Chapter 4: The electromagnetic Interaction

Early observations
The Greeks noticed by at least 600 B.C. that amber rubbed with fur could attract things.

Demo: rod, cats fur, bits of paper

Franklin hypothesized that a “fluid” was exchanged in the charging and discharging process

Too little fluid-negative
Too much fluid-positive

Some Experiments: hanging rods
1. Two rubber rods repel one another.
2. A glass rod and a rubber rod attract one another.
3. Two glass rods repel one another.

We say:
- the rubber rod is negative
- the glass rod is positive

P2: When you run a hard rubber comb through your hair on a dry day, the hair stands up. It is also attracted to the comb. What interaction is at work?
Electrically charged objects attract or repel one another

Like charges repel and opposite charges attract.
The more “charged” the objects are, the stronger the interaction.
The closer charged objects are, the stronger the interaction.

Coulomb quantified the electric force law

\[ F = \frac{kQq}{d^2} \]

Familiar “inverse square” relationship.

Q and q can be positive or negative (M and m could only be positive in gravity).
k is much, much bigger than G, so the electrical interaction is much stronger than the gravitational interaction.

J. J. Thompson showed that Franklin’s “fluid” model was not entirely correct.

Matter is composed of positive and negative charged particles
The positive parts of atoms had essentially the same mass as the atoms

The Millikan/Fletcher oil drop experiment provided conclusive proof that charges come in lumps


A note of interest to BYU, Harvey Fletcher

Electrical Model of Matter (1)

1. Matter contains two kinds of electrically charged particles: “-” negatively charged electrons (e-) and “+” positively charged protons (p+). Electrons have little mass and can be quite easily transferred from one object to another. Protons are far more massive (1836 times) and are most often bound tightly inside the nucleus. They are not easily removed.

* Charge is discrete.
Electrical Model of Matter (2)

2. Many objects have equal numbers of protons and electrons. Such objects are electrically neutral.
3. Objects with more electrons than protons are negatively charged (Ben Franklin’s naming). Those with fewer electrons than protons are positively charged. The amount of extra charge of either kind is called “the charge of the object.”

Electric Currents

- electric currents are moving charged particles (usually electrons)
- conductors: electrons move freely
- insulators: electron movement inhibited
- semiconductors: ease of movement is less than conductors, more than insulators

Quizlet: Storing charge

P3: What will happen when I rub a charged rod on an electroscope? Why?
P4: What sign charge is left on the electroscope?

After the electroscope is charged, why doesn’t the charge leave? (dry vs humid day)

Quizlet: Storing charge

P5: What will happen when I touch a charged rod to an electroscope, but also touch the electroscope with my other hand? Why?
P6: What charge is left on the electroscope?

Relative Strengths

Two electrons sitting side-by-side. How important is gravity?
The ratio of the strengths of the forces produced in the two interactions is:

Electromagnetic force \( \sim 10^{42} \)
Gravitational force

If switched the \( k \)

Gravitational attractive force would be \( \sim 10^{32} \) Tons!!
**Let's play with electricity**

Demo: Static Electricity (20,000 volts per inch),
(1) discharge rod (2) puffed rice; (3) light;
(4) Garfield's hair; (5) person

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**Horror of Static Cling**

- Equal amounts of positive and negative charge on scrap of paper. Positive charge on rod.

![Static Cling Diagram]

- Negative shifts slightly closer, since attracted; positive slightly away, since repelled.

![Charge Interaction Diagram]

- Since negatives are closer, net force is attractive on scrap.

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**P7: What happens here?**

Demo: tap water

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**Electric current: Charges in motion**

Generally the conducting wire remains neutral, even though charge is flowing

Resistance to flow causes energy loss

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**Electric circuits**

- Electric currents will continue to flow only if there is a closed circuit
- Electric currents need “sources” such as batteries or generators.
- For batteries, the current flows in the same direction at a constant rate, called direct current (D.C.) The electrons flow away from the negative terminal
- For many generators, the electric current changes direction back and forth 60 times per second, called alternating current (A.C.)

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**On to magnetism**

- A magnet and a compass needle aligning with the Earth's magnetic field

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Magnets produce a force on another magnet

- Freely suspended, one end of the magnet points toward the north, the other south.
- One end of the magnet is called the north pole, or north seeking pole, the other is the south pole.
- Like poles repel, unlike poles attract.
- If a material is attracted to a magnet it is said to be ferromagnetic, otherwise non-ferromagnetic.

Magnetic force

The direction of the force is a little more complicated than for electrically charged particles, but it still depends on distance between the magnets.

An electric current produces a magnetic field

The ferromagnetic material will deflect (point).

Permanent Magnets

Magnetism arises when the atoms (which act as tiny permanent magnets) align themselves in tiny domains.

If you heat a magnet up, the domains can reorient (Curie Temperature).

Changing magnetic fields can cause charges to move (Electricity)

Demo: light bulb and magnet

Electromagnetic Interaction

So:
- moving charges cause magnetic forces/fields
- moving magnetic fields cause electric current
- the complete interaction due to moving and stationary charges and fields is called the electromagnetic interaction.
The grand scheme of science

Laws

And it came to pass that...
\[ E \cdot dA = \frac{q}{\epsilon_0} \]
\[ \int E \cdot dA = 0 \]
\[ \int E \cdot ds = -\frac{dB}{dt} \]
\[ \int B \cdot ds = \mu_0 \int H \cdot dl \]

and there was Light!

Models

Physical Phenomena

If the electromagnetic force is so strong, why don’t we feel it?

Most matter is composed of equal parts of positive and negative charge.
So net charge is zero

Contact forces are due to electrical interactions.

Shows up as air friction, sliding friction, cutting, touching, pushing, resting on something, connected by a rope, etc.

It only exists when things touch.

Atoms can repel or attract, when being distorted from their stable position.

Forces of compression or tension

Push on the ends of chalk -electrons can move further apart relative to the nuclei.

Pull on the ends of the chalk - electrons can fill in

repulsion

attraction