Coulomb’s Law

PHY 114-01

Fall 2026

Welcome!

- Sit next to at least one person to work with
- Discuss: are you ready to turn in the homework tonight?

Agenda

- Last time:
  - Properties, behaviors, and sources of electric charge
  - Flow and distribution of charge in materials

- This time:
  - The electric force law

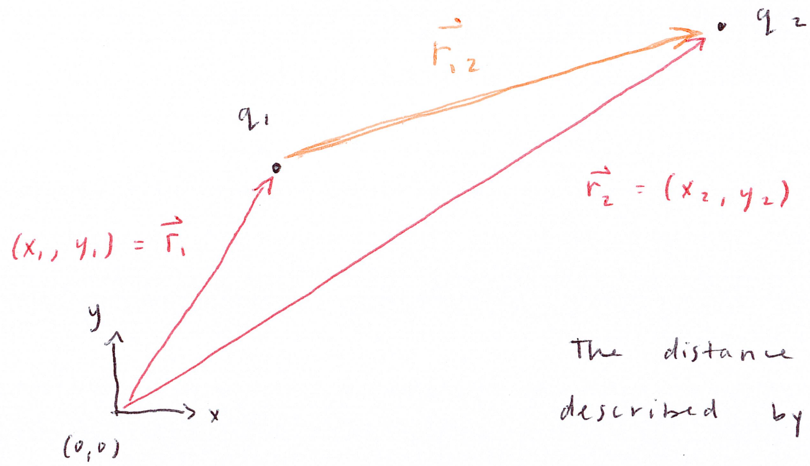
Observations about charge interactions

- Two kinds of charges
- Like charges repel
- Opposite charges attract
- Charges need to be close together to interact

Direction of the electric force

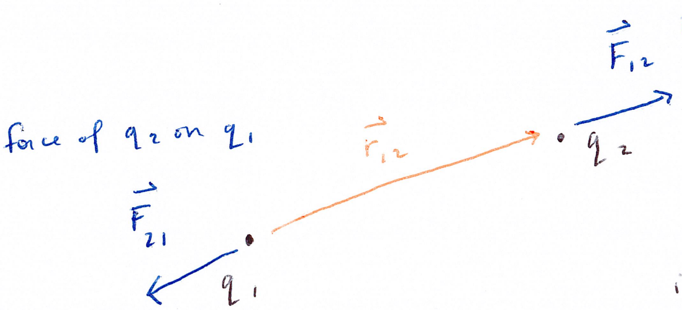
Opposites attract → For two charges q_1 and q_2, the force should line up with the connecting axis between the charges.

Likes repel



The distance between q_1 and q_2 is described by the vector $\vec{r}_{12}$

$$\vec{r}_{12} = \vec{r}_2 - \vec{r}_1 = (x_2 - x_1, y_2 - y_1)$$



Let's say q_1 and q_2 have the same sign. Then we can draw in the forces as shown to the left.

$\vec{F}_{12}$ is in the same direction as $\vec{r}_{12}$ $(\hat{F}_{12} = \hat{r}_{12})$

$\vec{F}_{21}$ is in the same direction as $\vec{r}_{21} = -\vec{r}_{12}$

$$\boxed{\text{So } \vec{r}_{12} \text{ gives the direction of } \vec{F}_{12}\text{, up to some } \underline{\underline{\text{sign change}}} \text{ for opposite changes.}}$$

Magnitude of the electric force

- What quantities should the magnitude of the force depend on?
  - Charge values
  - Distance between charges
  - Scaling

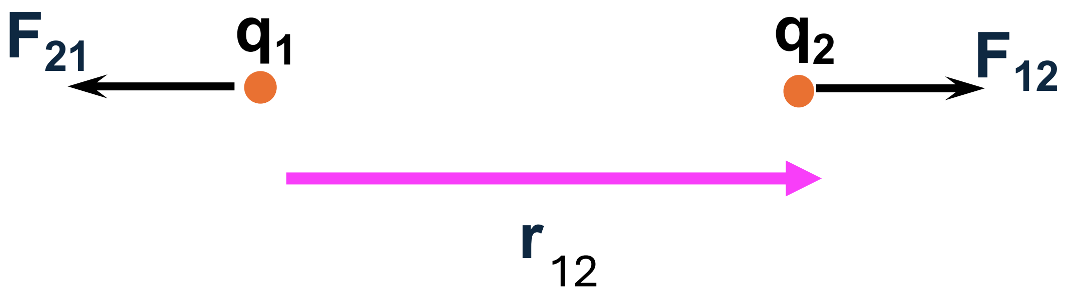
$$\frac{1}{r^2}$$

$$k = \frac{1}{4\pi\varepsilon_0} = 8.99\times10^9\,\frac{N\cdot m^2}{C^2}$$

ε_0 is called the permittivity of free space (we'll see this again later)

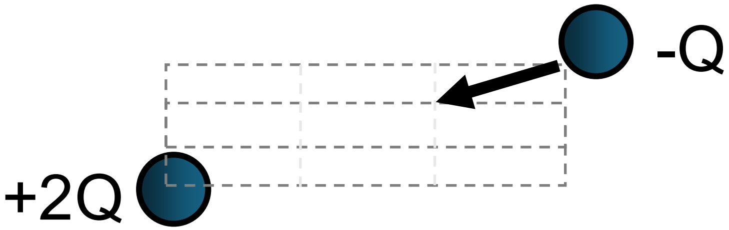
Coulomb's Law

- Congratulations! You have constructed Coulomb's law.
- $\overrightarrow{F_{12}} = \dfrac{kq_1q_2}{r_{12}^2}\,\hat{r}$



Check your understanding

Two charges, -Q and +2Q are placed a distance R apart. The magnitude and direction of the force F on the -Q charge is shown by the arrow. Which of the following arrows represents the ***approximate*** magnitude and direction of the force on the +2Q charge?



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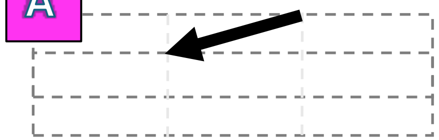

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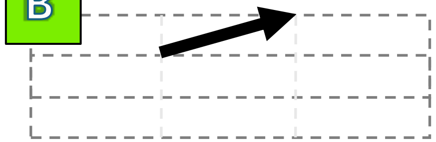

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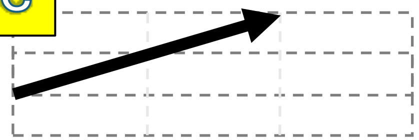

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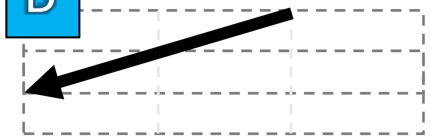
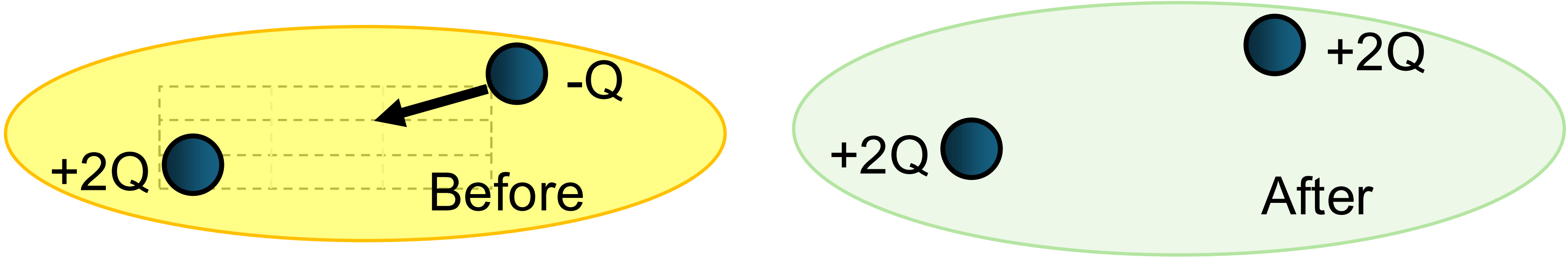
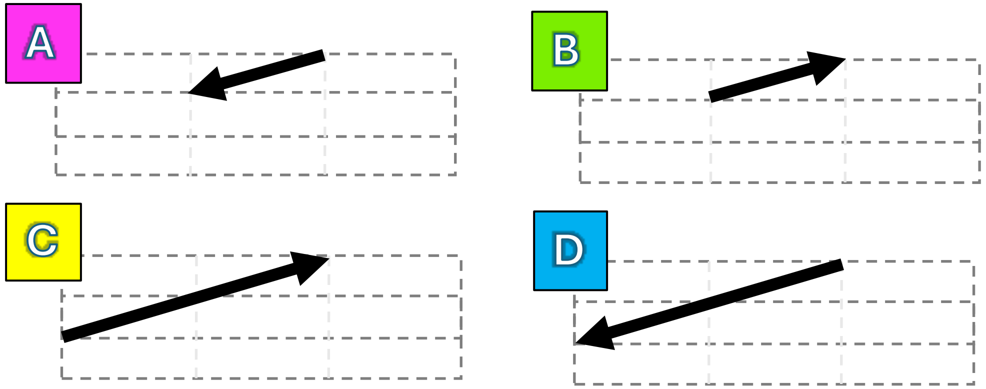


E None of the above

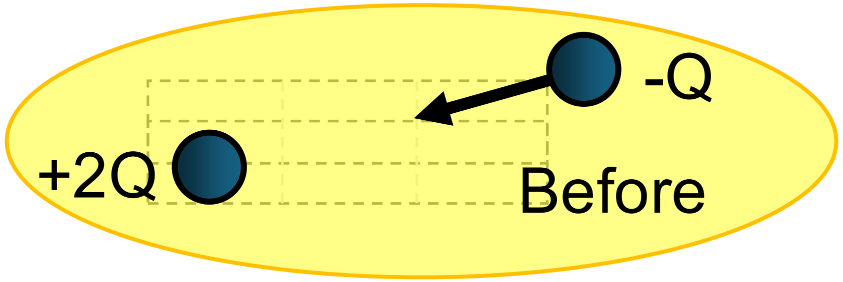
Two charges, -Q and +2Q are initially placed a distance R apart. The magnitude and direction of the force F on the -Q charge is shown by the arrow in the “Before” picture. Next, the –Q charge is changed to +2Q. Which of the following arrows represents the ***approximate*** magnitude and direction of the new force on the ***bottom*** +2Q charge?

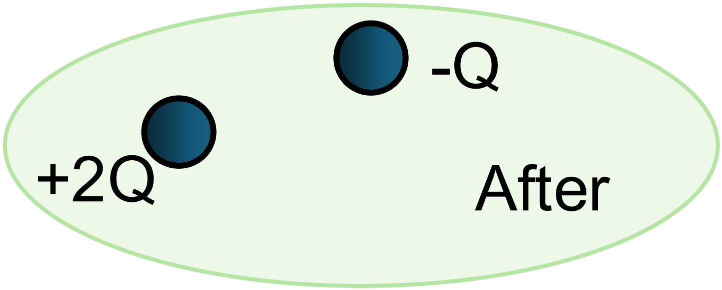


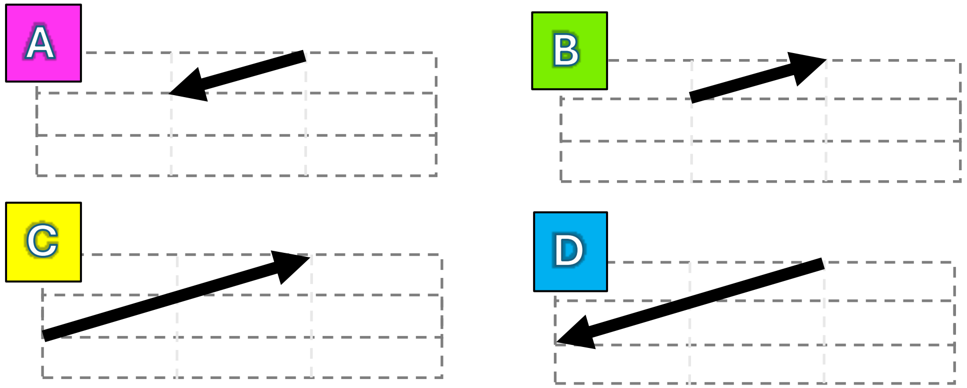


E None of the above

Two charges, -Q and +2Q are initially placed a distance R apart. The magnitude and direction of the force F on the -Q charge is shown by the arrow in the “Before” picture. The charges are then moved to a separation distance of R/2. Which arrow’s **direction and length** represents the new force on the +2Q charge?







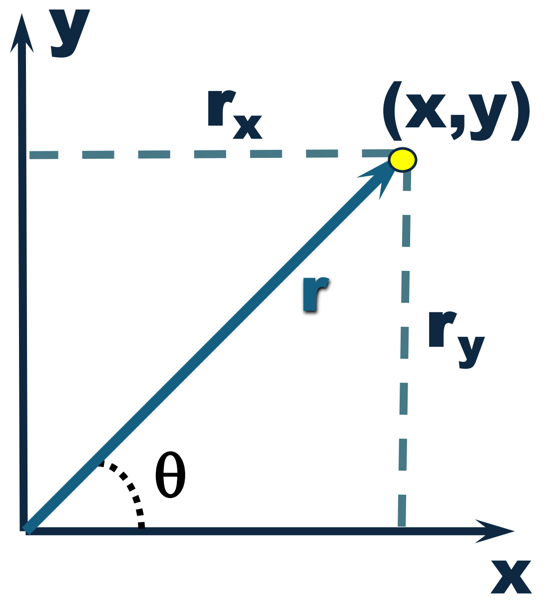
E None of the above

Vector Forces

- Forces have magnitude and direction
- This makes them a vector quantity!

Vectors and Components

- Components of **r** are its **(x,y)** coordinates
  - $\mathbf{r} = (r_x, r_y) = (x,y)$
- Components can be expressed as:
  - $r_x = x = r\cos\theta$
  - $r_y = y = r\sin\theta$



- From the components we can describe the vector
  - magnitude (length) found using Pythagorean theorem

$$|\mathbf{r}| = r = \sqrt{x^2 + y^2}$$

  - direction from trigonometry:

$$\theta = \arctan\left(y/x \right)$$

Writing Vectors

- **There are a number of ways of writing a vector:**

$$\vec{r} = \left(r_x, r_y, r_z\right)$$

writing the components as an x,y,z set

$$\vec{r} = r_x \hat{i} + r_y \hat{j} + r_z \hat{k}$$

writing the components in terms of unit vectors

- **Unit vectors:**
  - **vectors with magnitude of exactly 1 unit along each of the coordinate axes**

$$\text{x - axis} : \hat{i}$$

$$\text{y - axis} : \hat{j}$$

$$\text{z - axis} : \hat{k}$$

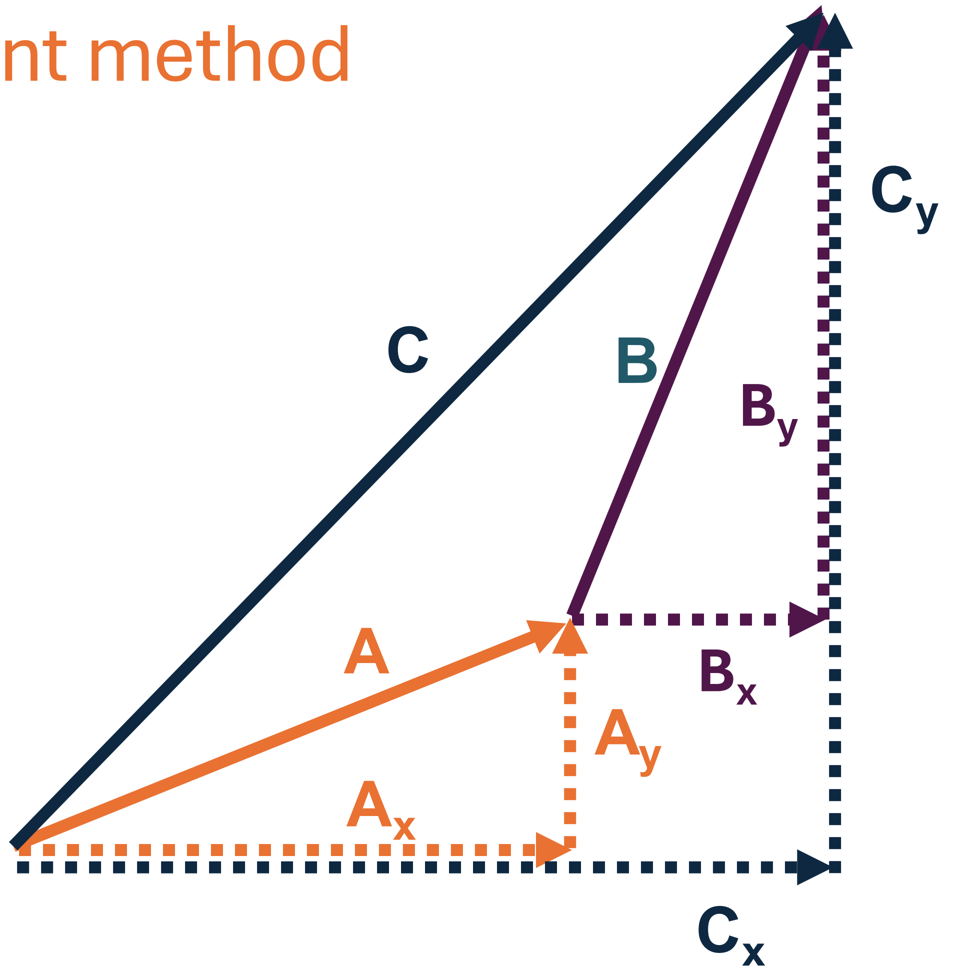
- **expressing vectors in terms of unit vectors is often the most convenient for calculations**

Vector Addition: Component method

If $\quad C = A + B$

then $\quad C_x = A_x + B_x$

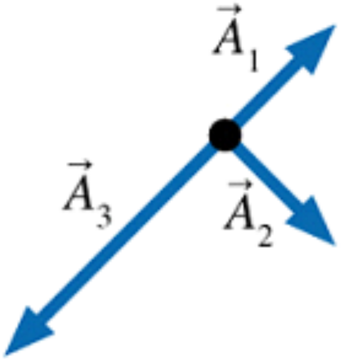
$C_y = A_y + B_y$

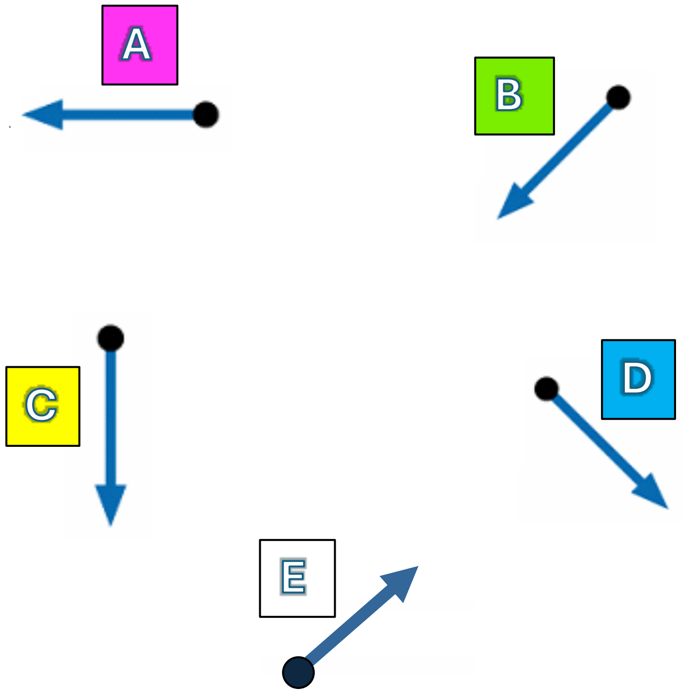


Vector addition:

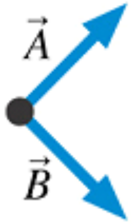
1. **add components**
2. **then use** $|C| = \sqrt{C_x^2 + C_y^2}$

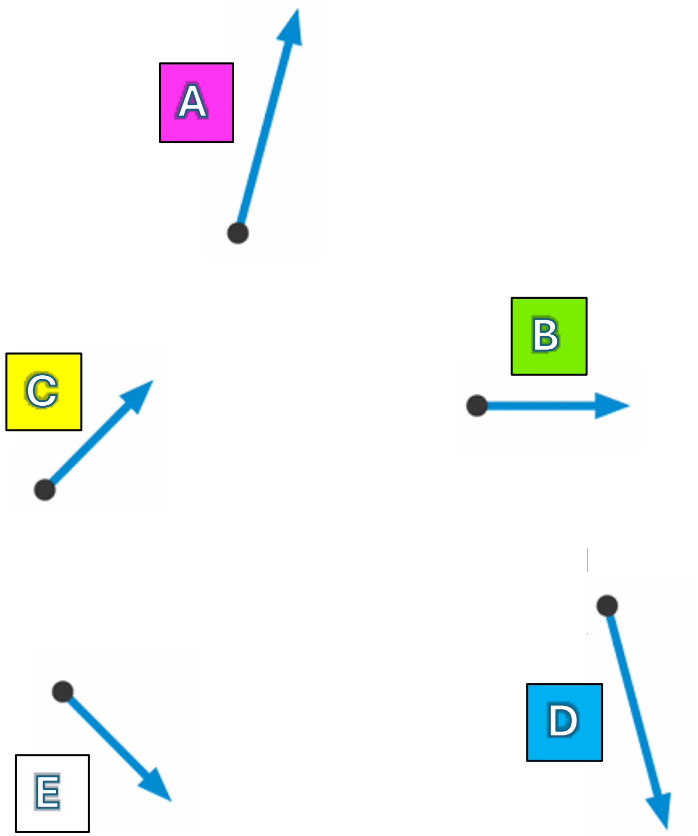
Which figure below best shows $\vec{A}_1 + \vec{A}_2 + \vec{A}_3$?





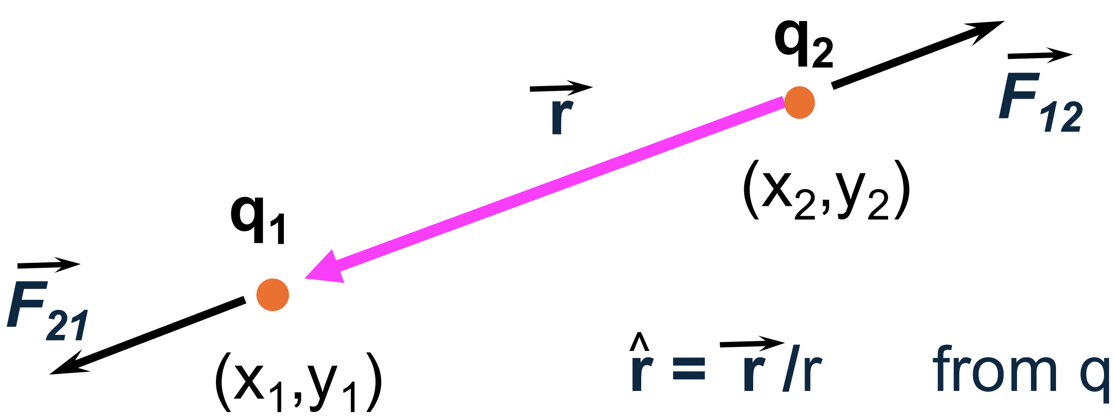
Which figure best shows $2\vec{A} - \vec{B}$?





Coulomb's Law (vector form)

- **The force between 2 charges arbitrarily located**



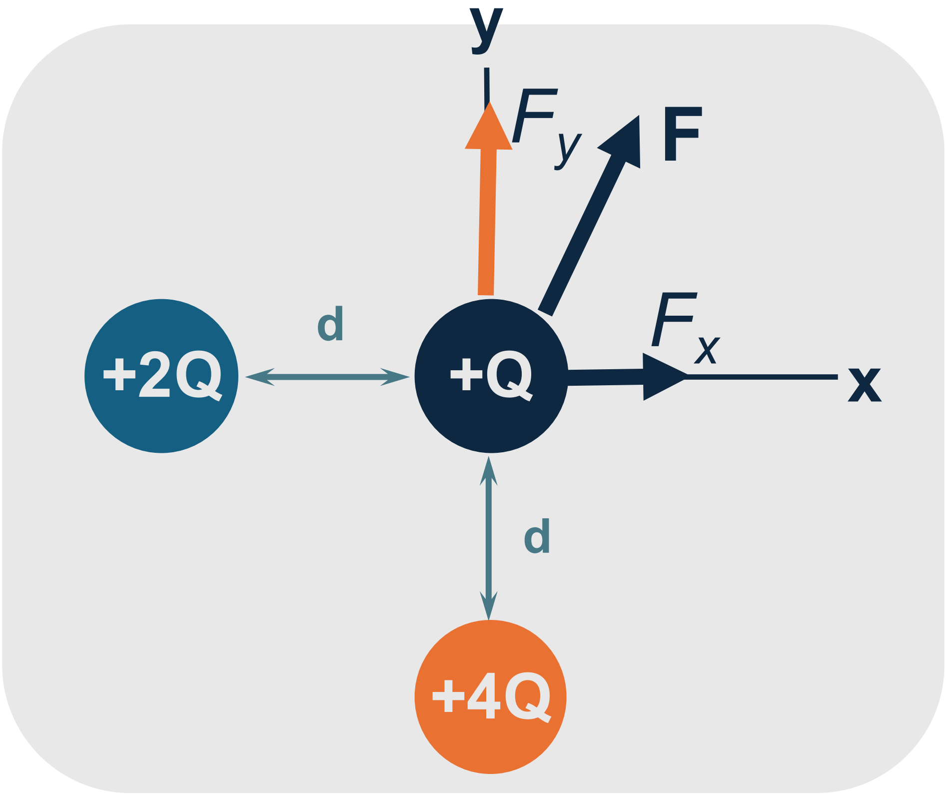
$\hat{\mathbf{r}} = \vec{\mathbf{r}}/r$ from q_2 to q_1

$$\vec{F}_{21} = \frac{k\, q_1 q_2}{r^2}\hat{r} = \frac{k\, q_1 q_2}{r^3}\vec{r}$$

$$= \frac{k\, q_1 q_2}{r^3}\left[(x_1 - x_2)\hat{\imath} + (y_1 - y_2)\hat{\jmath} + (z_1 - z_2)\hat{k}\right]$$

We need vectors to solve problems with multiple charges.

Find the direction and magnitude of the net force on charge +Q due to the other two charges.



Problem

Coulomb's Law

- **Charges are placed at each corner of a square 1.0 m on a side. Find the magnitude and direction of the net force on charge q_1 and q_2.**