P2

The unit of charge in the MKS system is the *Coulomb*, symbol C. Electric charges are made up of subatomic charges such as electrons, and a Coulomb contains many, many electrons. Each electron has this charge, known as e:

$$e = 1.6 \times 10^{-19}\ C$$

Charges come in two types — positive and negative, + and –. Electrons have negative charges, and protons have positive charges, for example.

Q. How many electrons are in 1 Coulomb?

A. The correct answer is 6.25×10^{18} electrons.

1. You know that the electric charge of an electron is

$$e = 1.6 \times 10^{-19}\ C$$

2. To find the total number of electrons in 1.0 Coulomb, divide by the charge of a single electron:

$$\text{Number} = \frac{1.0}{1.6 \times 10^{-19}\ C} = 6.25 \times 10^{18}\ \text{electrons}$$

1. How many electrons are in 0.60 Coulomb?

Solve It

2. How many electrons are in 800.0 Coulombs?

Solve It

A force exists between electrical charges. Say you have two charges, q_1 and q_2, and they are a distance r apart. The force pulling them together (if the charges have opposite signs, + and –) or forcing them apart (if the charges have the same sign, + and + or – and –) is

$$F = \frac{k \cdot q_1 \cdot q_2}{r^2}$$

What is k? You can measure this constant, and its value is 8.99×10^9 N-m²/C².

Sometimes, you also see this equation written using a constant ε_o, which is called the *permittivity of free space*, like this:

$$F = \frac{q_1 \cdot q_2}{4\pi\varepsilon_o \cdot r^2}$$

The constant ε_o has the value $8.854 \times 10^{-12}\ C^2/(N\text{-}m^2)$.

Q. What is the force between 2 Coulombs of positive charge 1 km apart?

A. The correct answer is 8.99×10^3 N away from each other.

1. Use this equation:

$$F = \frac{k \cdot q_1 \cdot q_2}{r^2}$$

2. Plug in the numbers:

$$F = \frac{k \cdot q_1 \cdot q_2}{r^2} = \frac{(8.99 \times 10^9) \cdot (1.0) \cdot (1.0)}{(1000)^2} =$$

8.99×10^3 N

Because the charges have the same sign, the force pushes them apart.

3. What is the force between an electron and a proton 1.0×10^{-8} m apart?

Solve It

4. What is the force between two protons 1 cm apart?

Solve It

5. What is the force between a charge of 1.0×10^{-3} Coulombs and a charge of -3.0×10^{-3} Coulombs 1.0 m apart?

Solve It

6. What is the force between a charge of 1 Coulomb and a charge of 2 Coulombs, both positive, 10.0 m apart?

Solve It

Take a look at Figure 15-1, which shows three charges: two negative and one positive. The negative charges are at (–1.0, 0.0) and (1.0, 0.0), and the positive charge is at (0.0, 1.0), where all distances are in centimeters.

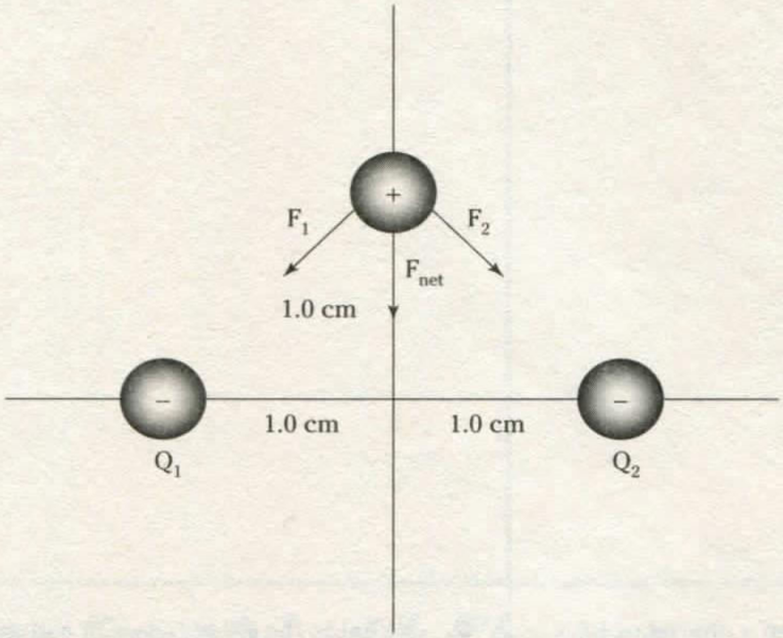

Figure 15-1: Three charges.

Because the force between electrical charges is a vector, those forces add as vectors. You might try to figure out the net force on the positive charge in the figure, for example.

Q. What is the net force on the positive charge if all charges have the magnitude 1.0×10^{-3} Coulombs?

A. The correct answer is 6.35×10^7 N downward.

1. As you can see in the figure $F_1 = F_2$, so:

$$F_{net} = 2\ F_1 \cos(45^\circ) = \sqrt{2}\ F_1$$

2. Solve for F_1:

$$F_1 = \frac{kQ_1Q}{r^2} = \frac{(8.99 \times 10^9)(1.0 \times 10^{-3})(1.0 \times 10^{-3})}{(0.01^2 + 0.01^2)} =$$

4.5×10^7 N

3. So that makes F_{net}:

$$F_{net} = 2\ F_1 \cos(45^\circ) = \sqrt{2}\ F_1 = \sqrt{2}\ 4.5 \times 10^7 = 6.35 \times 10^7\ \text{N}$$

As you can see in the figure, F_{net} points downward.

7. If the charges in Figure 15-1 all have the magnitude 1.0×10^{-8} C, what is the net force on the positive charge?

Solve It

8. If the charges in Figure 15-1 are two electrons and a proton, what is the net force on the proton?

Solve It

The electric field at a particular location is defined as the force felt per Coulomb at that location. Here's the equation for electric field (note that it's a vector):

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

What is the electric field from a single item of charge (often called a *point charge* because its physical dimensions are negligible), such as with a single electron? You know that for a point charge Q, the force felt by a charge q distance r away is

$$F = \frac{k \cdot q \cdot Q}{r^2}$$

What's the electric field from this point charge? Just divide by the magnitude of your test charge, q, to get the force per Coulomb:

$$E = \frac{F}{q} = \frac{k \cdot Q}{r^2}$$

What are the units? You have force divided by Coulombs, so the units are N/C.

An electric field is drawn as a field of vectors, as you can see in Figure 15-2. It points inward — toward the point charge — for negative charges and outward for positive charges.

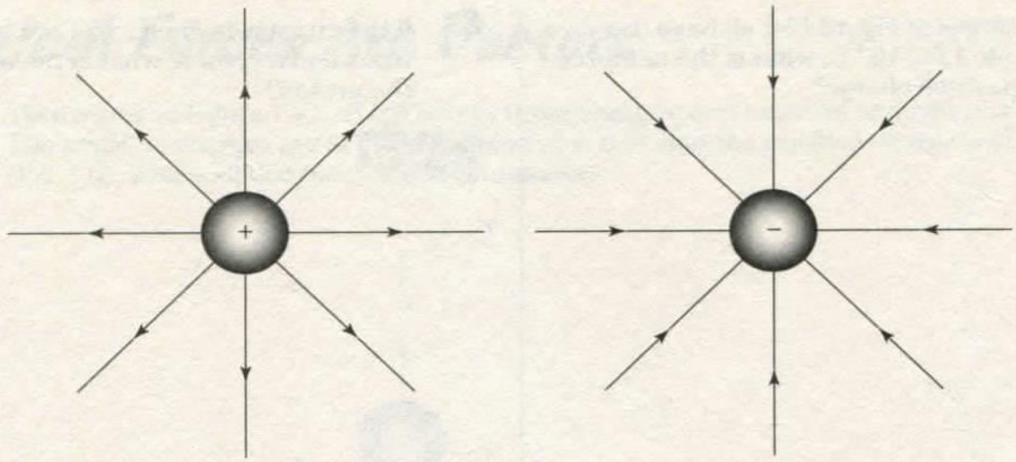

Figure 15-2: Electric fields from point charges.

Q. What is the electric field 1.0 cm away from a proton?

A. The correct answer is 1.4×10^{-5} N/C radially outward.

1. Use this equation:

$$E = \frac{kQ}{r^2}$$

2. Plug in the numbers:

$$E = \frac{k \cdot Q}{r^2} = \frac{(8.99 \times 10^9) \cdot (1.6 \times 10^{-19})}{(0.01)^2} =$$

$$1.4 \times 10^{-5} \text{ N/C}$$

The electric field of a positive charge extends radially outward.

9. What is the electric field from an electron 1.0 cm away from it?

Solve It

10. What is the electric field from a point charge of −1.0 C 1.0 m away from it?

Solve It