18.1 The Origin of Electricity

Example  A Lot of Electrons

(a) How many electrons are there in one litre of nitrogen at “standard temperature and pressure”?  (b) What charge \( Q \) do all those electrons represent?

Solution:
(a) At STP, one mole of an ideal gas (such as \( \text{N}_2 \)) occupies 22.4 L
\( n = \text{number of moles} = \frac{1.00 \text{ L}}{22.4 \text{ L}} = 0.0446 \)

Number of \( \text{N}_2 \) molecules: \( N_{\text{molecules}} = nN_A = (0.0466)(6.02 \times 10^{23}) = 2.69 \times 10^{22} \)

Each molecule contains two atoms, each nitrogen atom contains 7 electrons
\( \rightarrow \) Each molecule contains 14 electrons
\( \rightarrow \) 1.00 L of nitrogen contains
\( N_e = N_{\text{molecules}} \times 14 = (2.69 \times 10^{22})(14) = 3.76 \times 10^{23} \).

(b) \( Q = (q_e)(N_e) = (-1.60 \times 10^{-19} \text{ C})(3.76 \times 10^{23}) = -6.02 \times 10^4 \text{ C} \)

*** Your textbook is somewhat sloppy about the sign of the elementary charge \( e \), but the standard convention is the \( e \) is the (positive) charge of the proton, and an electron has charge \( -e \)
18.2 Charged Objects and the Electric Force

Electric charges impart very large forces. We don’t normally notice them in our everyday environment because atoms are generally neutral.

Exception: static electricity that builds up when objects rub on one another (e.g. your cat walking on carpet). The forces are especially noticeable in dry climates where the dry air prevents the “static” charges from dissipating.

Moisture in air generally dissipates static quickly, or prevent any buildup in the first place.

Typical static charges are
In the nC – µC range:

- peta- (P-) $10^{15}$ 1 quadrillion
- tera- (T-) $10^{12}$ 1 trillion
- giga- (G-) $10^9$ 1 billion
- mega- (M-) $10^6$ 1 million
- kilo- (k-) $10^3$ 1 thousand
- hecto- (h-) $10^2$ 1 hundred
- deka- (da-)** $10^1$ 1 ten
- deci- (d-) $10^{-1}$ 1 tenth
- centi- (c-) $10^{-2}$ 1 hundredth
- milli- (m-) $10^{-3}$ 1 thousandth
- micro- (µ-) $10^{-6}$ 1 millionth
- nano- (n-) $10^{-9}$ 1 billionth
- pico- (p-) $10^{-12}$ 1 trillionth
- femto- (f-) $10^{-15}$ 1 quadrillionth

You are expected to know these

http://www.youtube.com/watch?v=tP-Csq96nXM
18.2 Charged Objects and the Electric Force

It is possible to transfer electric charge from one object to another by rubbing.

The body that loses electrons has an excess of positive charge, and the body that gains electrons has an excess of negative charge. E.g.

(1) Glass rod rubbing on fur, wool or silk makes the glass positively charged

(2) Ebonite (vulcanized hard rubber) rubbing on fur, wool or silk makes the ebonite negatively charged

One charged, like charges repel, while opposite charges attract

LAW OF CONSERVATION OF ELECTRIC CHARGE
During any process, the net electric charge of an isolated system remains constant (is conserved).
18.3 Conductors and Insulators

Not only can electric charge exist on an object, but it can also move through and object.

Substances that readily conduct electric charge are called electrical conductors. These allow some of its internal electrons to move freely within examples: metals, graphite, water, molten salts

Materials that conduct electric charge poorly are called electrical insulators. These have few electrons that are free to move within example: common ceramics, plastics, rubber, glass

Materials that tend to be good thermal conductors also tend to be good electrical conductors
18.4 Charging by Contact and by Induction

Charging by contact:

The excess charge flows into the metal sphere because the charges want to be as spread out as possible:

**Like charges repel !!!**

Charging by electrical induction.

In electricity, the **ground** (literally) behaves like an infinite reservoir of charge that can absorb or donate as many electrons as needed without changing its electrical potential.
18.4 Charging by Contact and by Induction

The negatively charged rod induces a slight positive surface charge on the plastic.

Neutral, but “polarizable” objects are attracted to both positive and negative charges.

The case in the video has the reversed polarity.

http://www.youtube.com/watch?v=g9GU3XpiepM
Example: Four identical metallic objects carry the following charges: +1.6, +6.2, −4.8, and −9.4 μC. The objects are brought simultaneously into contact, so that each touches the other three simultaneously. Then they are separated.
(a) What is the final charge on each object?
(b) What is the number of excess or deficit electrons on each?

Solution:

(a) The 4 objects are identical and are conductors so charge can flow freely between the four. Being identical, then the overall charge spreads out as evenly as possible over the four objects.

So \( q_1 = q_2 = q_3 = q_4 = q = Q/4 \), where \( Q \) = total charge of the four objects originally (and afterwards − charge is conserved!)

\[
Q = (1.6 + 6.2 − 4.8 -9.4) \, \mu C = -6.4 \, \mu C \Rightarrow q = -1.6 \, \mu C \] on each object.

(b) The charge \( q \) is negative so we have an excess of electrons

\[
Ne = q/(-e) = (-1.6 \times 10^{-6} \, C)/((-1.6 \times 10^{-19} \, C)) = 1.0 \times 10^{13}
\]
Towards a quantitative description of electrical interactions: **Electrical Force**

We already observed

(a) attraction/repulsion does not require contact (“action-at-a-distance”)

(b) The forces get stronger between two charged objects the closer they approach: what is the mathematical relationship between the separation and the magnitude of the force?

In terms of Newtonian forces, which are vectors, we also need to specify the direction of the electrical forces between two charged objects.

Like charges repel: The force on each charge points DIRECTLY away from the other

Opposite charges attract The force on each charge points DIRECTLY toward the other

In each case, the forces between a pair of charges are directed along the line connecting to the two charges
**18.5 Coulomb’s Law**

The **magnitude** of the **electrostatic force** exerted by one point charge on another point charge is directly proportional to the magnitude of the charges and inversely proportional to the square of the distance, \( r \), between them.

\[
F = |\vec{F}_{12}| = |\vec{F}_{21}| = k \frac{|q_1| |q_2|}{r^2}
\]

**“Coulomb’s Law”** is often understood to include both the inverse square law here plus the rules for the directions from the previous slide.

\[
k = \frac{1}{4\pi \varepsilon_0} = 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2
\]

\[
\varepsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/(\text{N} \cdot \text{m}^2)
\]

“permittivity of free space”

“Coulomb’s constant”
A “scientific law” is by definition the conceptual generalization of patterns observed in nature and in experiments.

Coulomb’s inverse square law was a generalization of a series of experiments conducted by Coulomb.

This video shows a demonstration of Coulomb’s Law by varying the distance between two charges and by reducing one charge by half.

http://www.youtube.com/watch?v=B5LVoU_a08c
Example  A Model of the Hydrogen Atom

In the Bohr model of the hydrogen atom, the electron is in orbit about the nuclear proton at a radius of $5.29 \times 10^{-11}$ m. Determine the speed of the electron, assuming the orbit to be circular.