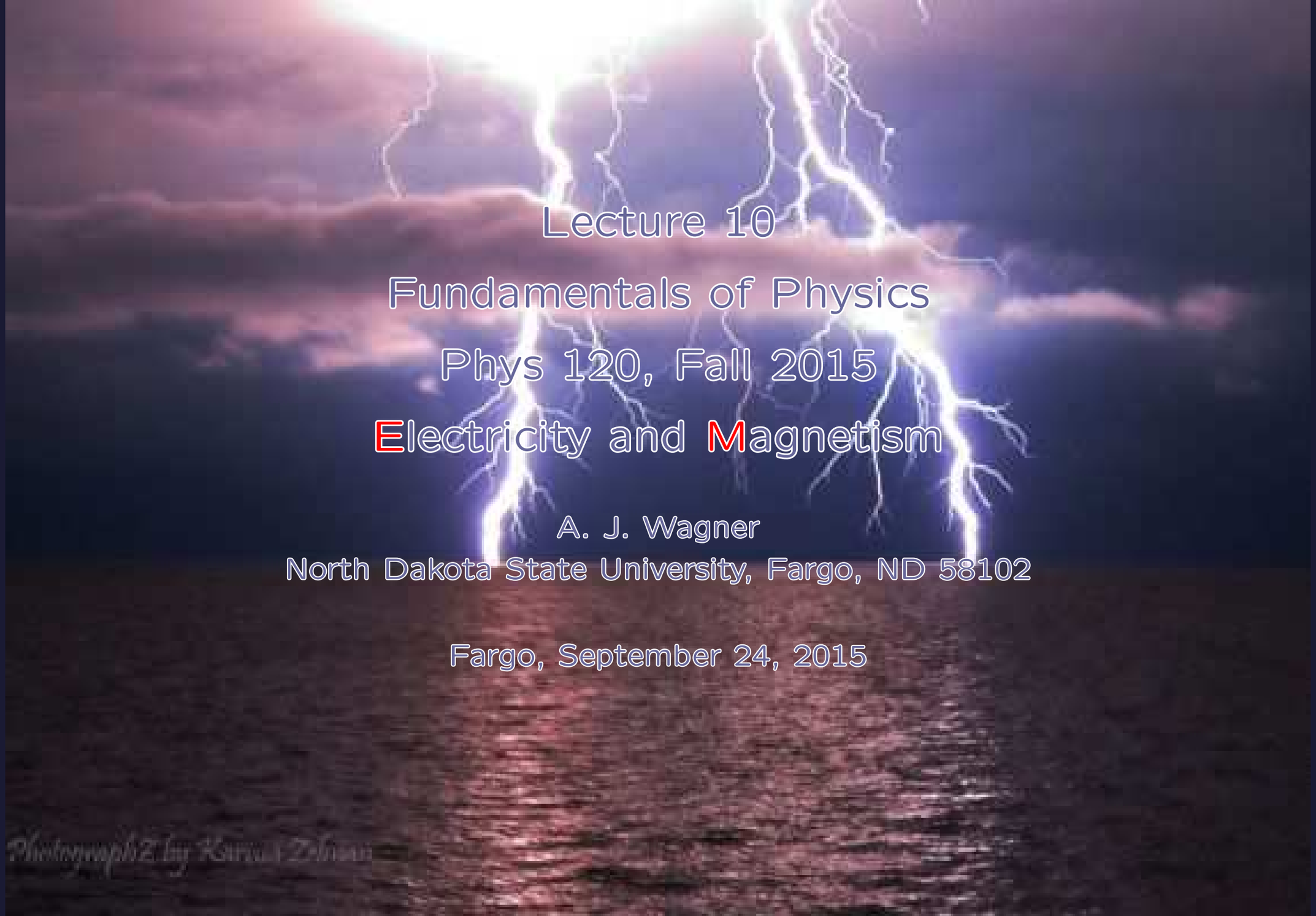


Lecture 10
Fundamentals of Physics
Phys 120, Fall 2015
Electricity and Magnetism

A. J. Wagner
North Dakota State University, Fargo, ND 58102

Fargo, September 24, 2015

Overview

- Unexplained phenomena
- Charges and electric forces revealed
- Currents and circuits
- Electricity and Magnetism are related!

Newton's dream

I wish we could derive the rest of the phenomena of Nature by the same kind of reasoning from mechanical principles, for I am induced by many reasons to suspect that they may all depend upon certain forces by which the particles of bodies, by some cause hitherto unknown, are either mutually impelled towards one another, and cohere in regular figures, or are repelled and recede from one another.

from the preface of Newton's Principia

What were those mysterious phenomena?

900 BC: Magnus, a Greek shepherd, walks across a field of black stones which pull the iron nails out of his sandals and the iron tip from his shepherd's staff (authenticity not guaranteed). This region becomes known as Magnesia.

600 BC: Thales of Miletos(Greece) discovered that by rubbing an 'elektron' (a hard, fossilized resin that today is known as amber) against a fur cloth, it would attract particles of straw and feathers. This strange effect remained a mystery for over 2000 years.

1269 AD: Petrus Peregrinus of Picardy, Italy, discovers that natural spherical magnets (lodestones) align needles with lines of longitude pointing between two pole positions on the stone.

ca. 1600: Dr.William Gilbert (court physician to Queen Elizabeth) discovers that the earth is a giant magnet just like one of the stones of Peregrinus, explaining how compasses work. He also investigates static electricity and invents an electric fluid which is liberated by rubbing, and is credited with the first recorded use of the word 'Electric' in a report on the theory of magnetism. Gilbert's experiments subsequently led to a number of investigations by many pioneers in the development of electricity technology over the next 350 years.

ca. 1620: Niccolo Cabeo discovers that electricity can be repulsive as well as attractive.

Experiment: Charge

There is an "electric" force between charged objects.

This force can be both attractive and repulsive.

More charge means more force.

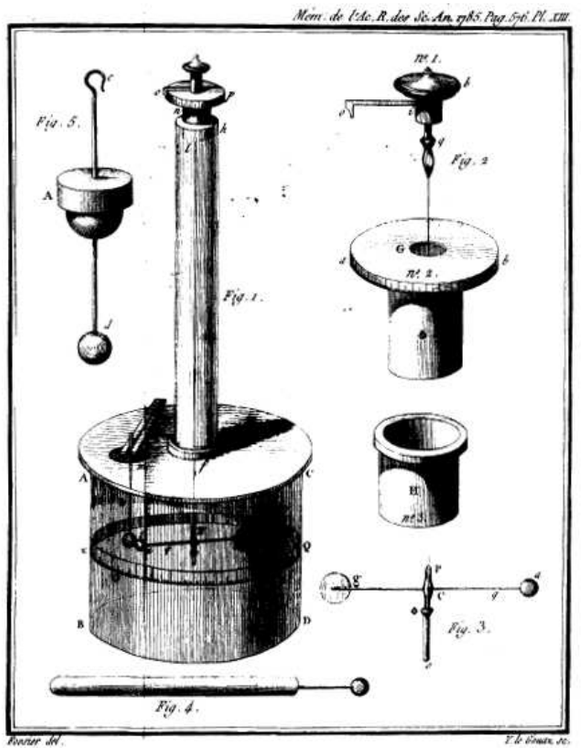
The force is stronger at shorter distances.

Many scientists work on this and speculate on the force law.

Coulomb

Charles-Augustin de Coulomb,
1736 – 1806
French

Coulomb is credited with showing that the electric force law has a similar constitution as Newton's law of gravity. He accomplished this feat by inventing a torsion balance, shown on the right.



Coulomb's law

$$\text{electric force} \propto \frac{(\text{charge of 1st object}) \times (\text{charge of 2nd object})}{\text{square of the distance between them}}$$

or in symbols

$$F \propto \frac{q_1 q_2}{d^2}$$

If the electric charge is measured in Coulomb, distance in meters, and force in Newtons, then the proportionality becomes:

$$F = 9 \times 10^9 \frac{q_1 q_2}{d^2}$$

Concept check

Two objects each carry a charge of 1 C. How much force do they exert on each other at a distance of 1 meter?

a) 1 N
b) 9 N
c) 9 million N
d) 9 billion N
e) about 10^{-10} N

Carl Friedrich Gauss

Carl Friedrich Gauß
1777 – 1855
German

There is a problem with Coulomb's definition of the force. What he actually managed to prove is that the force goes as the inverse square of the distance. However, he had no way of actually measuring the charge. This was turned around by Gauß, who proposed to use Coulomb's law to *define* a unit of charge.
One then has to show that this is consisten with the idea of the conservation of charge (initially held mostly on prinicple), i.e. that adding twice the charge on one sphere will double the force.

Measuring charge: Coulomb

1 Coulomb is the amount of charge that causes an electric force of 9×10^9N on an identical charge at a distance of 1m.

That is about the weight of 25,000 fully loaded highway trucks!

But 1 C is also the amount of charge that flows through a 100W lightbulb in about 1s.

Electric and Gravitational force

The force law looks very similar.

Gravity is only attractive, there is no negative mass!

Electric force between charged particles is vastly larger than gravitational force between those particles. (Hydrogen e-p: factor of 10^{39}!)

Forces have different origins, i.e. mass and charge.

Einstein tried to find a "unified field theory", but this still eludes us. (But electro-weak has been unified).

Making electricity flow

Alessandro Volta
1745–1827
Italian

Alessandro Volta showed in 1800 that it was possible to generate electricity by combining different metals in a pile, a first version of today's galvanic batteries. This invention was crucial as it opened to door to experiments with steady electric current. Within a few years many important discoveries followed like the ability of an electric current to separate water into two gases which were later identified as Hydrogen and Oxygen.

Voltaic Pile
(circa 1800)

Voltaic Pile, copper and zinc disks separated by disks of paper with brine.

Electric circuits

Law of conservation of charge: charge can be moved around and although charged particles can be created or destroyed no net charge (positive minus negative) can be created or destroyed.

Electric conductors: can conduct electric charges through them.

Resistance: charges moving through a conductor experience a resisting force

Current: the amount of charge traveling through a conductor per second

Voltage: the potential energy of the charge between two contacts

Ohms law: voltage = R $\times$ current, $V = RI$.

Electricity and Magnetism are related

Experiment: a magnetic compass needle next to a wire carrying a current.

1820: Hans Christian Oersted discovers that electric current in a wire causes a compass needle to orient itself perpendicular to the wire.

Magnetic Force Law

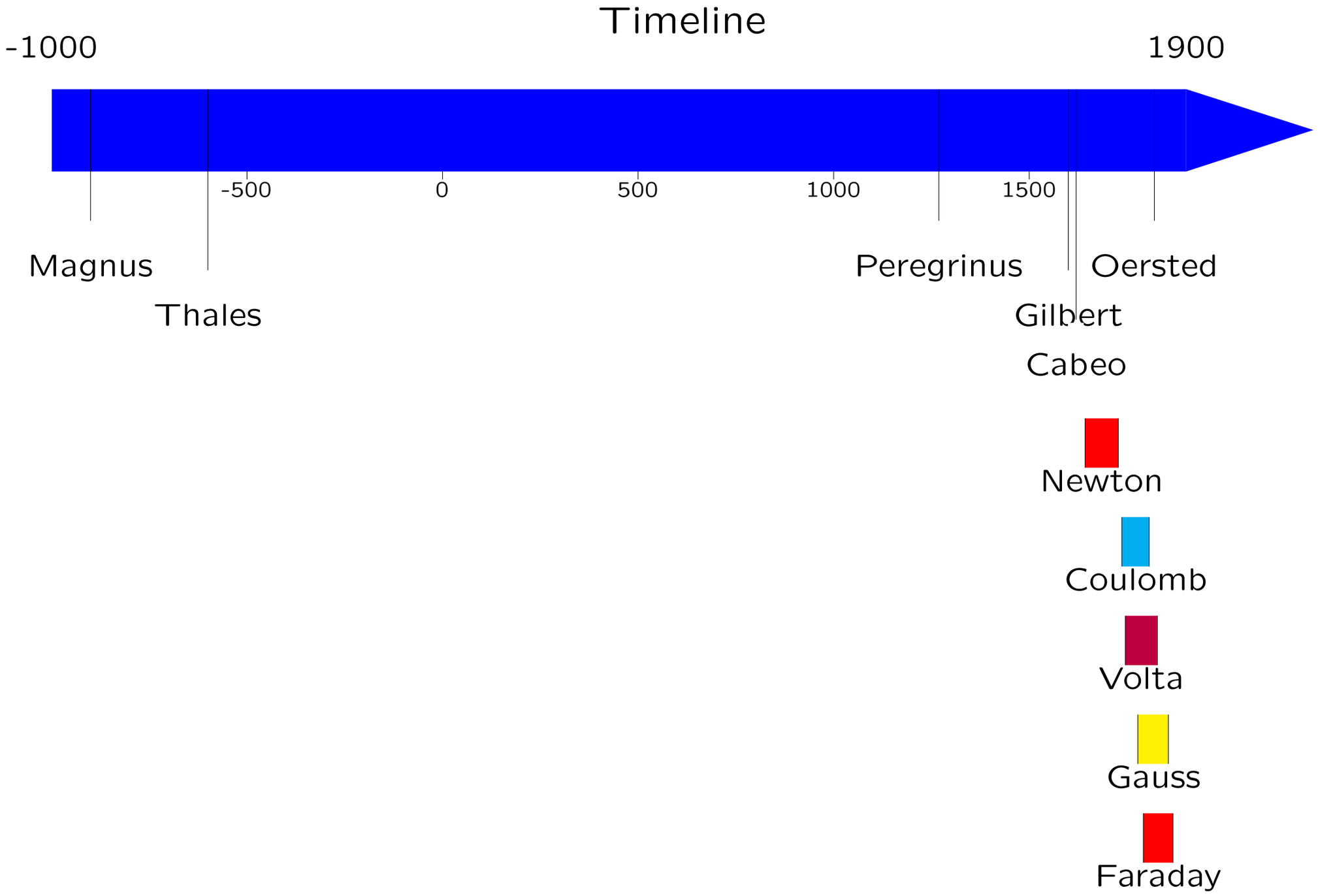
Charged objects that are moving exert and feel an additional force beyond the electric force that exists when they are at rest. This additional force is called the **magnetic force**. All magnetic forces are caused by the motion of charged objects.

Electricity and Magnetism are related

Experiment: a current is induced by a moving magnet.

Faraday's law

When a wire loop is placed in the vicinity of a magnet and when either the loop or the magnet is moved, and electric current is created within the loop for as long as the motion continues.


Timeline
-1000
1900
-500
0
500
1000
1500
Magnus
Thales
Peregrinus
Gilbert
Oersted
Cabeo
Newton
Coulomb
Volta
Gauss
Faraday

Summary

- There are other fundamental force out there (beside gravity)!
- There are magnetic objects that attract (and repell) each other. The earth is a magnet!
- There are electric charges of two kinds
- Equal charges repel, opposite charges attract
- Electrical charges can flow! (and you can build batteries)
- Electric and Magnetic effects are related!
- Currents create Magnetic fields, and changing magnetic fields can cause currents!