Lecture 11

Fundamentals of Physics

Phys 120, Fall 2015

Material underpinning of Electricity and Magnetism

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Lunar eclipse on Sunday (via Thomas Schmidt)

Overview

- What are the material underpinnings of Electricity and Magnetism?
- The electron
- Atoms
- Fields

Summary of last lecture

Key observations:

- electric charges that can be separated
- there are two kinds of electric charge: like repell, opposites attract.
- Volta developed a device to generate continuous electric currents
- moving electric charges cause magnetic fields
- permanent magnets have magnetic fields
- changing magnetic fields can induce currents

Physical underpinnings of Electric and Magnetic Phenomena

But what are these charges? There must be a physical underpinning for the observed charges and their currents. Up to now we don't know what we move when we "charge" and object.

What is the electric current, that generates the magnetic forces we observed, made off?

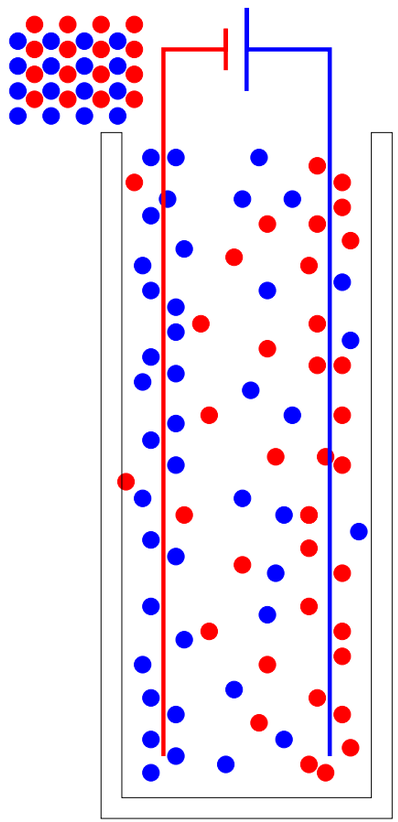
Faraday's observation of charged objects

Michael Faraday (1791-1867) observed that water becomes conductive when certain materials (salts) are dissoved in it. The components that precipitate[a] at the electrodes must have consisted of charged particles, which he called **Ions** (Greek for wanderers).

Swante Arrhenius (1895-1927) proposed that the explanation for this phenomenon is that molecules of electrolytes break up into charged ions in solution, whether there is a Voltage present or not.

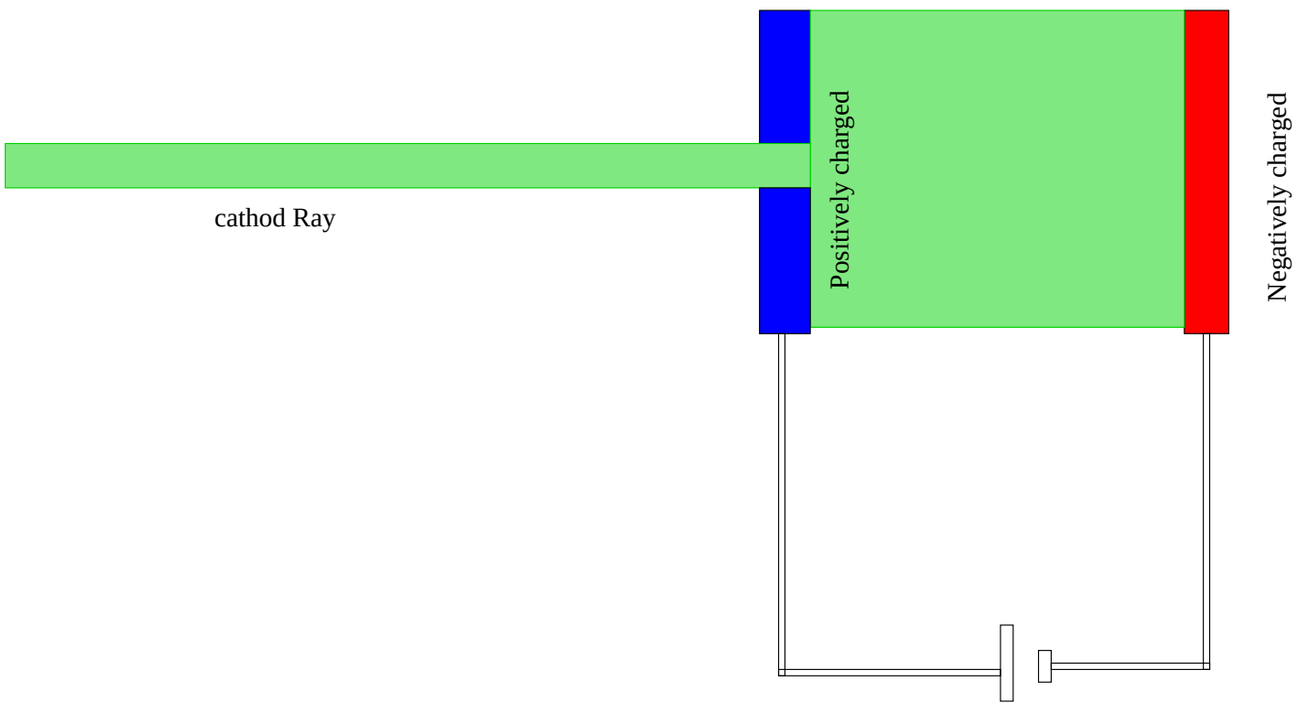
This was the first description of charged particles.

[a] These precipitates can either be gases or solid substances that then plate the electrodes.



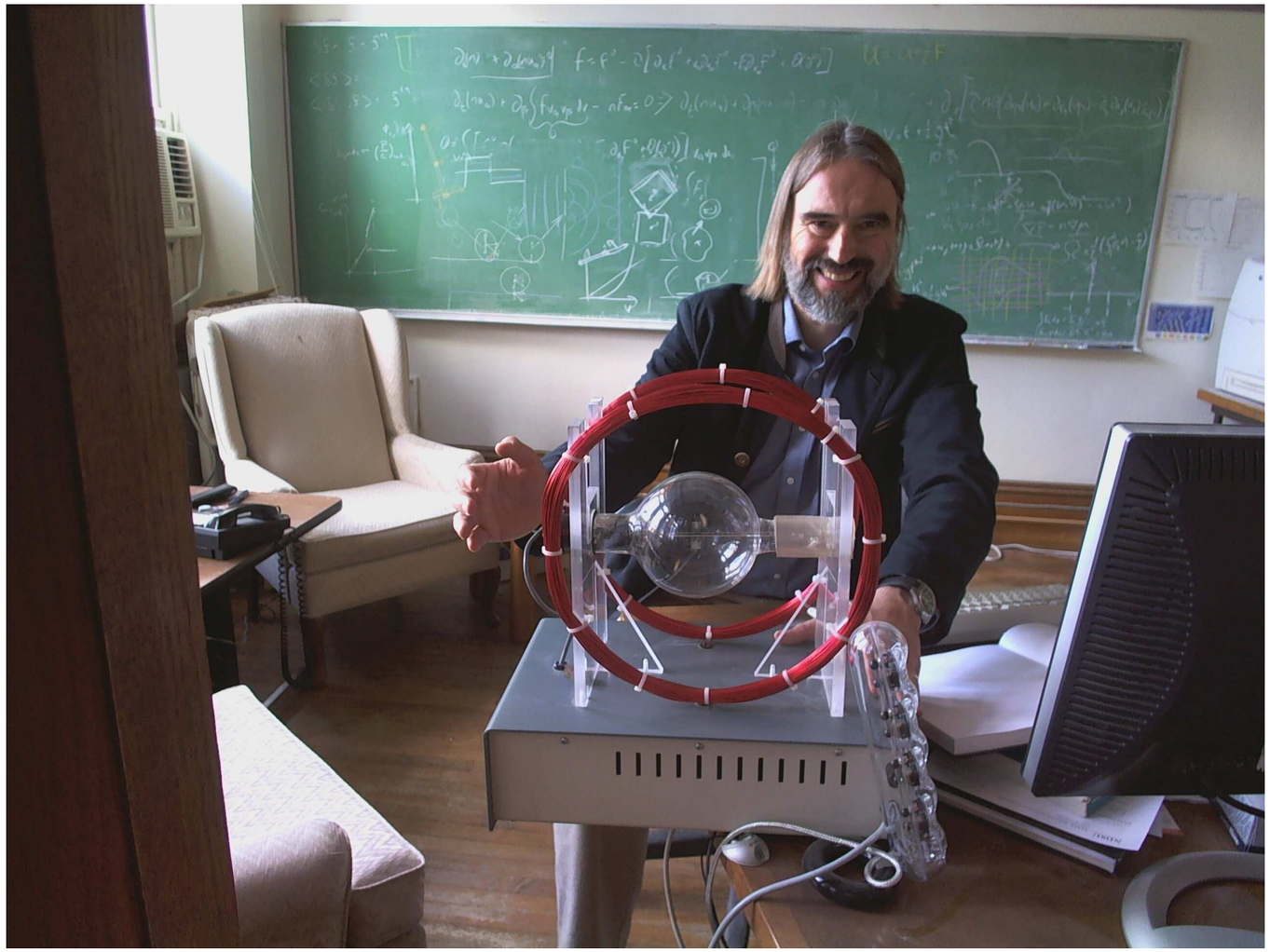
Cathod rays

The English Physicist J.J. Thompson developed Cathode rays:



Here a negatively charged plate is heated, and if it is hot enough, it releases a negatively charged substance that is pulled towards the positively charged plate. Therough a hole in the plate some of this substance carries on (and is visible by a faint glow).

Cathod ray experiments



See: Cathod Rays, the effect of a magnet on the rays, the effect of an electro magnet.

J.J. Thomson's discovery of the electron

J.J. Thomson
1856–1940

Up until 1897 only ions (charged Atoms) were known to carry charge.

Using electric and magnetic force laws he deduced that the mass of the objects making up the Cathode Rays had to be far smaller than ions, about 1/2000th of an ion mass.

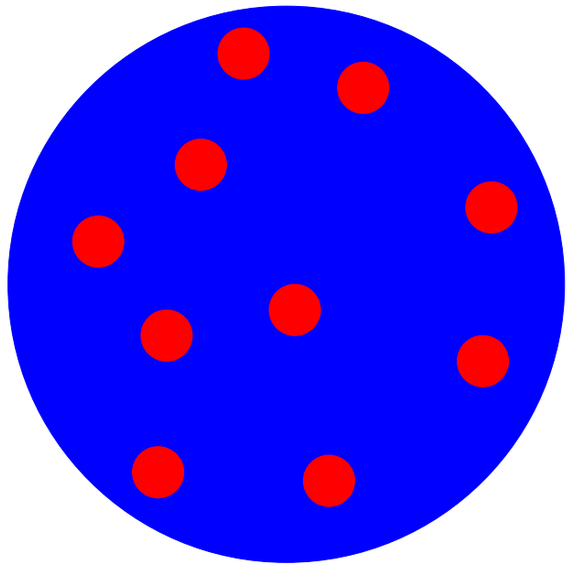
This meant that **atoms had parts**. *At first there were very few who believed in the existence of these bodies smaller than atoms. . . . It was only after I was convinced that the experiments left no escape from it that I published my believe in the existence of bodies smaller than atoms.* Thompson had discovered the electron!

Quantization of charge

YouTube Movie on Thomson's discovery
If there are particles that carry the charge, then charge will be quantized. We find that the charge of one electron is

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

Its mass is about 1/2000 that of a Helium atom. ($9.1 \times 10^{-31} kg$)



'plum pudding' model of the atom according to Thompson consists of negatively charged electrons embedded in positively charged matter.

X-Ray discovery

W.C. Roentgen ()was working with a Cathod ray tube, when he covered the back of it up with thick black paper. However, a screen a few feet away still showed a flourescent light.

Hence he had discovered a new kind of "invisible light" that passed through the black paper. He later showed that it will pass through most objects and can be used to take images.

He called this form of invisible light X-rays because in mathematics "x" often stands for an unknown quantity.

α-Particles

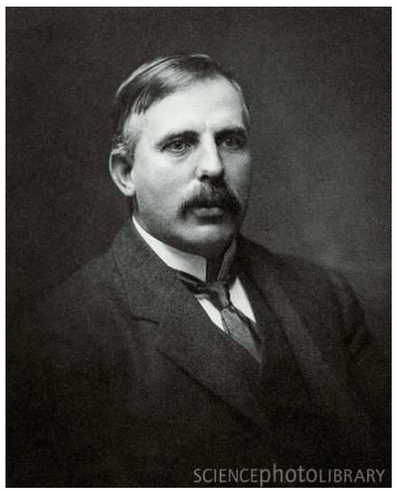
Henri Becquerel used naturally flourescent minerals to study the properties of x-rays. He exposed a substance* to light and then put the material in dark room to expose a photo-plate.

One day this experiment "failed" because there was no sunshine. He repeated the procedure nonetheless, and found that the exposure of the photographic plate was as clear as ever, so in fact this radiation was not related to floures-cence, but an independent property of the material!

Such "radioactive" materials could emit different kinds of radiation, which were characterized by their interaction with magnetic fields: the first kind was the called the α-particle, which was positively charge, the second kind was called a β-particle (and was later shown to be identical to a cathod ray) and the third kind was uncharged, and was called a γ-particle.

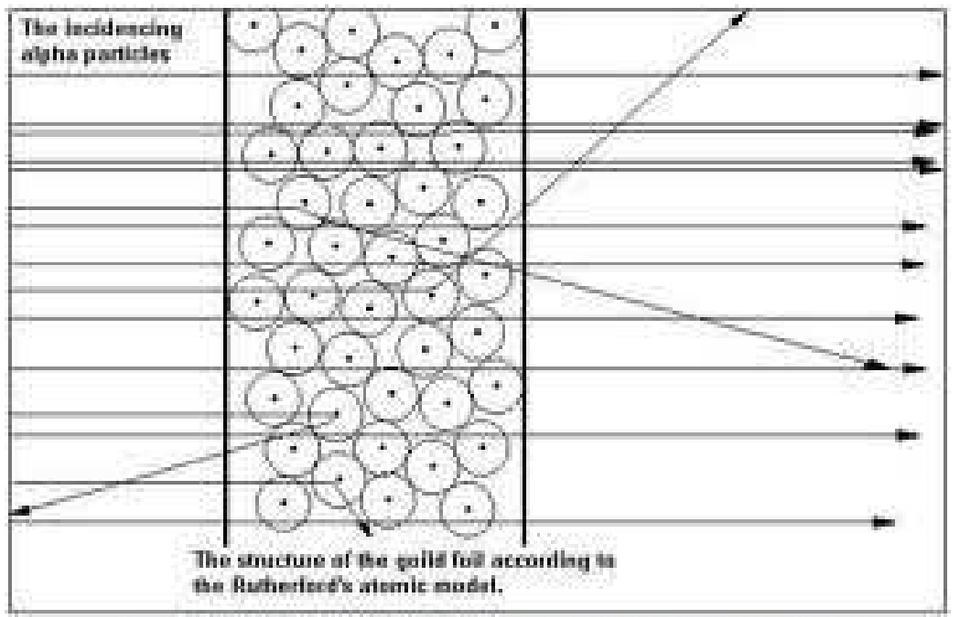
*Posassium uranyl sulfate

Rutherford's experiments on scattering of particles



Ernest Rutherford
1871–1937
Born in New Zealand
died in Cambridge, U.K.

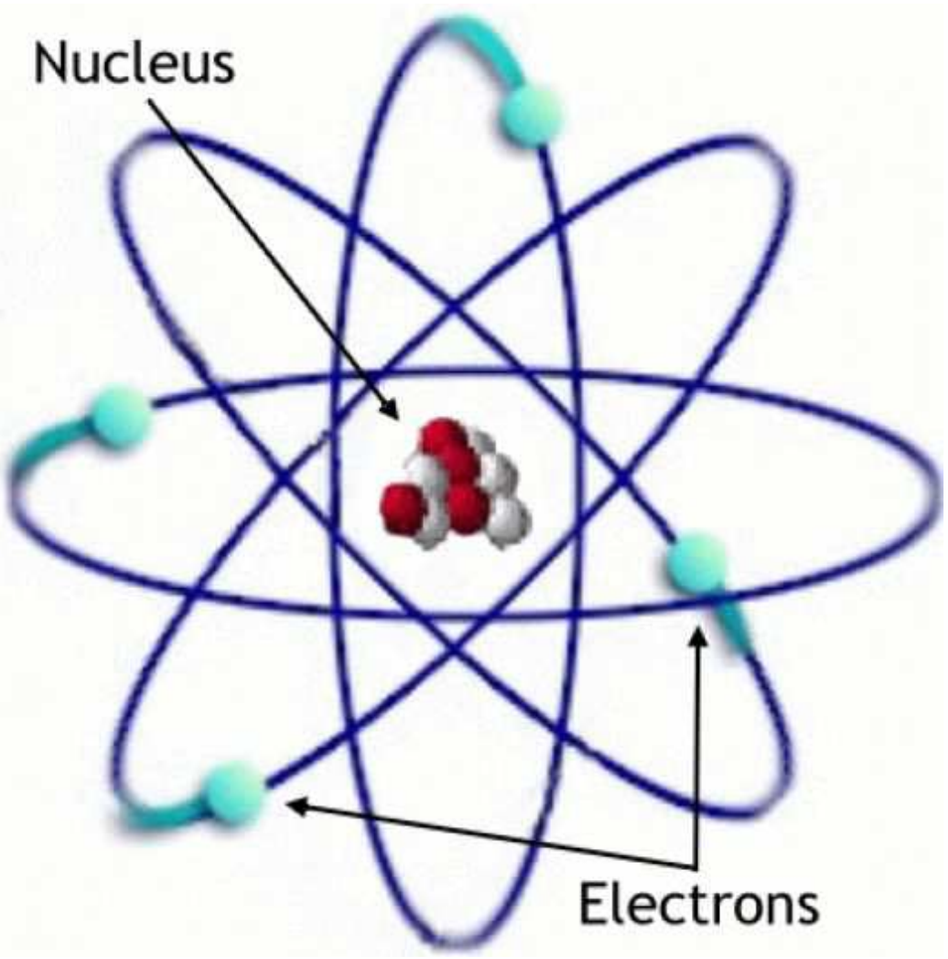
Rutherford did experiments α-particle scattering. He noticed that many particles simply passed through a thin gold foil, but occasionally particles would be strongly scattered. This would not be observed if the theory of his teacher J.J. Thomson of a plum pudding atom were correct!



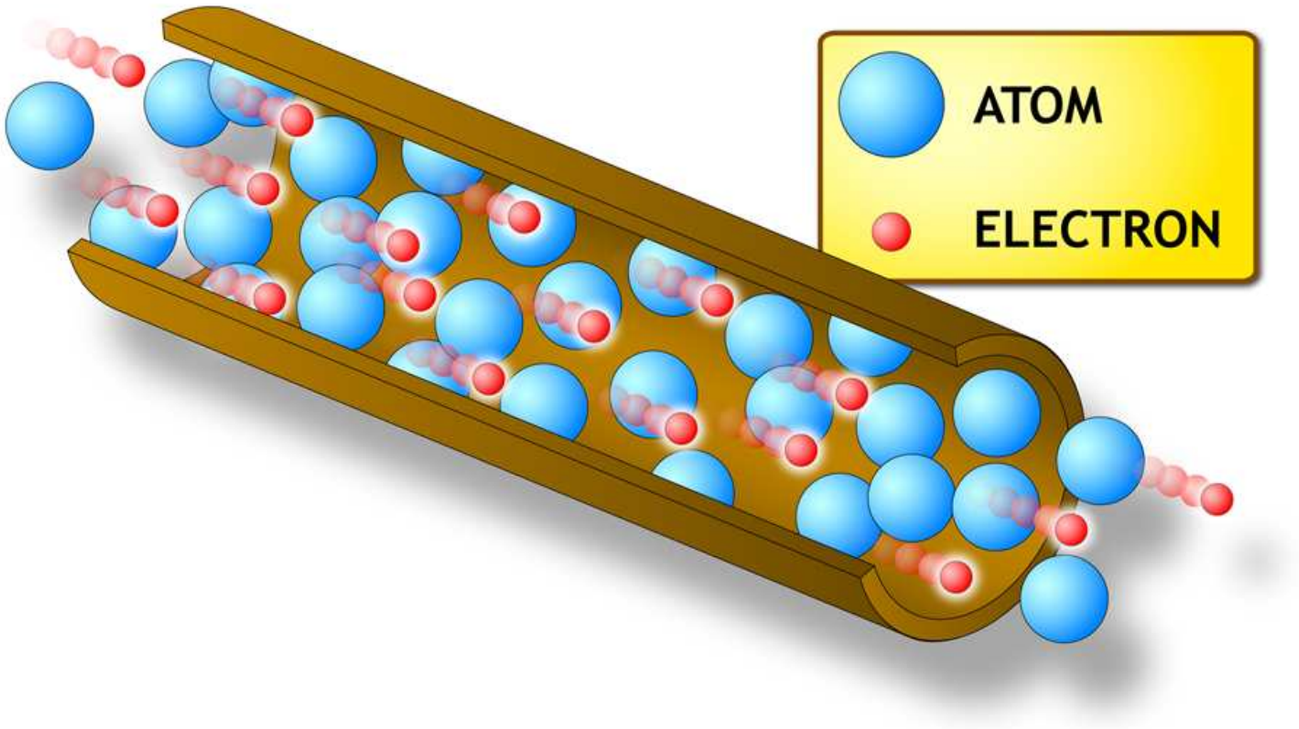
The alpha particles propagated on the atomic nucleuses of the gold foil.

The planetary atomic model

This suggested that the atom had a small part that contained all the mass, which was called the nucleus, sourrounded by the negatively charged electrons discovered by J.J. Thomson.



A microscopic view of electric current



Current = Charge/time

Ohm's law:

$$V = IR$$

Magnetic Fields

Magnetic field lines are closed.

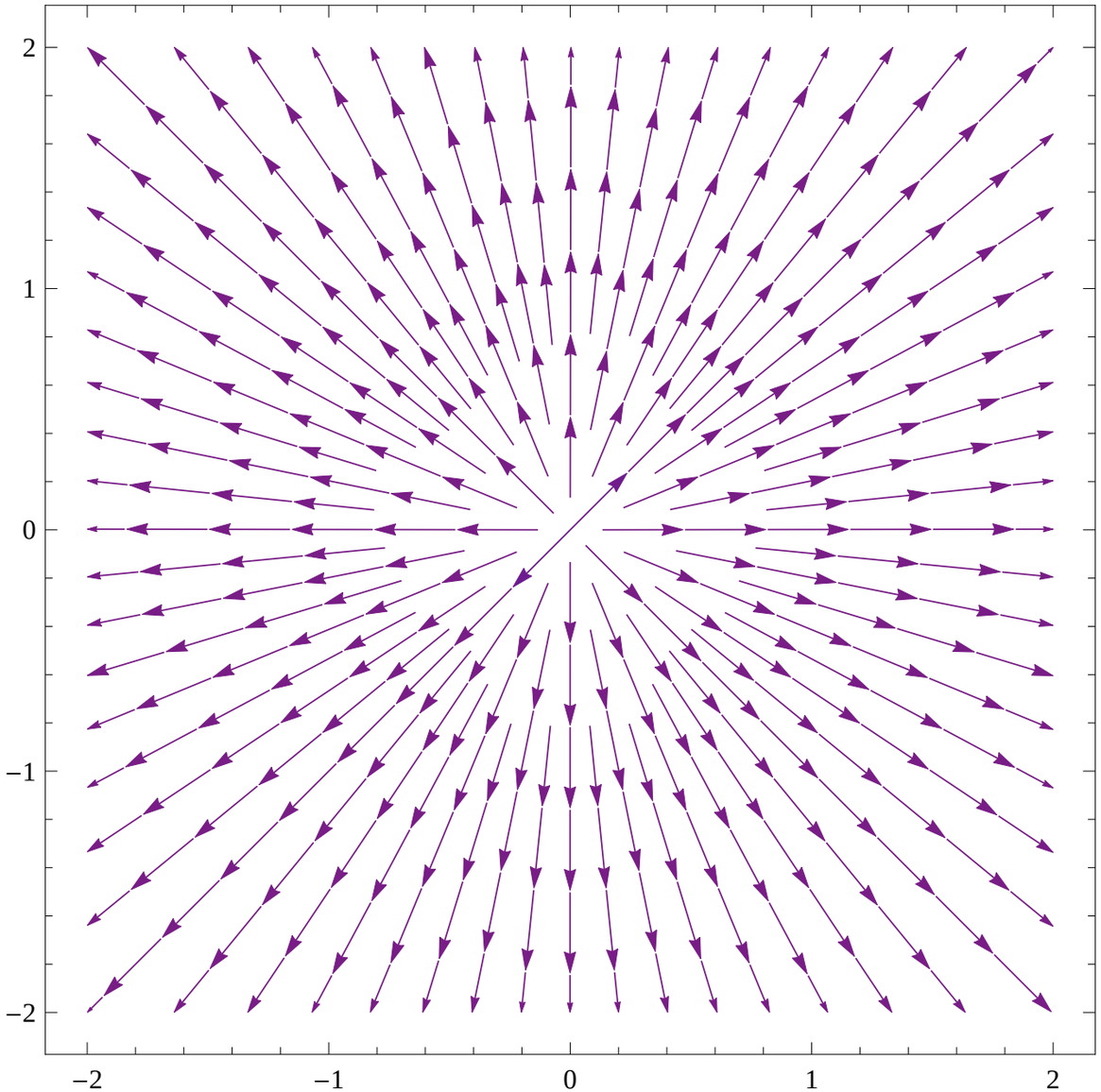
Experiment!

Other fields

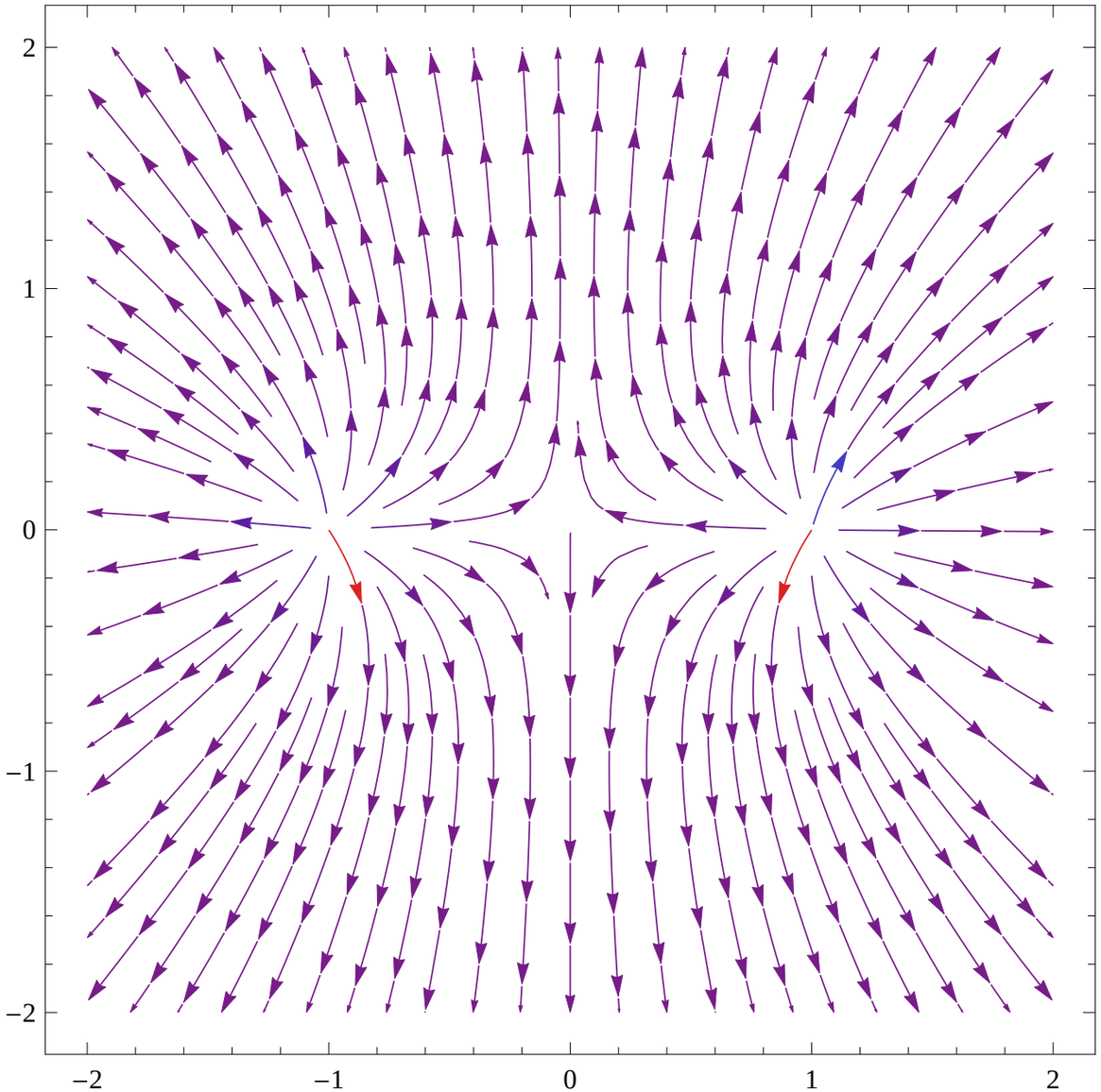
Other force-laws can also be expressed with the help of fields. We may use this to express electric and magnetic fields as the force a test mass (charge) would feel at a specific point.

Electric field lines end at charges (or are closed loops)

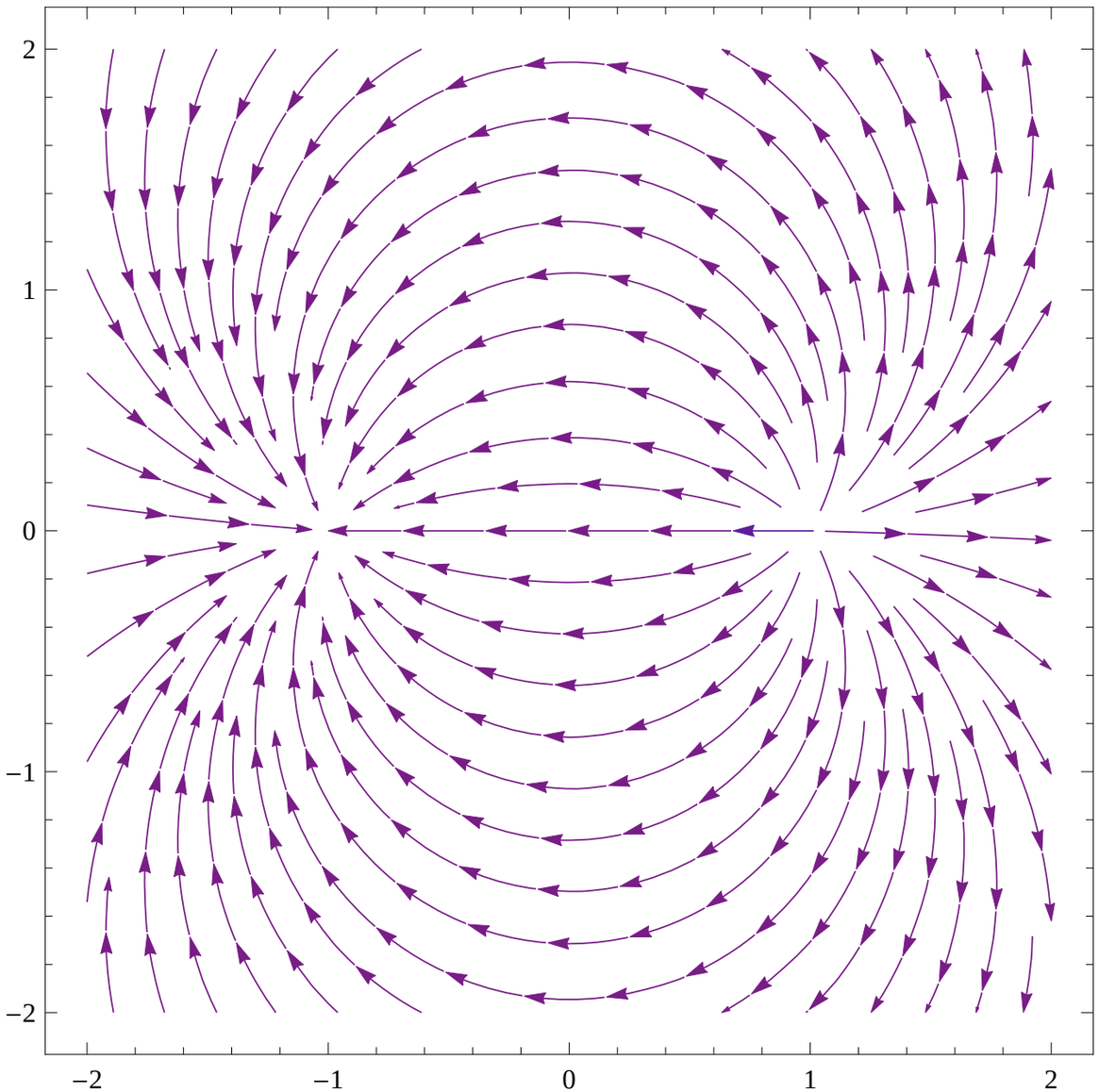
Field of a single charge

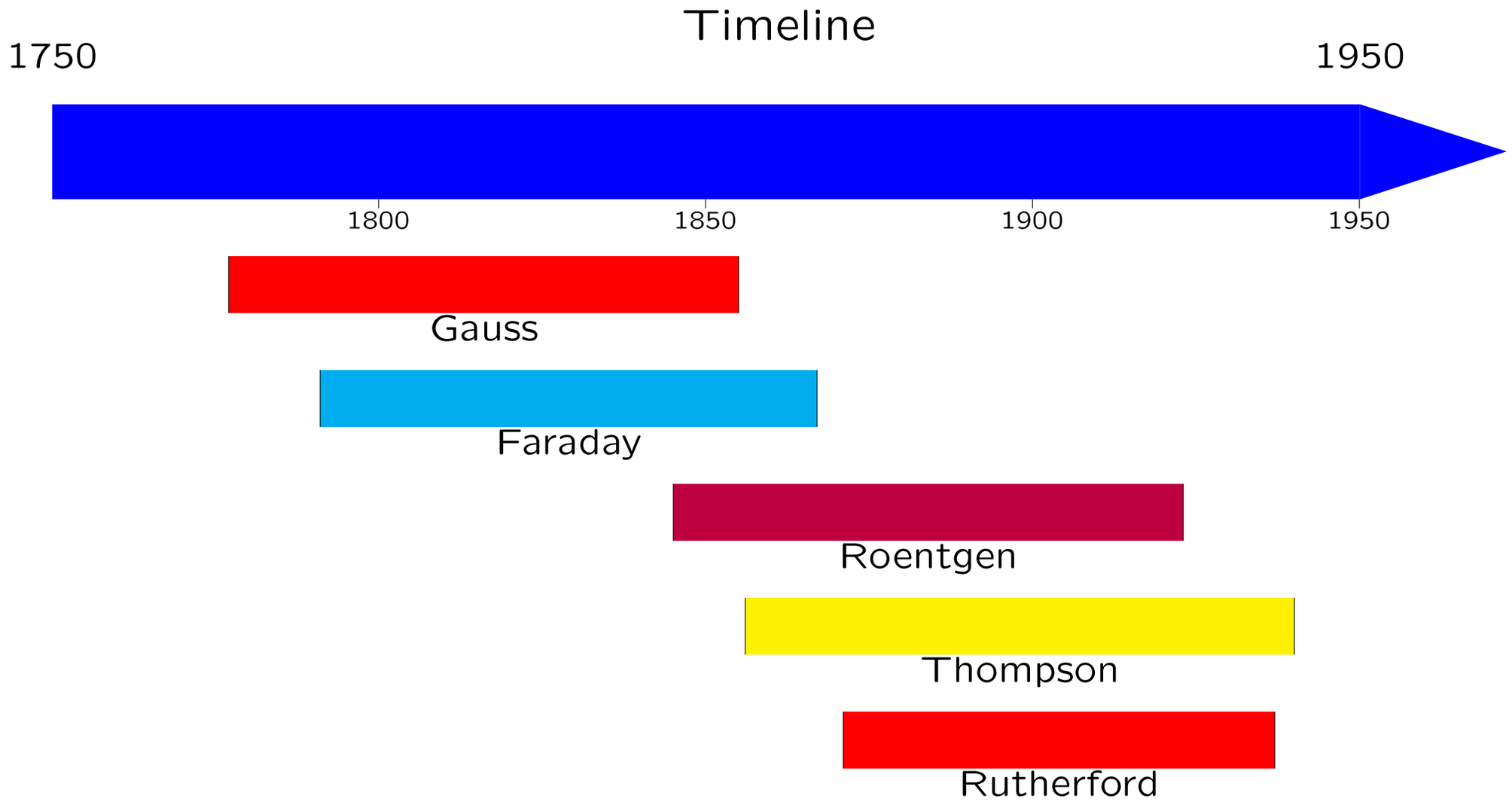


Field of two equal charges



Field of two opposite charges




Timeline
1750
1950
1800
1850
1900
1950
Gauss
Faraday
Roentgen
Thompson
Rutherford

Summary

- Cathode Ray experiments
- Discovery of the electron
- Discovery of the atomic nucleus
- A new model of internal atomic structure
- Definition of fields