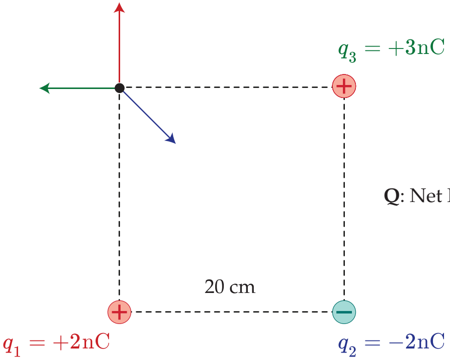
Incepting Ideas (6)

Hint: Think vectorially. No pairing needed

Q: Net Field on q_3



Q: Net Field on q_4

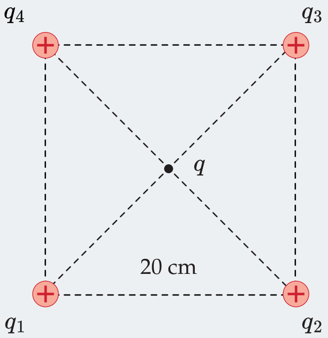


Incepting Ideas (7)

Hint: Think vectorially. No pairing needed

Homework Practice Problem: Try it Yourself

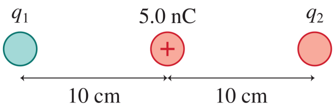
Q: Calculate $\vec{E}$ at the center. Take $q_1 = q_2 = q_3 = q_4 = +2$ nC.



Incepting Ideas (8)

Hint: Force cancellation

Q: q_2 is in equilibrium. What is q_1? What type?



Incepting Ideas (12)

Hint: Practice! Practice! Practice!

Some Problems to Practice at Home on $\vec{E}$ and $\vec{F}_E$ topic

Example Problem 21.1, p-715, 21.2, p-716, 21.3, 21.4, p-717, 21.8, p-724. | Young-Freedman
Exercise Problem 21.38, p-739, 21.55, p-740 | YF
Checkpoint 2, p-615, 1, p-634, 3, p-646 | Resnick-Halliday
Sample Problem 21.01, p-616, 21.02, p-618, 22.01, p-634 | RH
Exercise Problem 3, 8, 9, p-623, 10, p-625, 14, p-652, 7, 9, p-653 | RH

YouTube:

- https://youtu.be/S3GXdZnfBDQ
- https://youtu.be/LnuqOURImqY

That is it for today!