### Electric Force

Coulomb’s Law: Electric force between two charges:

\[
F_e = k \frac{q_1 q_2}{r^2}
\]

(Coulomb’s Law Constant)

\( q_1, q_2 = \text{charges (C)} \)

\( r = \text{charge separation (m)} \)

This equation yields force, not direction.

Since charge can be positive or negative, force has a positive or negative sign which indicates direction.

Positive = repulsive force, negative is attractive.

### Electric Force Details

Electric force is a field force, like gravity, where contact is not necessary.

Big difference: gravity is attractive, while electric force is repulsive or attractive.

### Hydrogen Example:

In hydrogen, the electron and proton are separated by 5.3 E -11 meters. Find the electric force: the charges are –1.6 E -19 C and +1.6 E -19 C.

**Setup:**

\[
F_e = k \frac{q_1 q_2}{r^2}
\]

\[ F_e = 9.0 \times 10^9 \frac{N \cdot m^2}{C^2} \left( \frac{-1.6 \times 10^{-19} C \cdot 1.6 \times 10^{-19} C}{(5.3 \times 10^{-11} m)^2} \right) = -8.2 \times 10^{-8} N \]

The negative sign indicates an attractive force between the particles.

### Ratio Examples

2. Consider two positive charges. How would the force between them change if one were doubled?

\[
F_e = k \frac{q_1 q_2}{r^2} \rightarrow k \frac{2q_1 \cdot q_2}{r^2} \]

The force doubles.

3. How would the force change if one were tripled, and the other halved?

\[
F_e = k \frac{q_1 q_2}{r^2} \rightarrow k \frac{3q_1 \cdot \frac{1}{2} q_2}{r^2} \]

The force increases by a factor of 1.5.

4. If both charges double, and the radius triples?

\[
F_e = k \frac{q_1 q_2}{r^2} \rightarrow k \frac{2q_1 \cdot 2q_2}{(3r)^2} \]

The force diminishes by a factor of 4/9.
**Superposition**

With several charges, the net force equals vector sum of the individual forces.

1 and 2 are attracted

1 and 3 are attracted

1 is attracted by 2 and 3, so its overall response is the red vector.

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**4. Conceptual Force Vectors**

For the following configurations, what is the resulting force on the test charge?

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**5. Superposition Example:**

For the following system, find the magnitude and direction of the force on q₃.

\[ F = k \frac{q_1 q_3}{r^2} \]

\[ = 9.0 \times 10^9 \frac{N \cdot m^2}{C^2} \cdot \frac{(+6.0 \times 10^{-9} C)(+5.0 \times 10^{-9} C)}{(5.0 m)^2} \]

\[ = +1.1 \times 10^{-8} N \] (Repulsive force)

**Superposition Answer 1**

Calculate forces for both pairs of charges:

1. Decompose:
   \[ F_{q_1-q_3} = +1.1 \times 10^{-8} N \text{ at } 37^\circ \]
   x-component: \[ F_{x} = F \cos \theta = 1.1 \times 10^{-8} N \cos 37^\circ = 8.8 \times 10^{-9} N \]
   y-component: \[ F_{y} = F \sin \theta = 1.1 \times 10^{-8} N \sin 37^\circ = 6.6 \times 10^{-9} N \]

2. Add x and y components separately:
   X-component: \[ 3.2 \times 10^{-9} N \]
   Y-component: \[ 6.6 \times 10^{-9} N \]

**Superposition Answer 2**

Vector sum:

1. Decompose: \[ F_{q_1-q_3} = +1.1 \times 10^{-8} N \text{ at } 37^\circ \]
   x-component: \[ F_{x} = F \cos \theta = 1.1 \times 10^{-8} N \cos 37^\circ = 8.8 \times 10^{-9} N \]
   y-component: \[ F_{y} = F \sin \theta = 1.1 \times 10^{-8} N \sin 37^\circ = 6.6 \times 10^{-9} N \]

2. Add x and y components separately:
   X-component: \[ 3.2 \times 10^{-9} N \]
   Y-component: \[ 6.6 \times 10^{-9} N \]

**Superposition Answer 3**

Magnitude:

\[ F = \sqrt{x^2 + y^2} = \sqrt{(3.2 \times 10^{-9} N)^2 + (6.6 \times 10^{-9} N)^2} = 7.3 \times 10^{-9} N \]

Direction:

\[ \theta = \tan^{-1} \left( \frac{y}{x} \right) = \tan^{-1} \left( \frac{6.6 \times 10^{-9} N}{3.2 \times 10^{-9} N} \right) = 64.1^\circ \]

**Homework**

10.2 Problems.
DUE: Next Class.