# Physics 25 Chapter 18

Electric Charge and Electric Force
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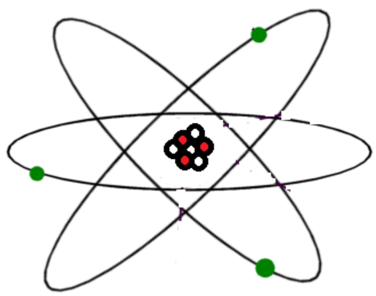
Video Lecture 1: Electric Force

There is an error in Video Lecture 1. The expression shown for the force A is actually the expression for the force B, and vice-versa. The numerical answers for A and B are correct, however: Both answers are the same: $2.56 \times 10^{-9}$ N.

Video Lecture 2: Adding Forces



## Electric Charge

All atoms consist of electrons which orbit the nucleus, and "quarks," which are found inside the protons and neutrons that reside in the nucleus.

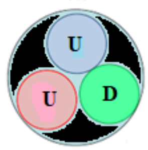
Electrons and quarks have a property called "electric charge," symbolized as q, and measured in "coulombs," C. A quantity of charge that occurs often in this chapter is symbolized for convenience as indicated below:

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

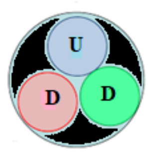
The charges of the electron and the quarks are shown in the table below as a multiple of e:

| Particle | Charge |
|---|---|
| Electron | -e |
| Up quark | 2/3 e |
| Down quark | -1/3 e |

Protons consist of two up quarks and one down quark:

| | |
|---|---|
| Proton  | $(2/3)\ e + (2/3)\ e + (-1/3)\ e = e$<br><br>The proton charge is $1.6 \times 10^{-19}$ C. |

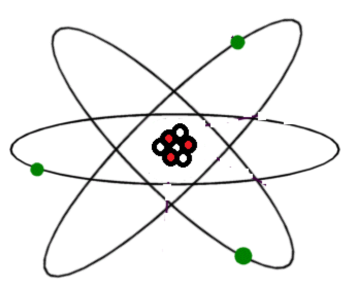
Neutrons consist of two down quarks and one up quark:

| | |
|---|---|
| Neutron  | $(-1/3)\ e + (-1/3)\ e + (2/3)\ e = 0$<br><br>The neutron is "neutral" ; its charge is zero. |

# Atoms

Atoms have a central core where 99.99% of the atom's mass resides. The nucleus occupies an almost negligibly small fraction of an atom's volume. The nucleus compared to the atom's volume is similar to the comparison between a marble and an empty football stadium.

The nuclei of atoms consist of protons and neutrons.



Atoms are "neutral"; there are as many electrons orbiting the nucleus as there are protons in the nucleus. Thus, the net charge is zero.

## Ions

When electrons are added to, or removed from, an atom, the resulting object is called an "ion" and the atom is said to have been "ionized."

For example, if one of the lithium atom's electrons is removed, what is left behind is a lithium ion, which has a net charge q = e. The symbol for the lithium ion is $Li^+$. The superscript "+" indicates that the ion's charge is e.

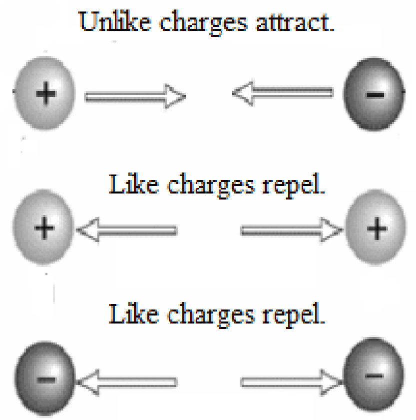
The symbol for a ionized chlorine ion, created when a chlorine atom acquires an electron, is $Cl^-$.

## Electric Force Law ("Coulomb's Law")

Every charged object in the universe exerts a mutual electric force on every other charged object. The force is said to be "mutual" because the force each object feels is the same as the force the other one feels, by Newton's Third Law. This mutual electric force depends on the amount of charge each object possesses, and how far apart they are, according to the electric force law described below:

In the equation below, the upper-case Q's are the *absolute values* of the q's.

$k = 9 \times 10^9$ N-m$^2$/C$^2$
r = Distance between centers
$F = kQ_1Q_2/r^2$




Example A:

A proton and a doubly-ionized magnesium ion, Mg++, are separated by 2.0 Å. What is the mutual force of repulsion (in nano-newtons) between these objects?

1.0 angstrom (Å) = 1.0 x $10^{-10}$ m

$Q_1$ = 1.6 x $10^{-19}$ C
$Q_2$ = 2 (1.6 x $10^{-19}$ C)
= 3.2 x $10^{19}$ C

F = 9 x $10^{9}$ (1.6 x $10^{-19}$) (3.2 x $10^{-19}$) / (2.0 x $10^{-10})^2$
= 1.15 x $10^{-8}$
= 11.5 x $10^{-9}$ N
= 11.5 nN

Example B:

The mutual force between two equal charges Q is 1000 N. What would be the new force if one of the charges were tripled, the other halved, and the separation halved?

$F_1 = kQ/r^2$
$= 1000$ N

$F_2 = k\,(3Q)\,(Q/2)\,/\,(r/2)^2$
$= 6\,(kQ\,/r^2)$
$= 6\,(F_1)$
$= 6\,(1000)$
$= 6000$ N

Example: The electron in a hydrogen atom travels around the nucleus (A proton) in a circular orbit of radius $5.29 \times 10^{-11}$ m. The electron's mass is $9.11 \times 10^{-31}$ kg. What is the electron's speed?

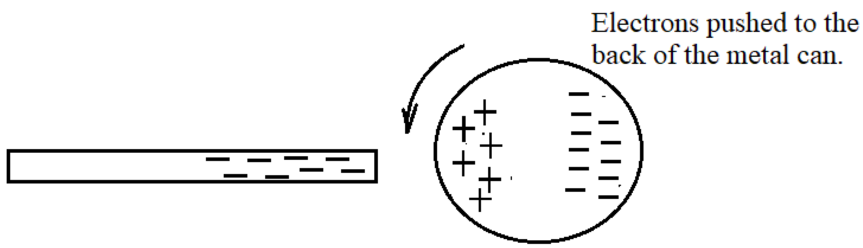
$$ma = F$$
$$m(v^2/r) = ke^2/r^2$$

$$v = (ke^2/mr)^{1/2}$$
$$= 2.19 \times 10^6 \text{ m/s}$$

## Polarization

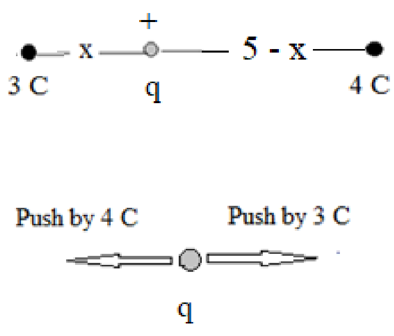
The outermost orbital electrons in metals are easily detached and move freely throughout the metal. This is illustrated below.

As the negatively-charged rod is brought near a metal can, the metal's electrons move away from the rod, leaving behind un-neutralized positively charged metal ions, thereby "polarizing" the can. The positive side of the can experiences a pull toward the rod that is greater than the repulsion the negative side of the can experiences; the can rolls toward the rod.




Example:

The two charges below are separated by 5.0 m. At what distance x to the right of the 3 C charge in the figure may an object with a positive charge q be placed and feel zero net force?



The pushes must be equal:

$k (4)(q) /(5 - x)^2 = k (3)(q)/x^2$

Divide by k (q):

$4 /(5 - x)^2 = 3/x^2$

$x = 2.32$ m

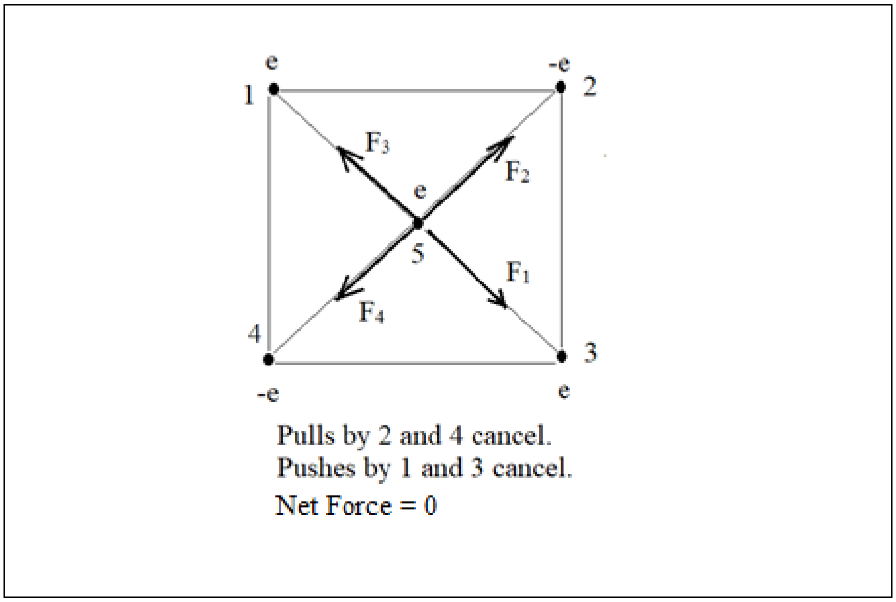
The value of the charge q is irrelevant: its value is canceled out of the equation. Any positive charge placed 2.32 meters from the 3-C charge would feel zero net force.

Any negative charge, too, placed there, would feel zero net force.

Example:

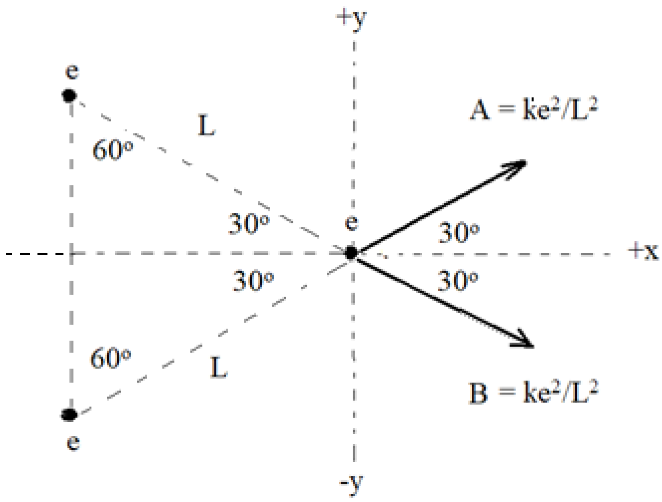
Two protons (q = e) are at Vertices 1 and 3 of a square; two electrons (q = -e) are at Vertices 2 and 4. At the center of the square, at Point 5, is a proton (q = e).

What is the net force on the center proton?




<u>Example</u>:

A proton is located at each vertex of an equilateral triangle of side length L = 2.0 angstroms. What is the net force (in nano-newtons) acting on each proton?




$ke^2/L^2 = 9 \times 10^9 (1.6 \times 10^{-19})^2 / (2.0 \times 10^{-10})^2$
$= 5.76 \times 10^{-9}$ N

**C** = **A** + **B**

$C_x = A_x + B_x$
$= A \cos 30 + B \cos 30$
$= (ke^2/L^2) \cos 30 + (ke^2/L^2) \cos 30$
$= 9.98 \times 10^{-9}$ N
= 9.98 nN

$C_y = A_y + B_y$
$= (ke^2/L^2) \sin 30 - (ke^2/L^2) \sin 30$
$= 0$

$C = (C_x^2 + C_y^2)^{1/2}$
$= (C_x^2 + 0^2)^{1/2}$
$= C_x$
= 9.98 nN

Students who wish to review vector addition using components may consult Physics 23 Chapter 1 linked-to in the website at physics23.com

## Electric Field Intensity

The "electric field intensity" at a point in space is the ratio of the electric force that would act on a charged object placed there, per coulomb. The symbol used to represent the value of the electric field intensity is E.

Let F be the force that would be exerted, and let Q be the magnitude of the test charge placed at that point. The electric field intensity is the force per coulomb that would be exerted on any charge placed at the point:

$$E = F/Q$$

The SI units of electric field intensity are newtons per coulomb (N/C).

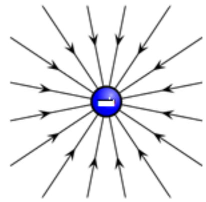
Note: E is a property of a location--a point in space; it's not a property of an object. The table below shows the imagined results of a measurement of E at some point. The force acting on a few different test charges is shown, along with the calculated value of E:

| Q (C) | F (N) | E = F/Q (N/C) |
|---|---|---|
| 2.0 | 6.0 | 3 |
| 4.0 | 12.0 | 3 |
| 7.0 | 21.0 | 3 |

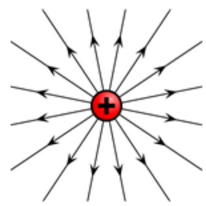
Place a positive test charge on any one of the several curved paths in the figures below and the charge will travel along that path in the directions indicated by the arrowheads. These visual representations of the results of the tests are called "electric fields."

We can obtain a sense of the intensity of the electric field at any point by noting that E is greater where the curves are closely-spaced, and vice-versa.

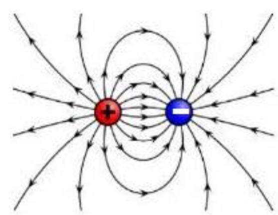
Electric Field due to a Negative Charge



Electric Field due to a Positive Charge



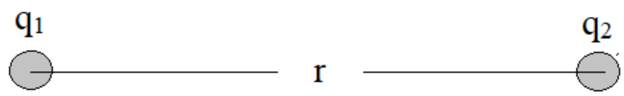
Electric Field of a Dipole



## Electric Potential Energy

The potential energy of a pair of charged objects (shown below) is

$$U = k\, q_1 q_2 / r$$




The physics of the hydrogen atom will be discussed at length in Chapter 30. Applying the equation above to the electron-proton system, we have the following:

$$U = -ke^2/r$$

We will return to this equation later.