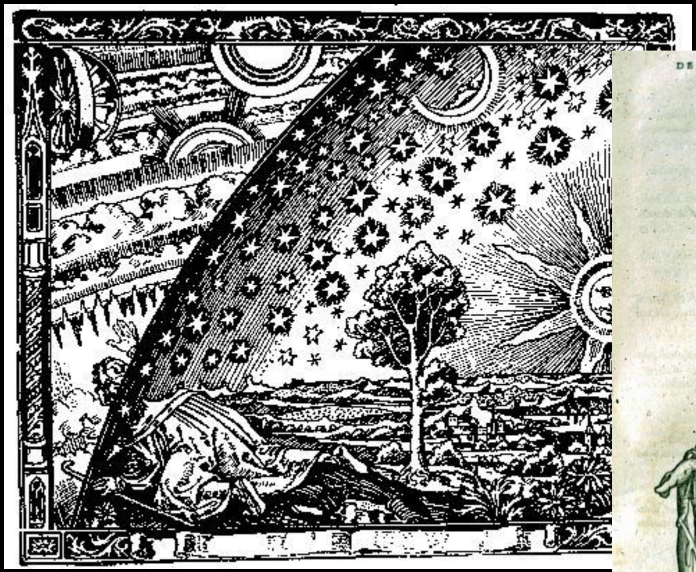
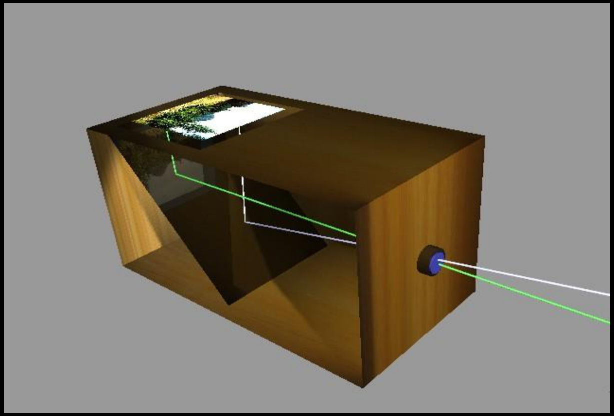
THE HUNTINGTON

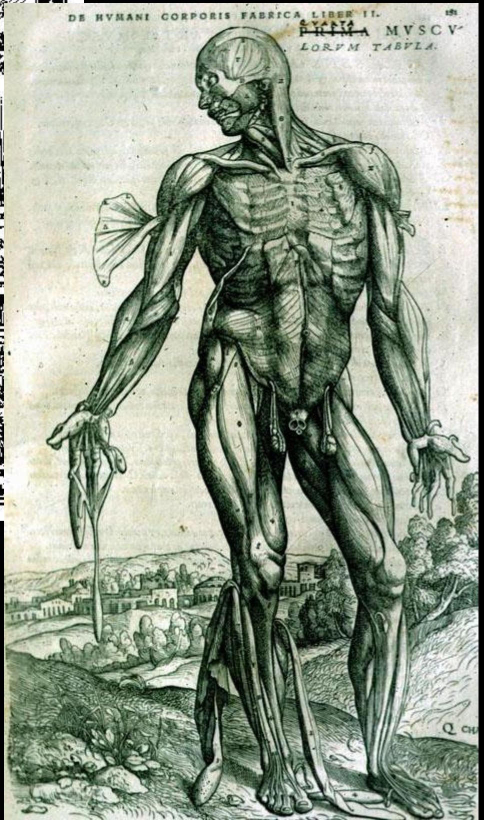
Library, Art Collections, and Botanical Gardens

History of Science School Program

Week 3







The Triumph of Newtonianism

- Three Laws of Motion
- Theory of Gravity
- Theory of light and color
- Calculus
- Solving the problem of comets
- Prediction of the oblate shape of the earth (measured and confirmed by **Maupertuis** in late 1730s.
- Prediction of the return of Halley's comet in 1758
- Exact prediction of the Venus Transits, in 1761 and 1769

- And later: discovery of the planet Neptune before it was directly observed, 1846

The Newtonian Era

- The Newtonian example of general or universal laws in physics (natural philosophy) excited searches for general laws in other realms, including
- John Locke (1632-1704): Social and Political Science, Psychology
- Adam Smith (1723–1790): Economics
- Voltaire (1694–1778) and Montesquieu (1689–1755): Politics
- Richard Owen (1804-1892), and Charles Darwin (1809-1882): Natural History
- David Hume (1711-1776), tried to make use of Newtonian experimental principles in the examination of moral subjects.

Newton’s Experimental Philosophy and New fields of investigation in physical sciences:

Chemistry:

- Quantitative study of chemical reactions
- Pneumatic chemistry
- The concept of Phlogiston
- Discovery of oxygen
- Dalton’s atomic theory

- Classical Sciences (i.e. astronomy, mechanics, mathematics, and optics) vs. Baconian Sciences:
- Heat
- Light
- Electricity
- Magnetism

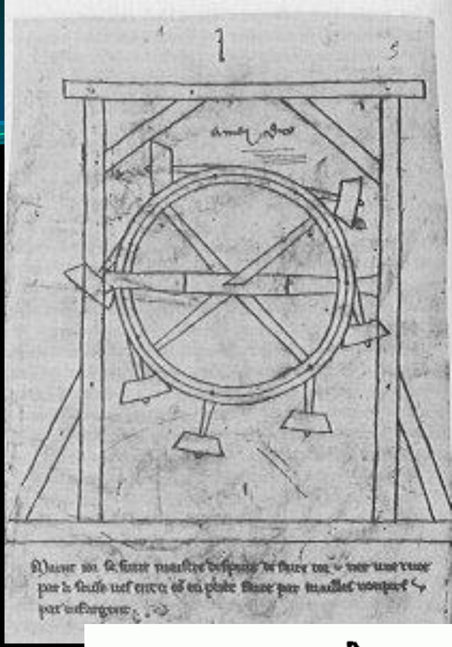
- **The impact of the Industrial Revolution:**

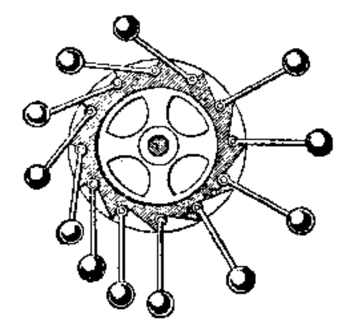
- The question of work: how to exploit the forces of nature to power machinery

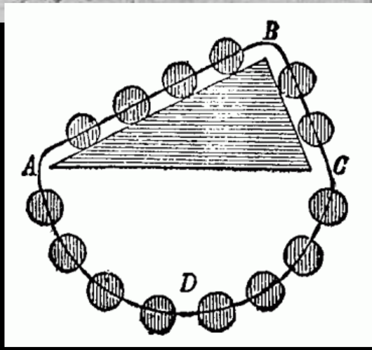
- Studying the philosophical principles that underlay the operation of different kinds of machinery, as well as looking at how to turn the different powers of nature to produce motive force (or work), seemed an increasingly profitable line of inquiry.

Work, Energy, Efficiency

Perpetual Motion Machines: movement that goes on forever

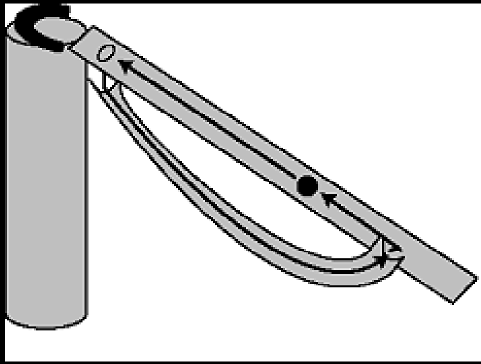




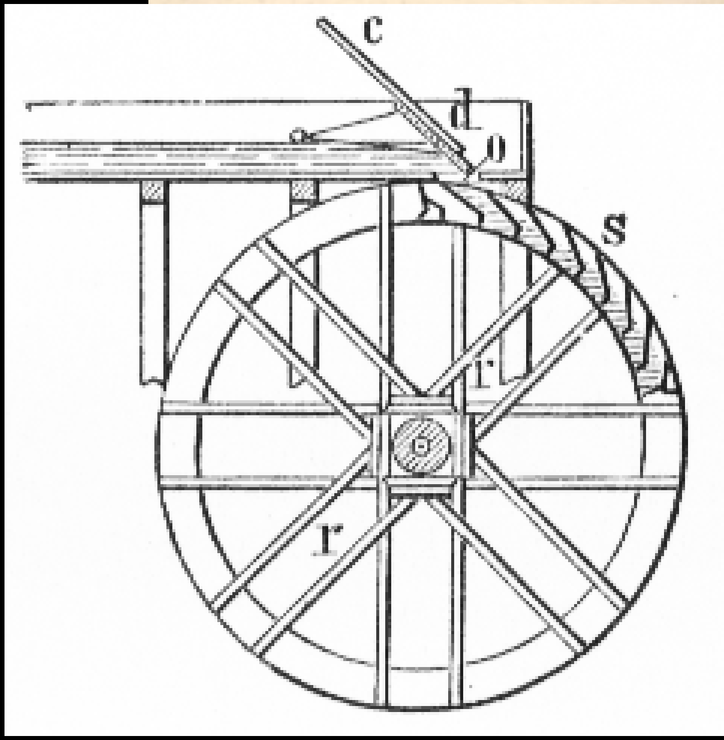


Unfortunately, none of the "perpetual motion" engines worked perpetually!

Although their inventors claimed that their designs were logical and only bad machinery or some unknown problems stopped their machines, the problem was rooted in nature's basic rules.

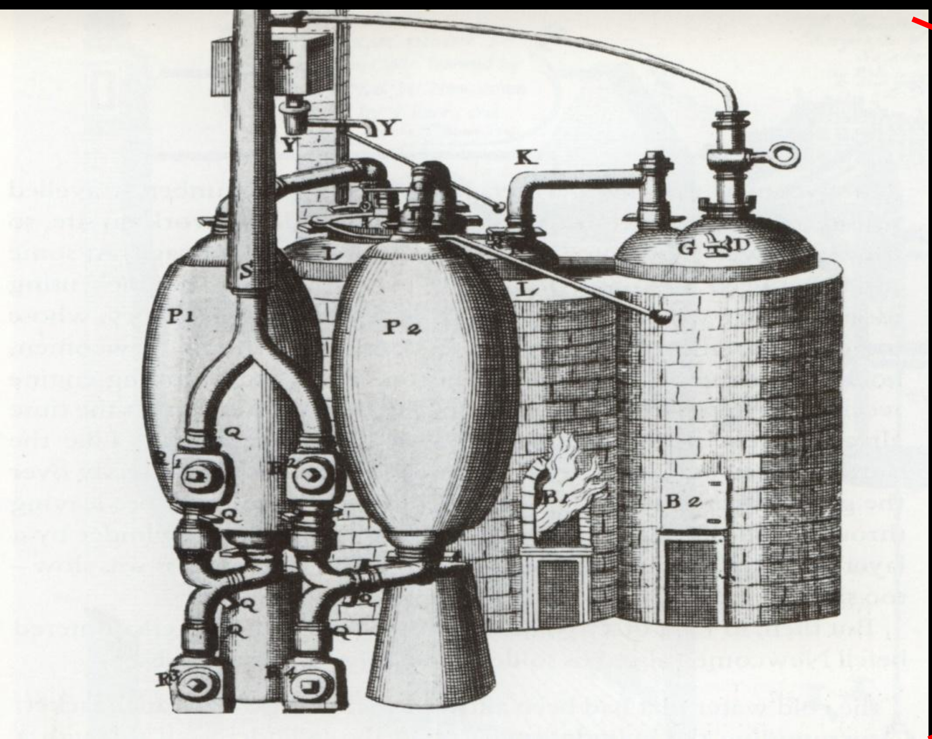


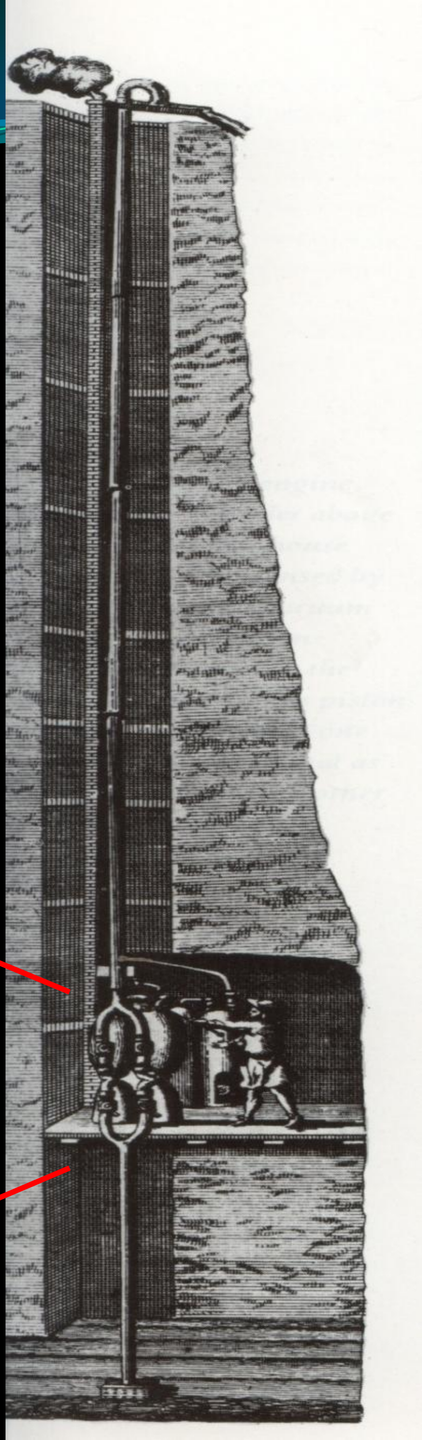
- The French engineer Lazar Carnot (1753-1823) was one of the first scientists to study water wheels quantitatively to find out about the amount of work produced by the wheel and its relationship with the distance the water fell between levels in making the wheel turn.



Problem with the engines:

To pomp out the water from coal mines was one of the main factors behind the development of the steam engine.





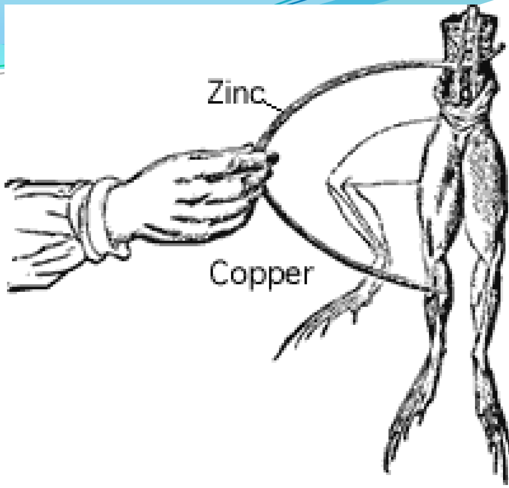
- Lazar Carnot's son, Sadi, focused his attention on the steam engine, and carefully analyzed the workings of a hypothetical heat engine.

- His assumption was that by understanding the operations of the actual steam engine he could gain an insight into the principles underlying the properties of the abstract heat engine as well.

Carnot said that caloric (the energy of heat) was **conserved** as water was conserved while producing work in a water mill: in the water mill water did work by falling one level to a lower level; in a heat engine, caloric did work by falling from one temperature to a lower temperature.

- **More search to find possible relationships between forces in nature**

- **Chemical affinity and electrical affinity**
- In 1783 Galvani discovered that when two different metals touch dissected frog legs they induce a motion to them. He used the term "Animal Electricity" to describe the phenomenon.



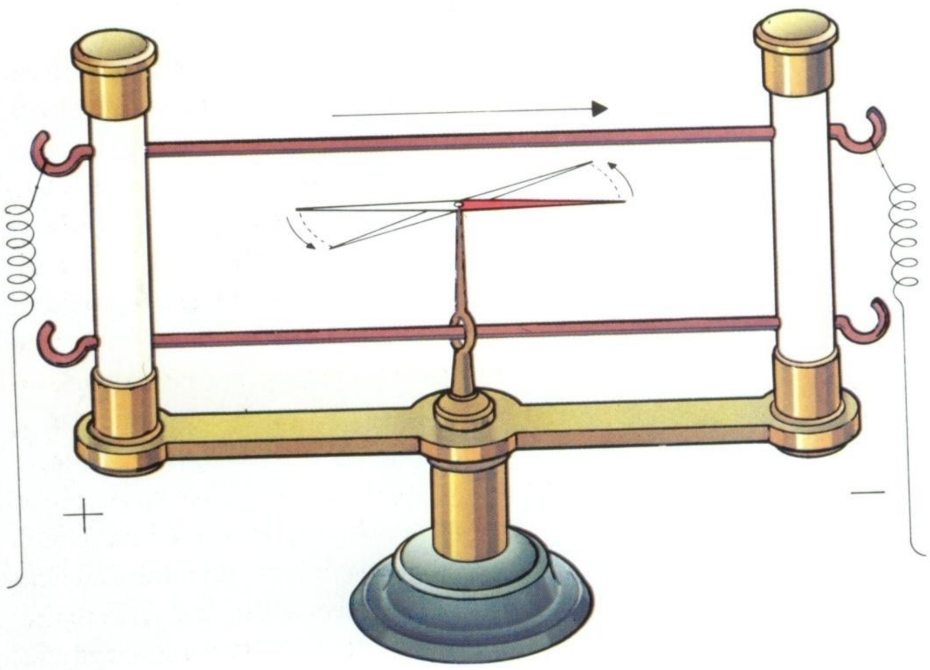
- Alessandro Volta invented electric battery by studying Galvani's animal electricity. He assumed that electricity was produced simply by the contact of different metals.

- Humphury Davy believed that the battery worked by transforming chemical affinity into electrical

Alessandro Volta

Hans Christian Oersted

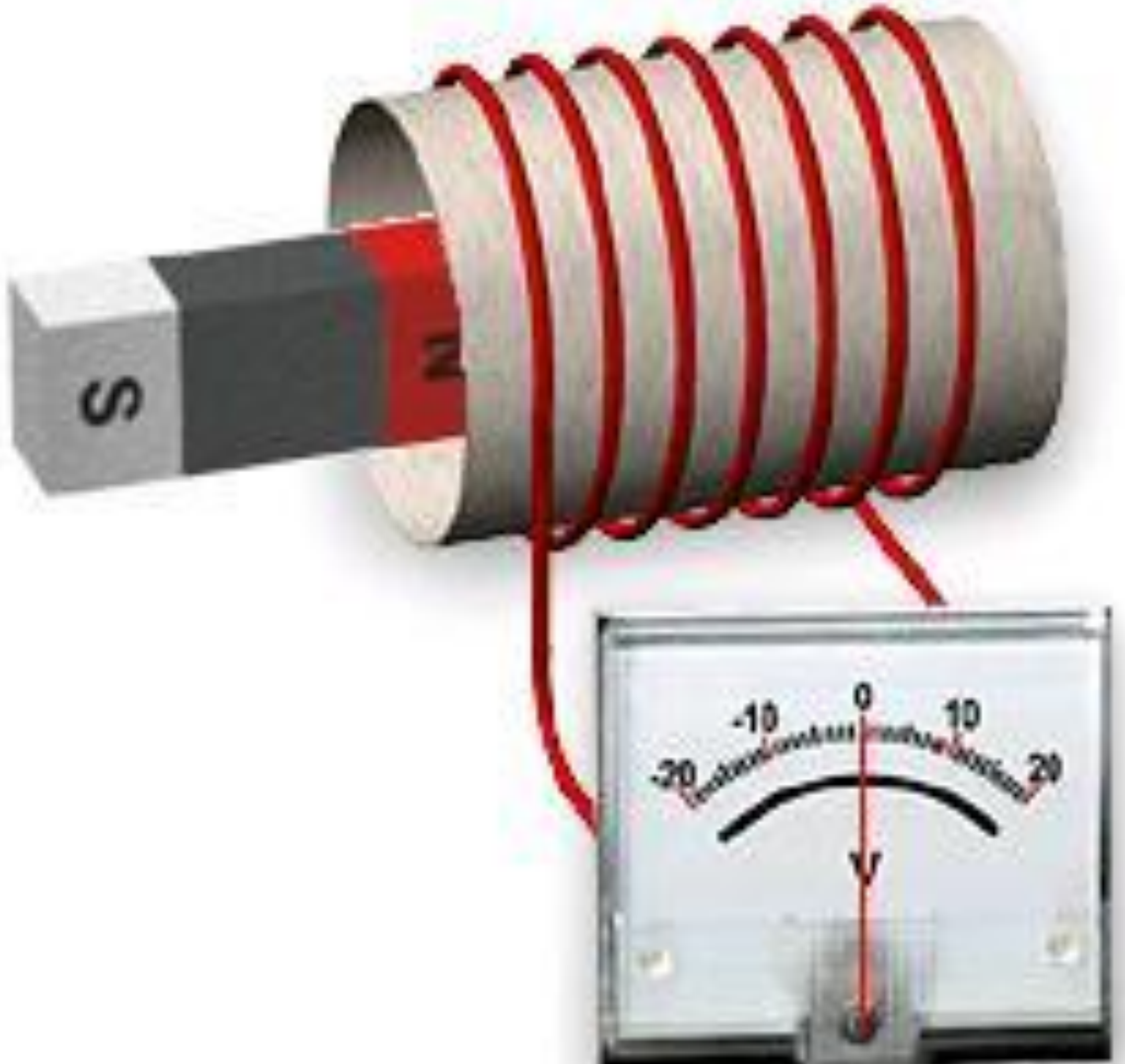
1820: Discovery of the link between electricity and magnetism: electricity can create magnetism



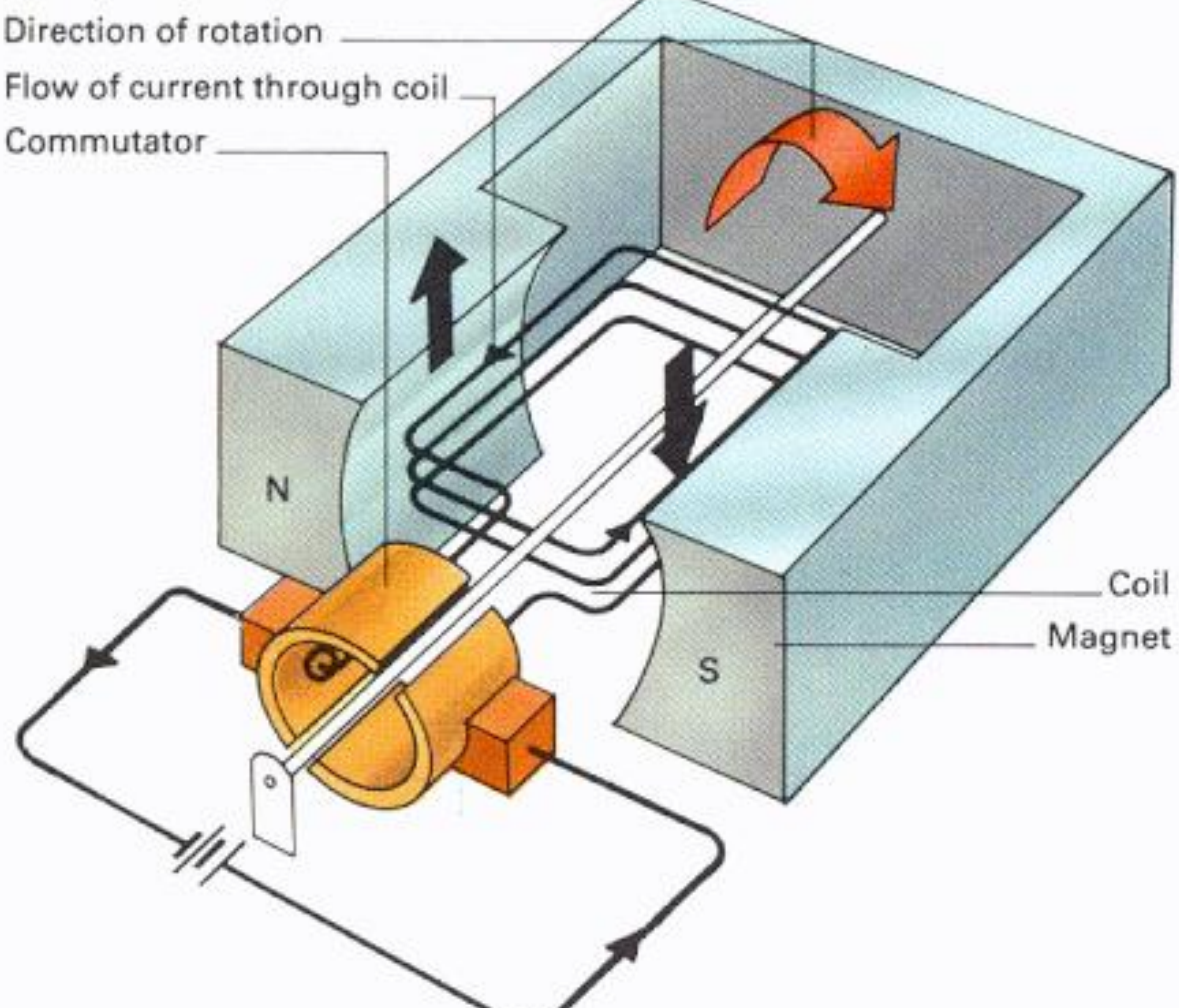
Michael Faraday

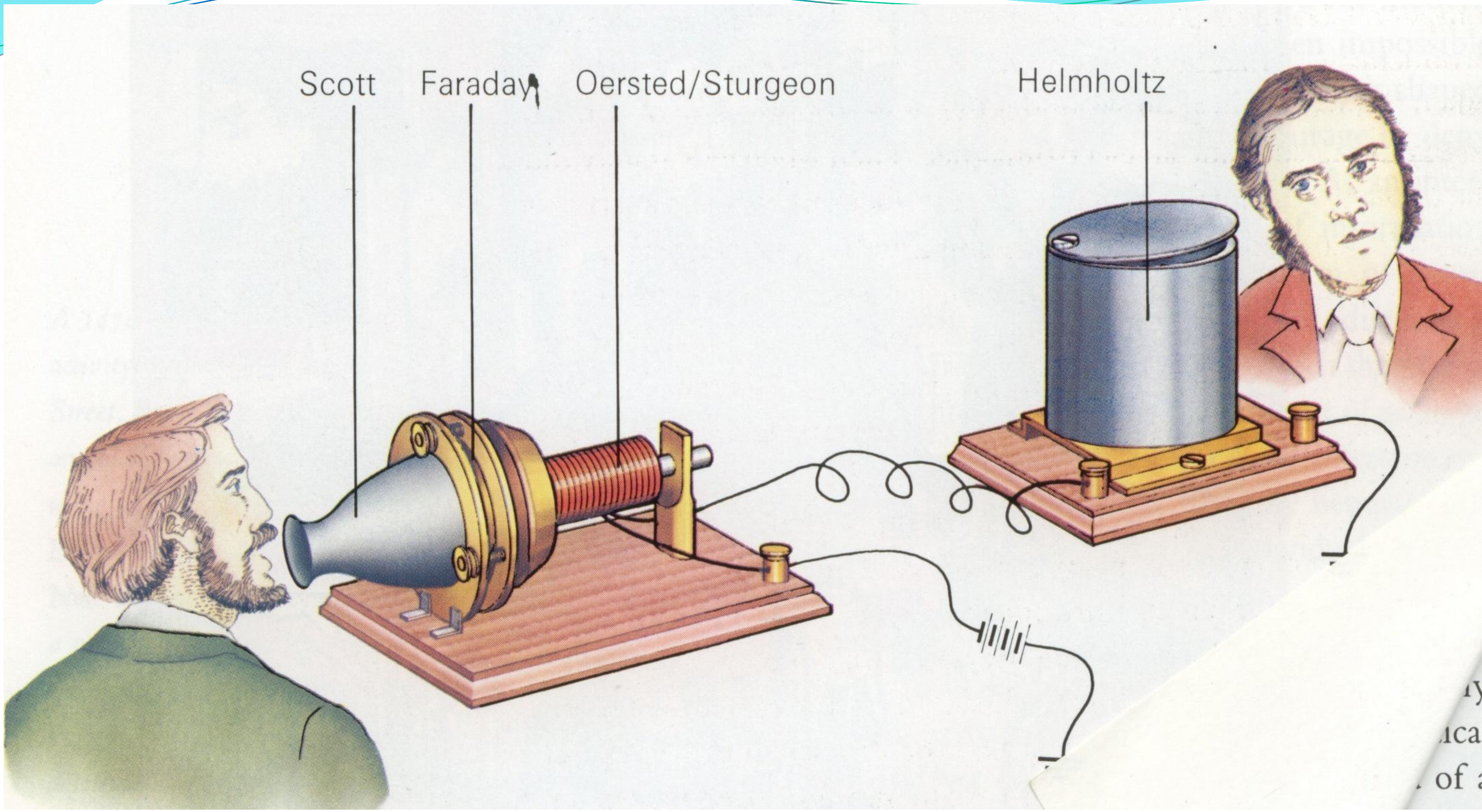
1821: discovered that a current-carrying wire can rotate (or move) around a magnet: Electricity and magnetism combined could be used to produce motive force

André-Mari Ampère
1820s: showed that a current carrying wire arranged as a coil acted as an ordinary magnet.


S
N
-20
-10
0
10
20
V

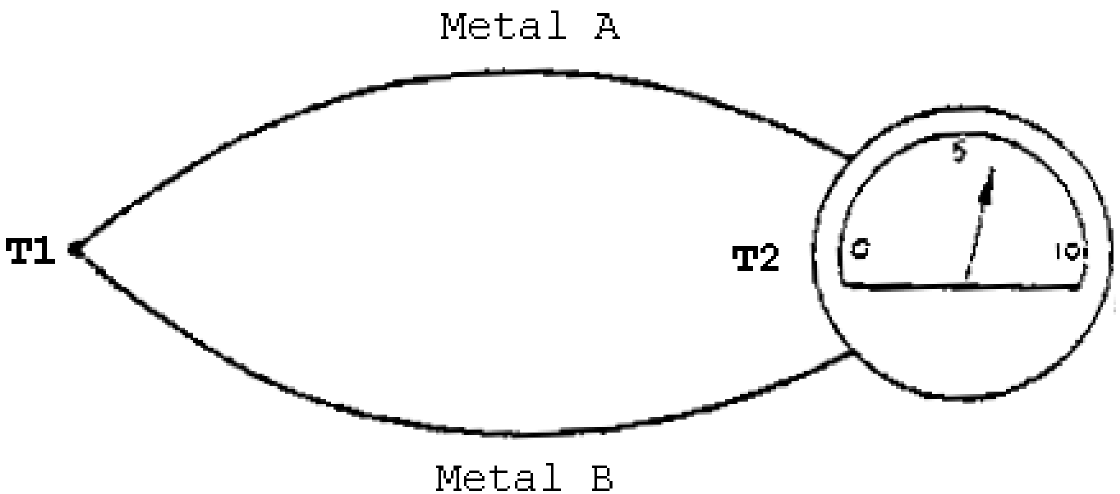
William Sturgeon electromotor 1830


Direction of rotation
Flow of current through coil
Commutator
N
S
Coil
Magnet


Scott
Faraday
Oersted/Sturgeon
Helmholtz

In the 1820s Thomas Johann Seebeck set out to examine the connections between electricity, magnetism and heat. He discovered ***thermoelectricity***.

After a few years Robert Grove discovered ***photoelectricity***.



BASIC THERMOCOUPLE CIRCUIT WITH INSTRUMENT

Figure A

-

What is the connection between heat, light, electricity, and magnetism?

-How do they transmit from one point to the other?

-How do they transform from one form to the other?

-What is the “active” agent in these forces?

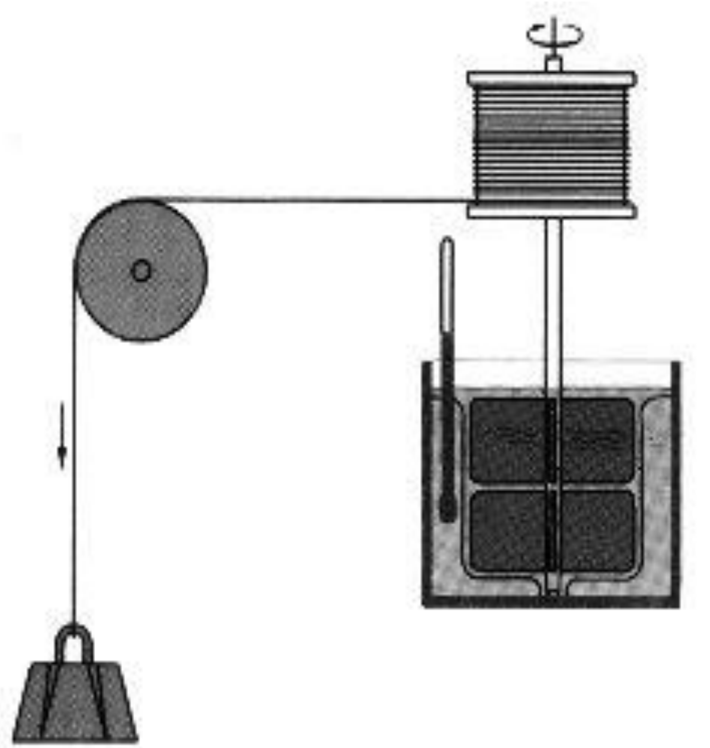
>> Quantitative approach: Measure all aspects of those forces and find the relationships

James Prescott Joule

Tried to measure the quantity of the work done by a steam engine to find out its efficiency.

In a general sense, he wanted to measure the relationship between heat and work.

Using the following device

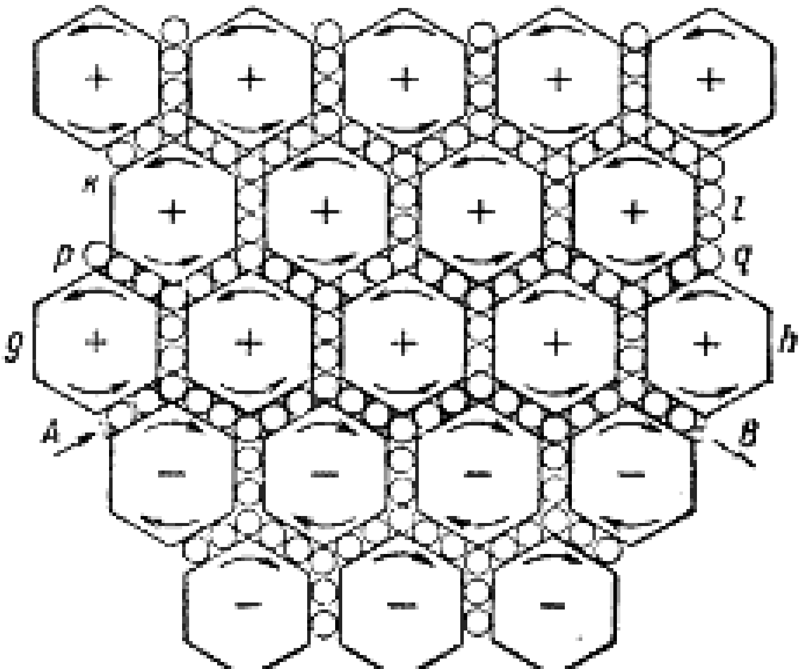


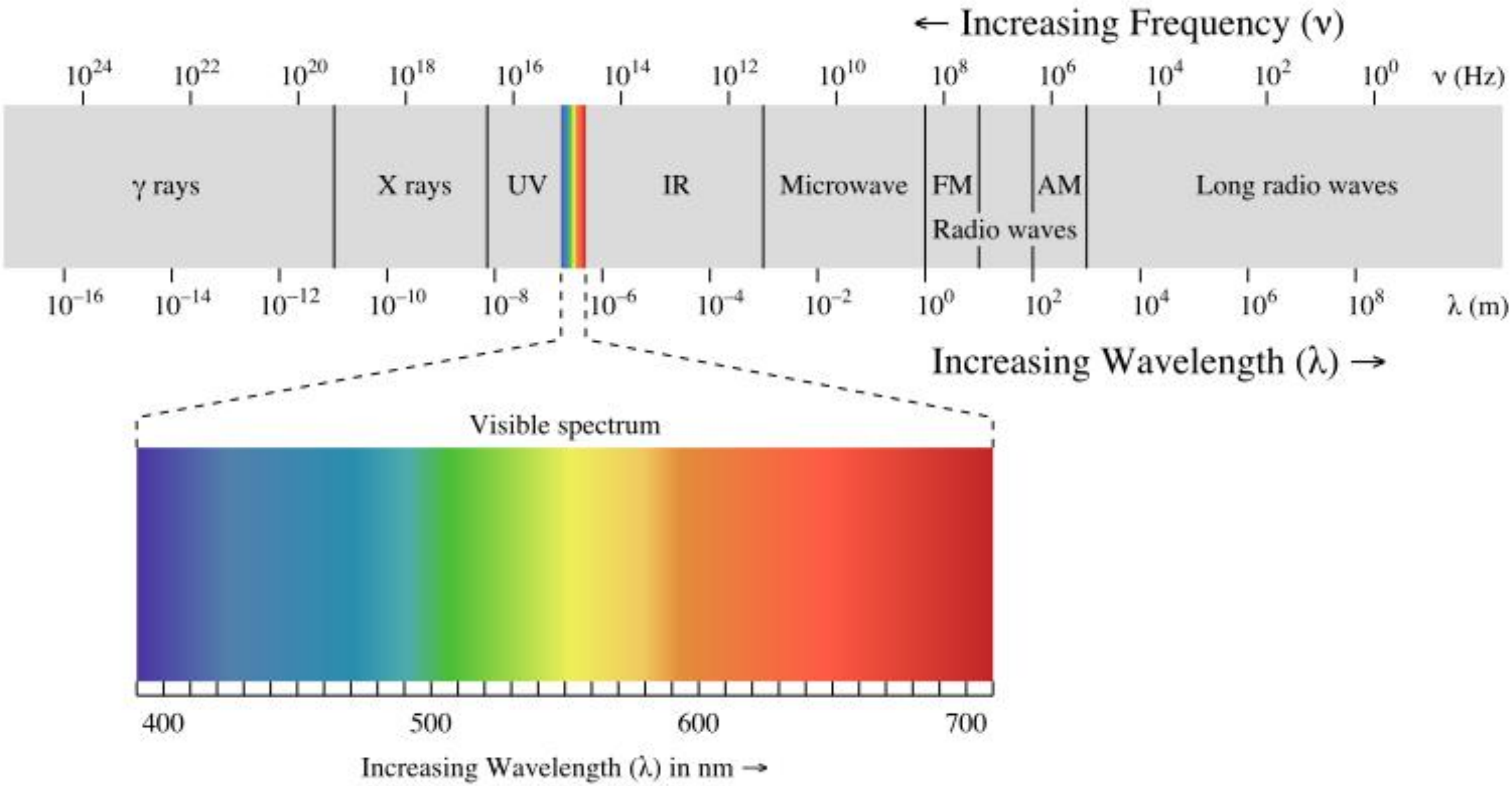
he found that by rotating the blades in the water, water's temperature rises: he argued that work could be transformed into heat, and we can measure it.

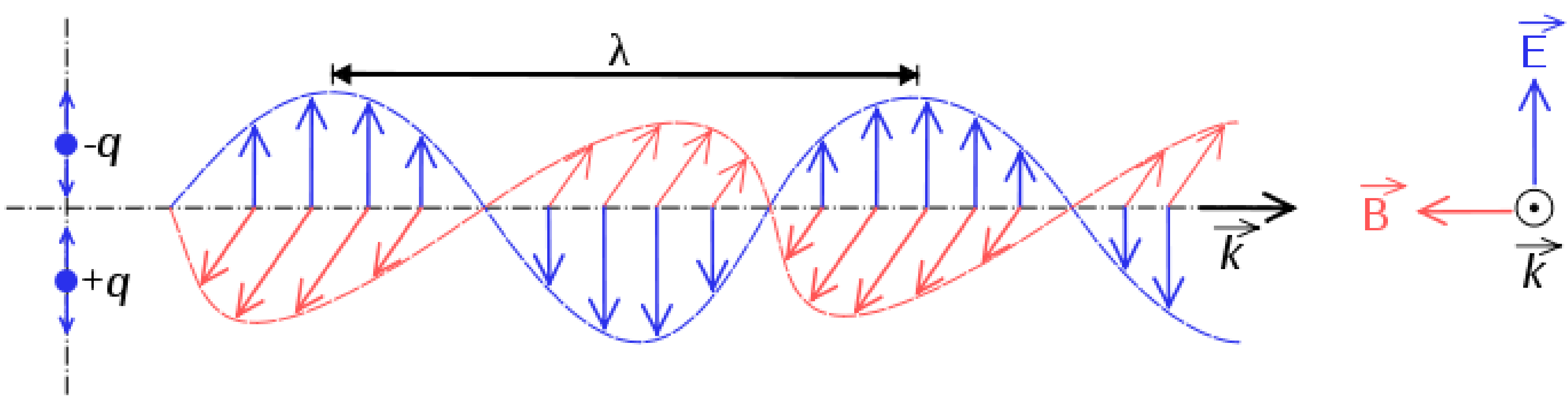
Maxwell:

The relationship between electricity, magnetism, and light

The concept of "Electromagnetic Radiation"




← Increasing Frequency (ν)
10^24 10^22 10^20 10^18 10^16 10^14 10^12 10^10 10^8 10^6 10^4 10^2 10^0 ν (Hz)
γ rays
X rays
UV
IR
Microwave
FM
AM
Radio waves
Long radio waves
10^−16 10^−14 10^−12 10^−10 10^−8 10^−6 10^−4 10^−2 10^0 10^2 10^4 10^6 10^8 λ (m)
Increasing Wavelength (λ) →
Visible spectrum
400 500 600 700
Increasing Wavelength (λ) in nm →


λ
-q
+q
k
E
B
k

Heinrich Hertz (1857 –1894) German physicist who clarified and expanded the electromagnetic theory of light that had been put forth by Maxwell. He was the first to satisfactorily demonstrate the existence of electromagnetic waves by building an apparatus to produce and detect VHF or UHF radio waves.

History of Physics

In the 19^{th} and 20^{th} centuries

1-The structure of the Atom

2- X-ray

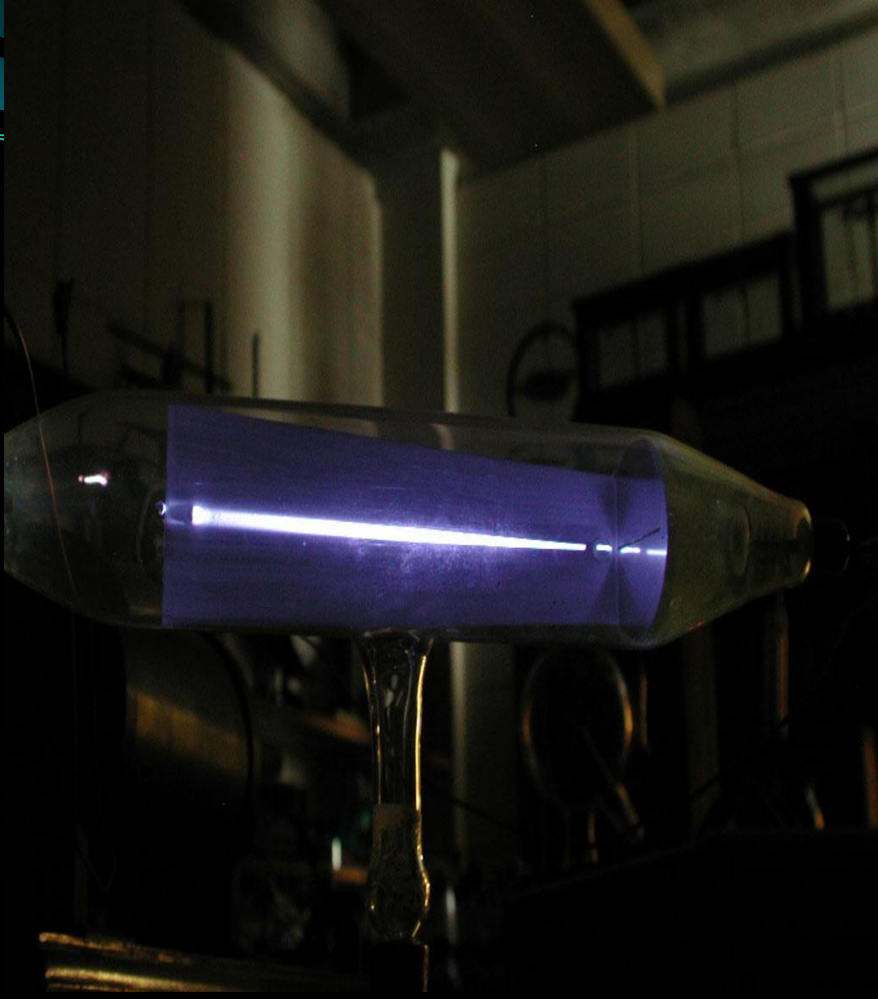
3-Radioactivity

4-Atomic Models

Key question about the fundamental structure of matter: was it made up of discrete units like atoms or was it continuous and indefinitely divisible?

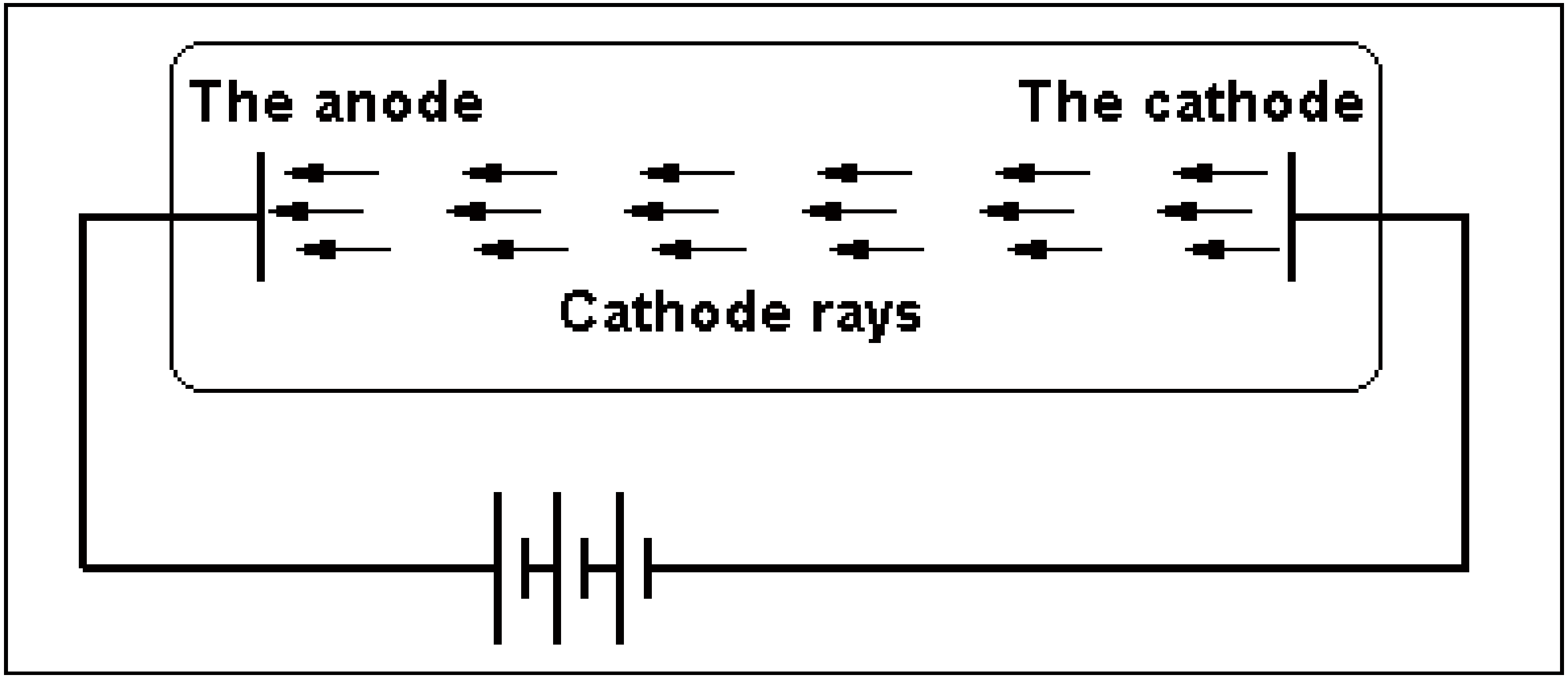
Cathode Rays

In 1838, Michael Faraday rarified the air inside a glass tube, attached electrodes to the ends of the tube and passed electricity through them. He noticed a strange light arc with its beginning at the cathode (negative electrode) and its end at the anode (positive electrode).



Experiments with cathode rays

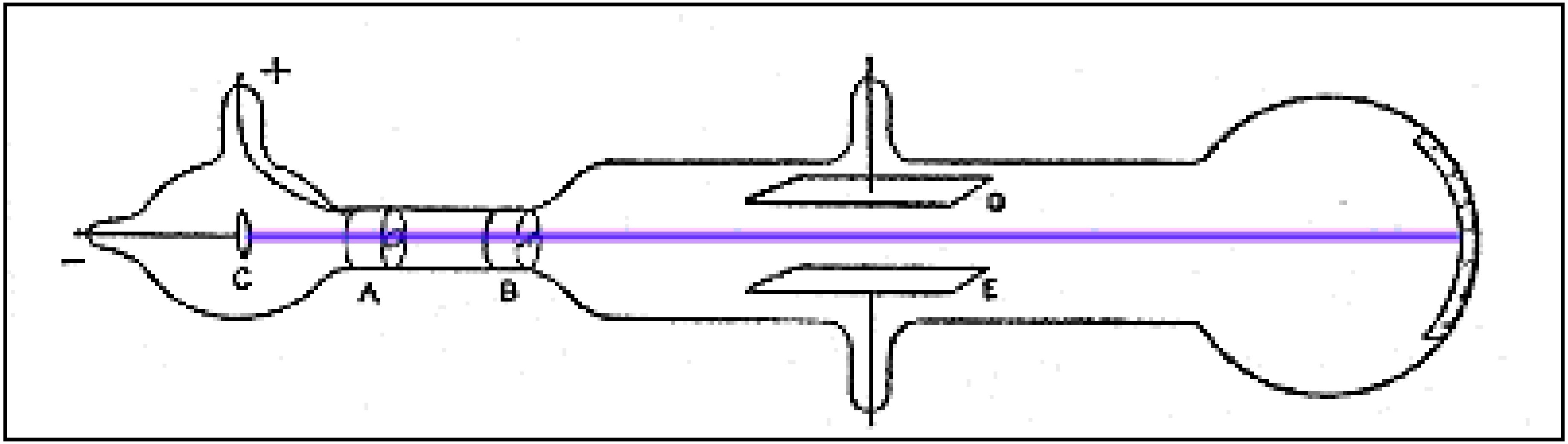
Cathode ray tubes were important "toys" at all physics laboratories and studying the nature of mysterious rays emanating from the cathode was an interesting research project for physicists.



Cathode rays going out the cathode.

- **Sir J. J. Thomson**
- J. J. Thomson (1856-1940) was an English physicist who discovered the electron in 1897. Thomson began research at the Cavendish Laboratory of Cambridge University in 1880 and in 1884 was made chair of the physics department there. For his accomplishments, Thomson **was granted the Nobel** Prize for physics in 1906 and was knighted in 1908. Thomson was an influential teacher at Cavendish, and many of his students, including Ernest Rutherford, were awarded Nobel Prizes.

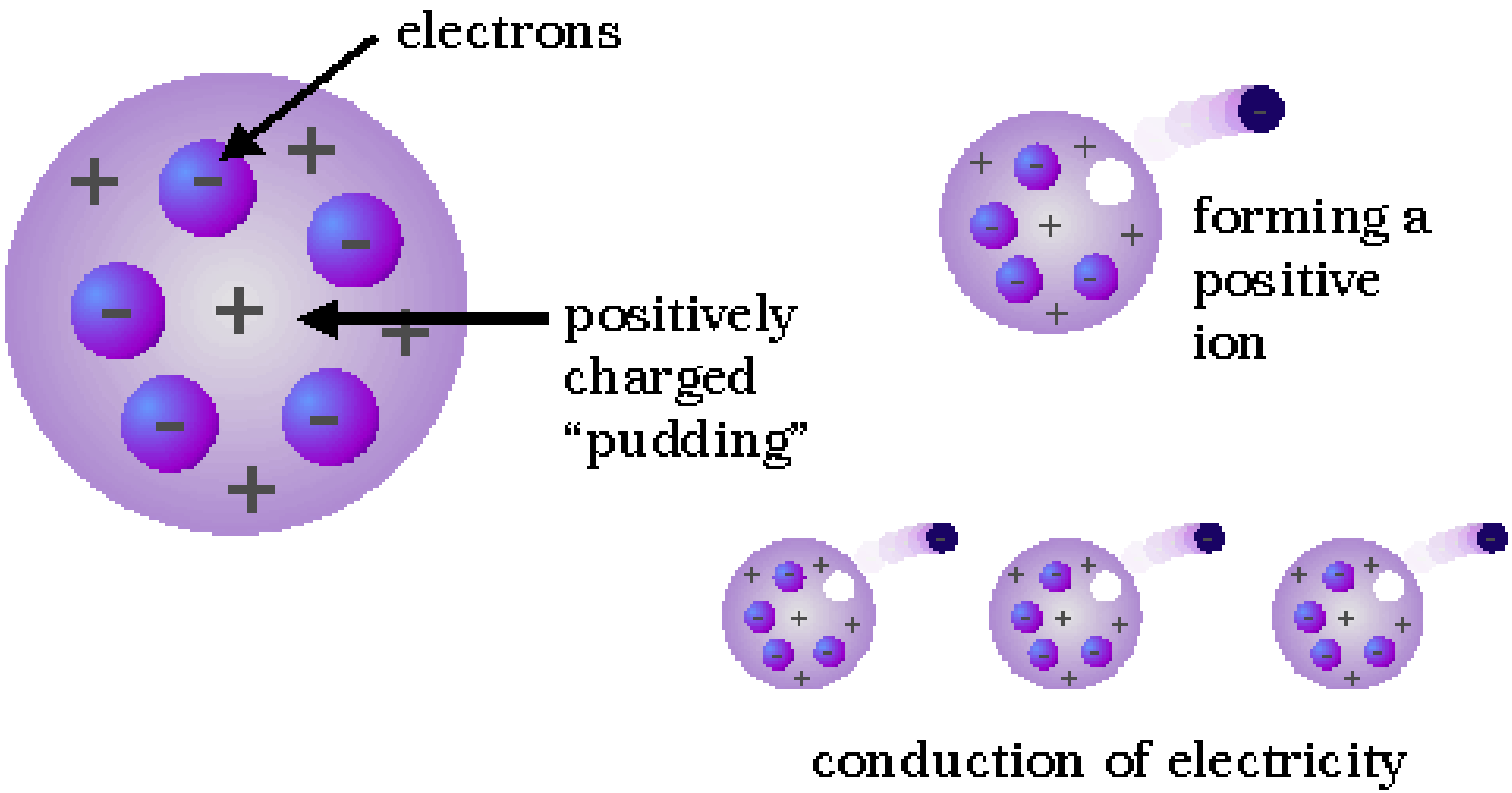
In the last decade of the 19th century, British physicists, J. J. Thomson at Cavendish Laboratory (Cambridge) designed several experiments to discover the nature of cathode rays.



The “Ray” is deflected in the presence of electric (and magnetic) fields. Therefore, it is not the same as light: Only charged particles can display such behavior.

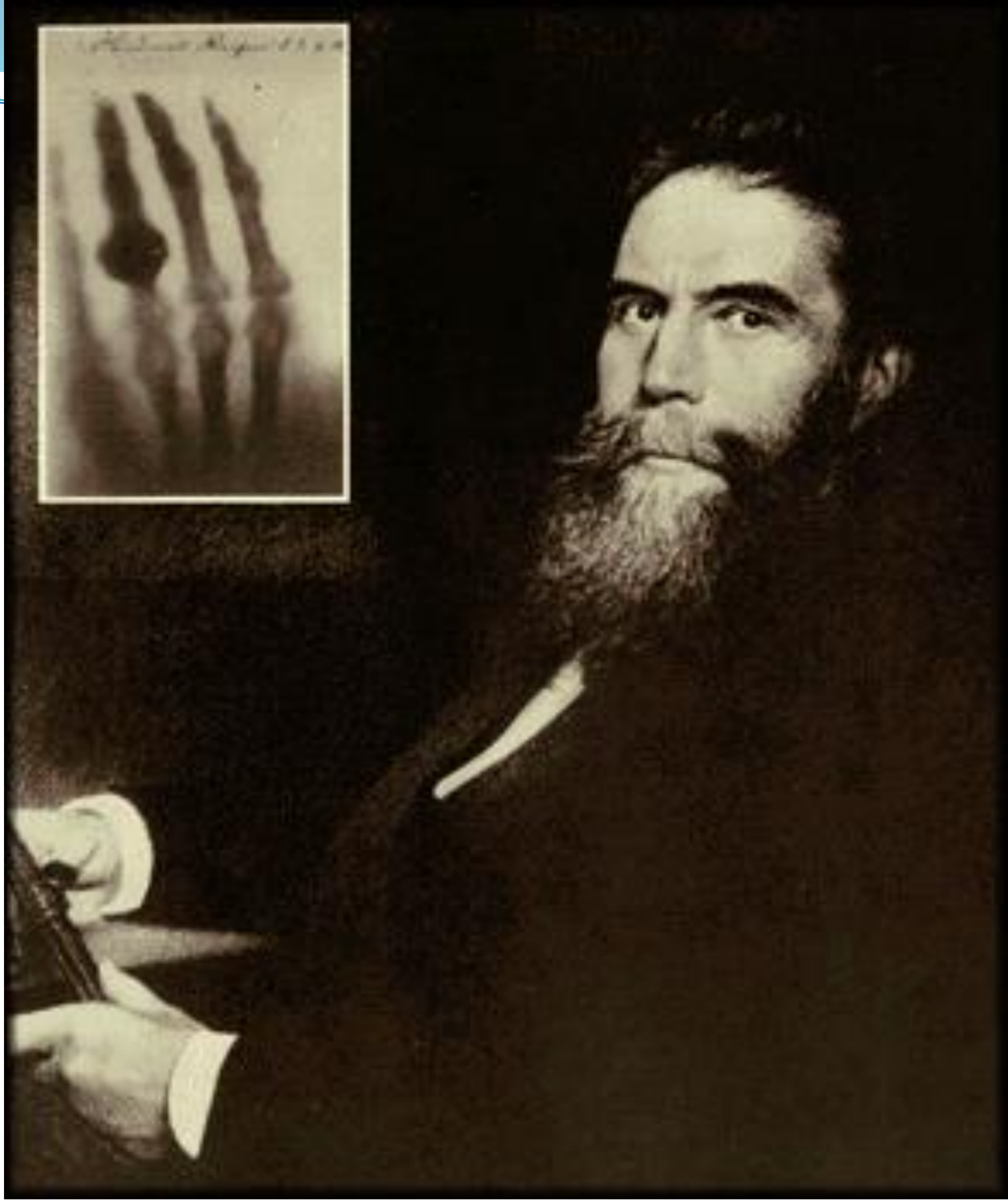
The particles of the cathode ray carry negative charge. The atom, then, should contain another particle with a positive charge. In other words, the atom is not like a billiard ball, but it made up of at least two parts.

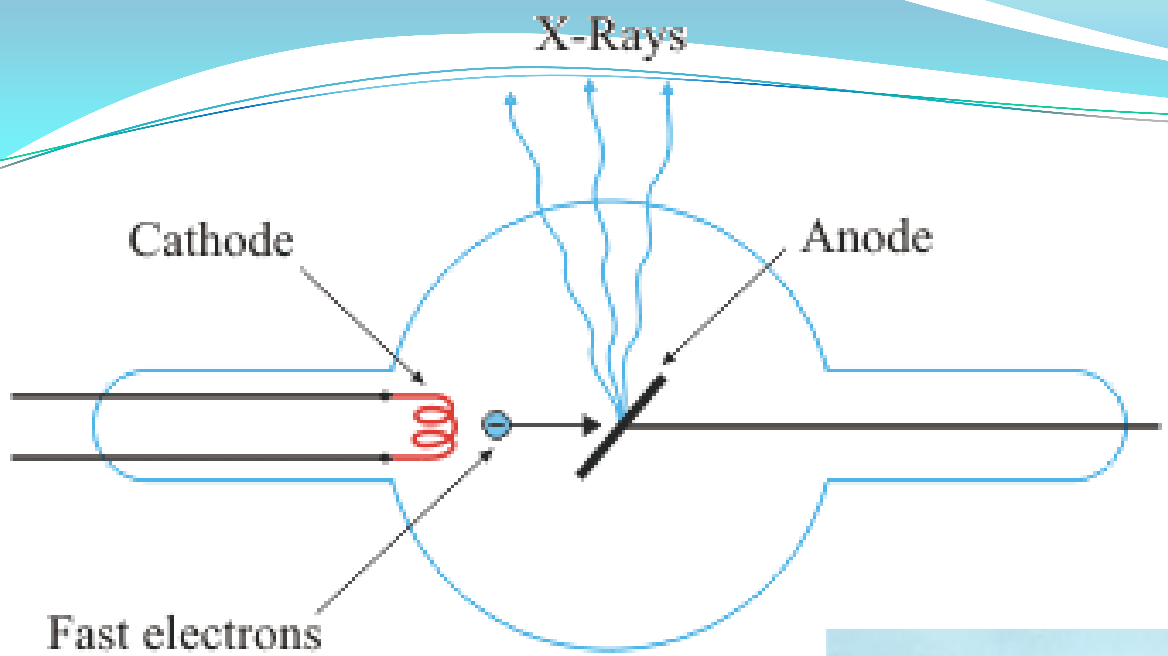
Thomson's Plum Pudding Atom



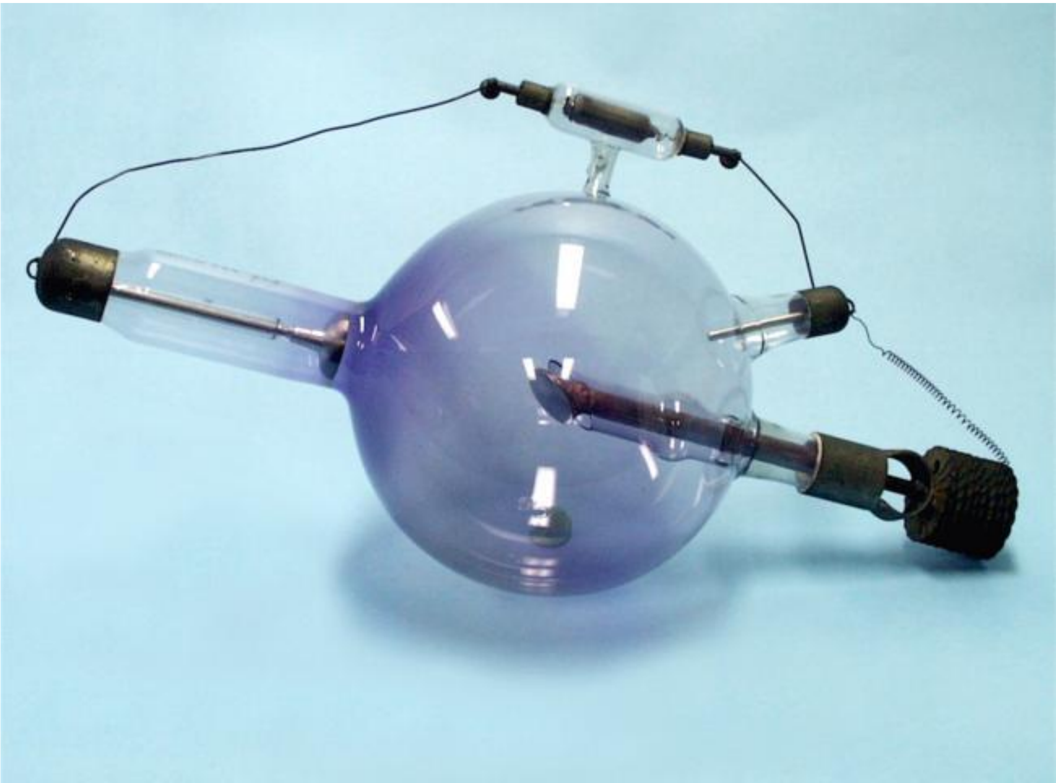
A year before Thomson's announcement of the discovery of the electron, German physicist Wilhelm Röntgen discovered an entirely new kind of ray, soon became famous as X-ray, because nobody knew about its nature. X-rays were able to pass solid objects as if they were sheets of transparent glass.

Rontgen: 1895





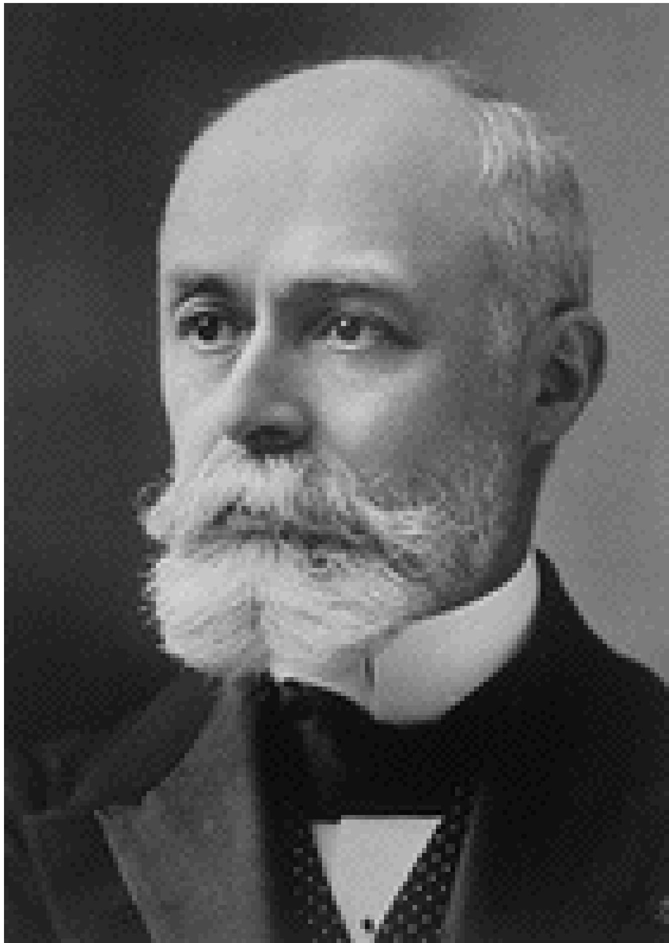
X-Ray tubes



- **During the same years (last decade of the 19th c.), physicists encountered another mystery related to the fine structure of matter: Henri Becquerel discovered a new kind of ray emanating from uranium salts: discovery of the Radioactivity**

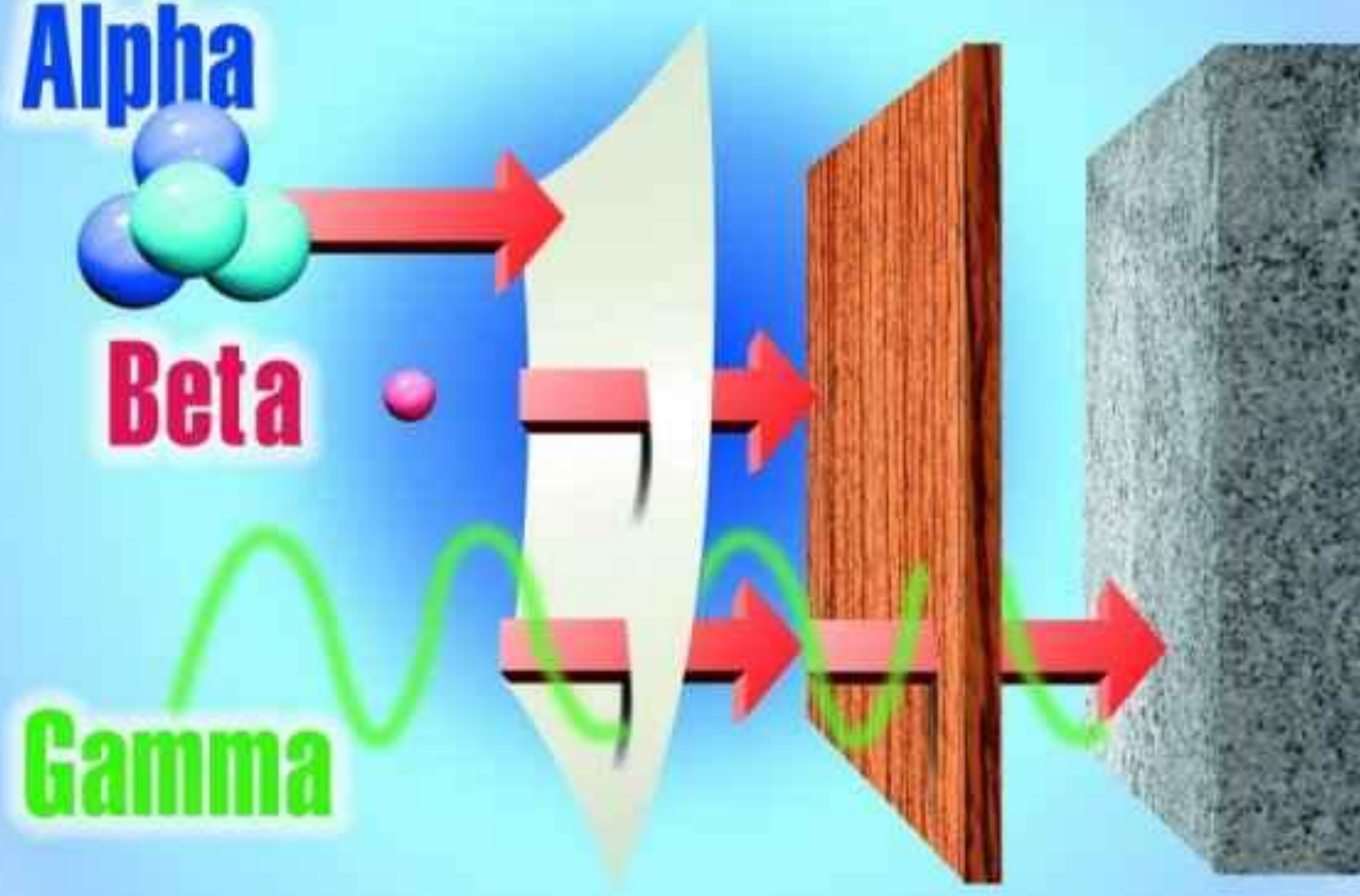
Henri Becquerel

Marie Curie



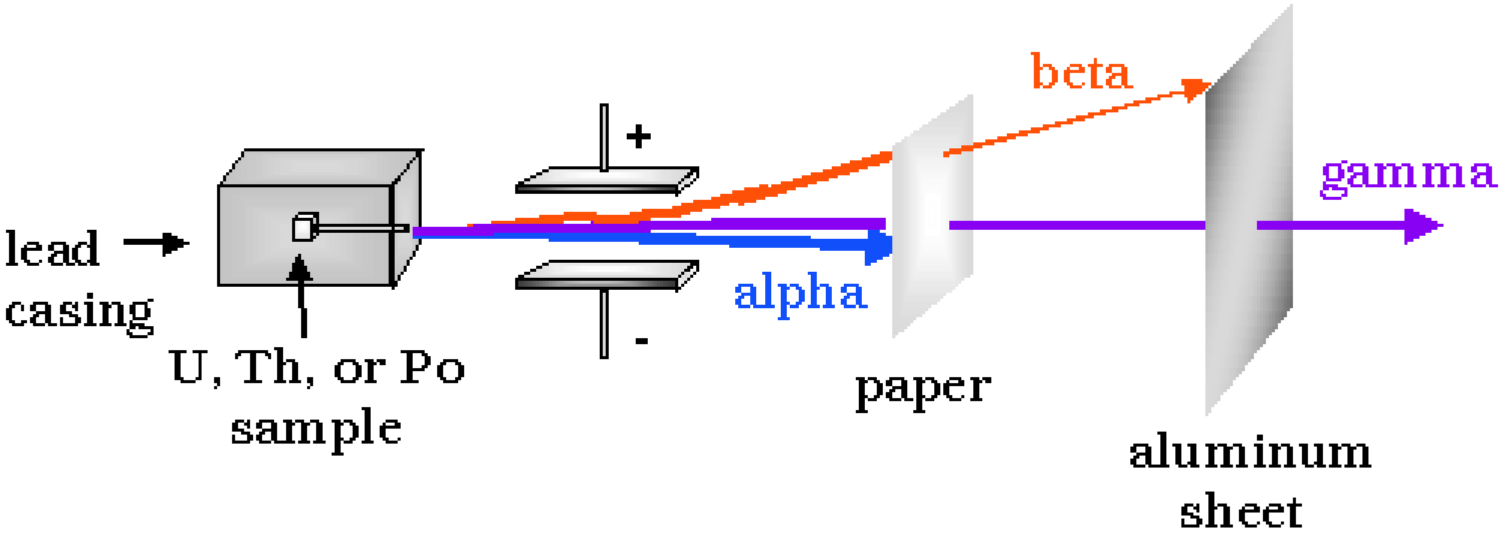
Pierre Curie
Marie Curie

Radiations emanating from radioactive materials



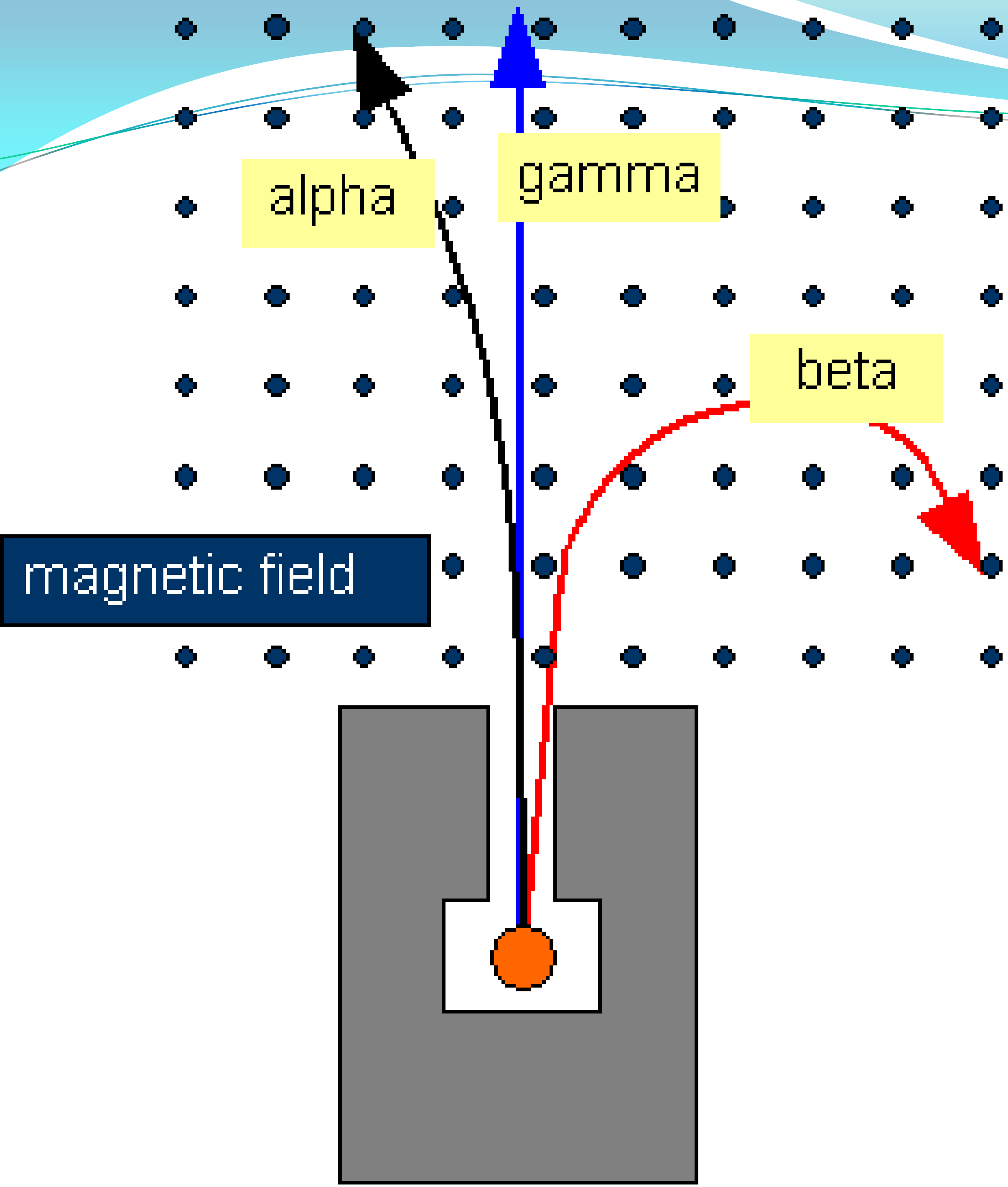
Probing Atomic Structure:

Alpha Rays

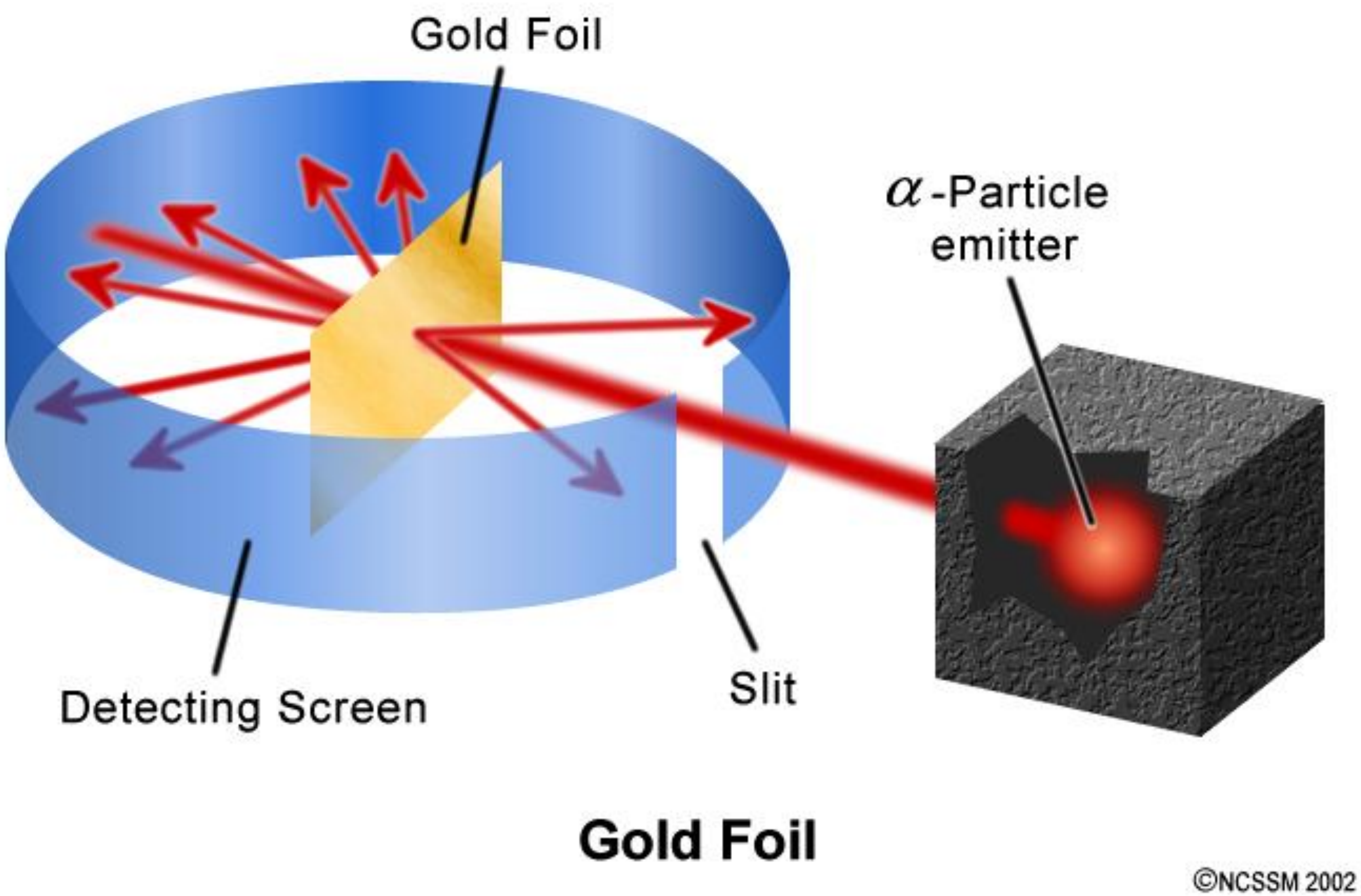


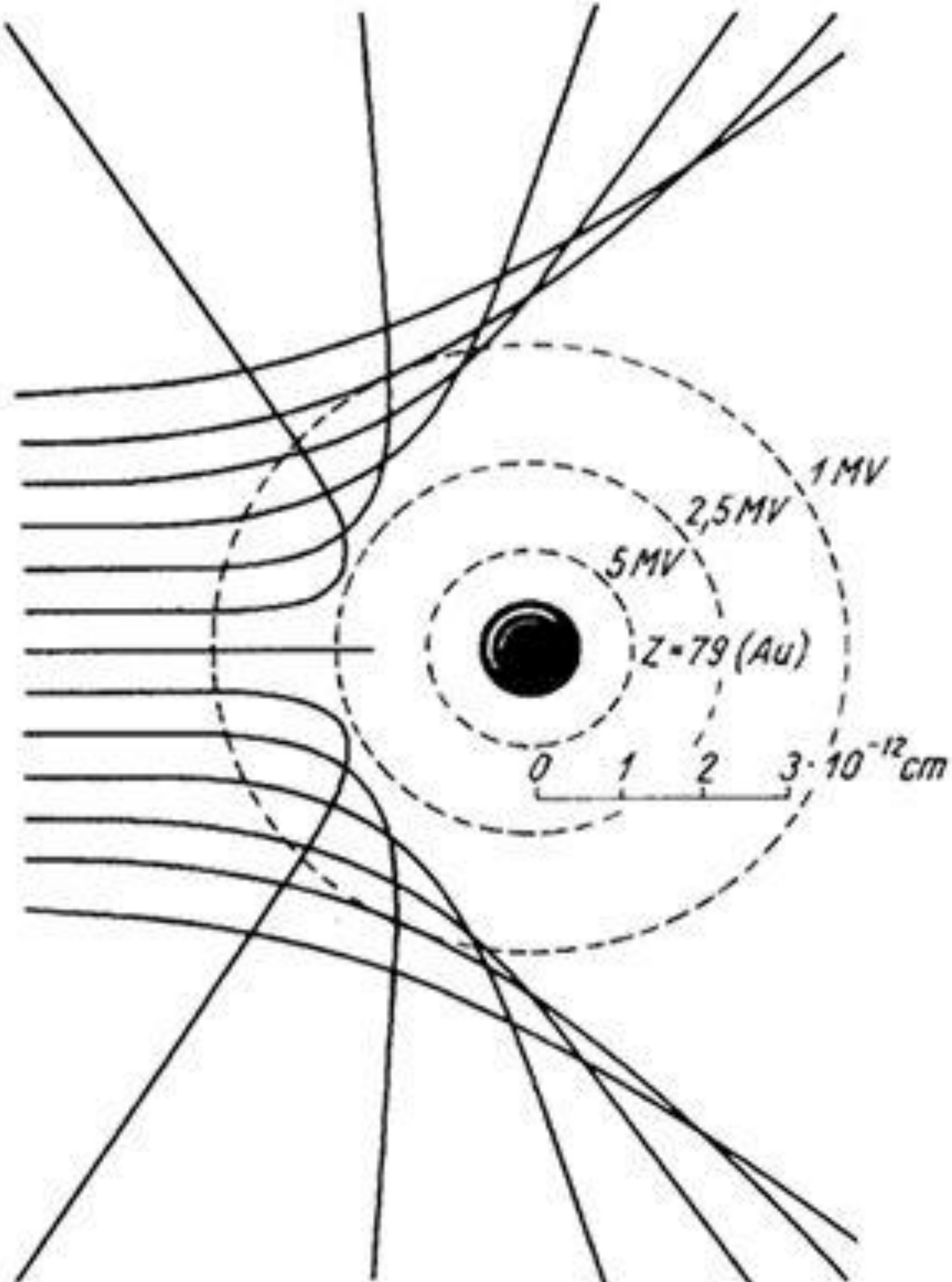
Properties of Alpha Particles:

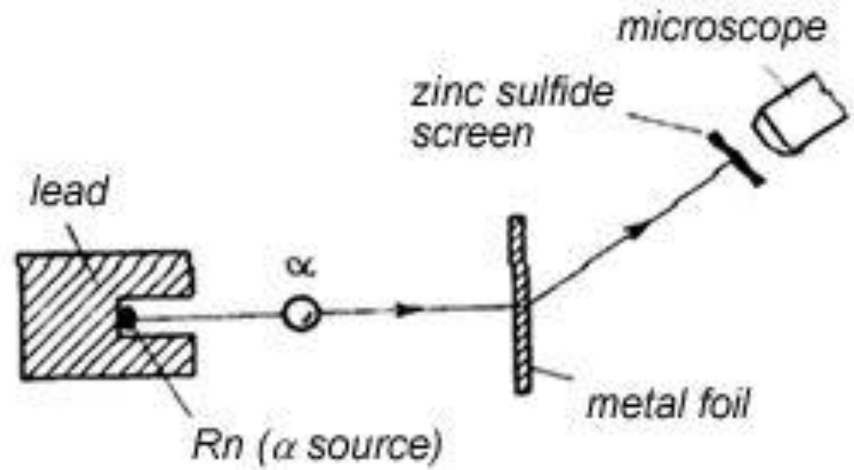
- much more massive than electrons
- positively charged
- expose photographic film


alpha
gamma
beta
magnetic field

Ernest Rutherford and the discovery of proton

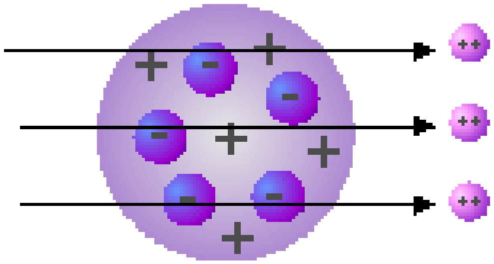



1 MV
2,5 MV
5 MV
Z = 79 (Au)
0
1
2
3 · 10⁻¹² cm

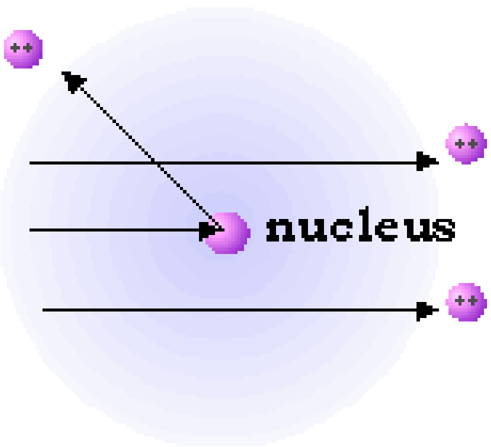

microscope
zinc sulfide screen
lead
α
metal foil
Rn (α source)

The Nuclear Atom

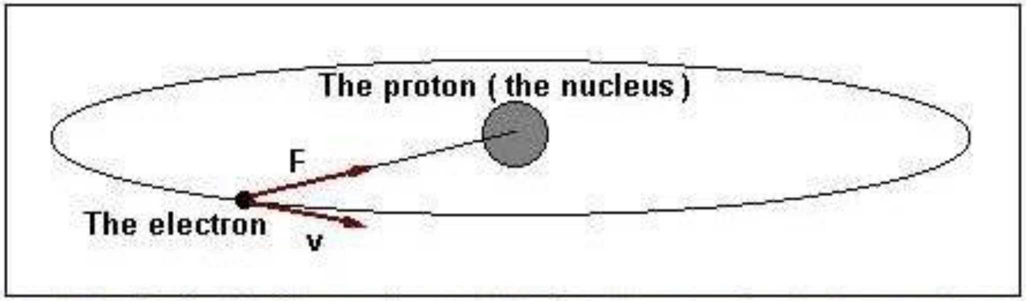
- **Thomson's Atom**
  - diffuse mass and charge



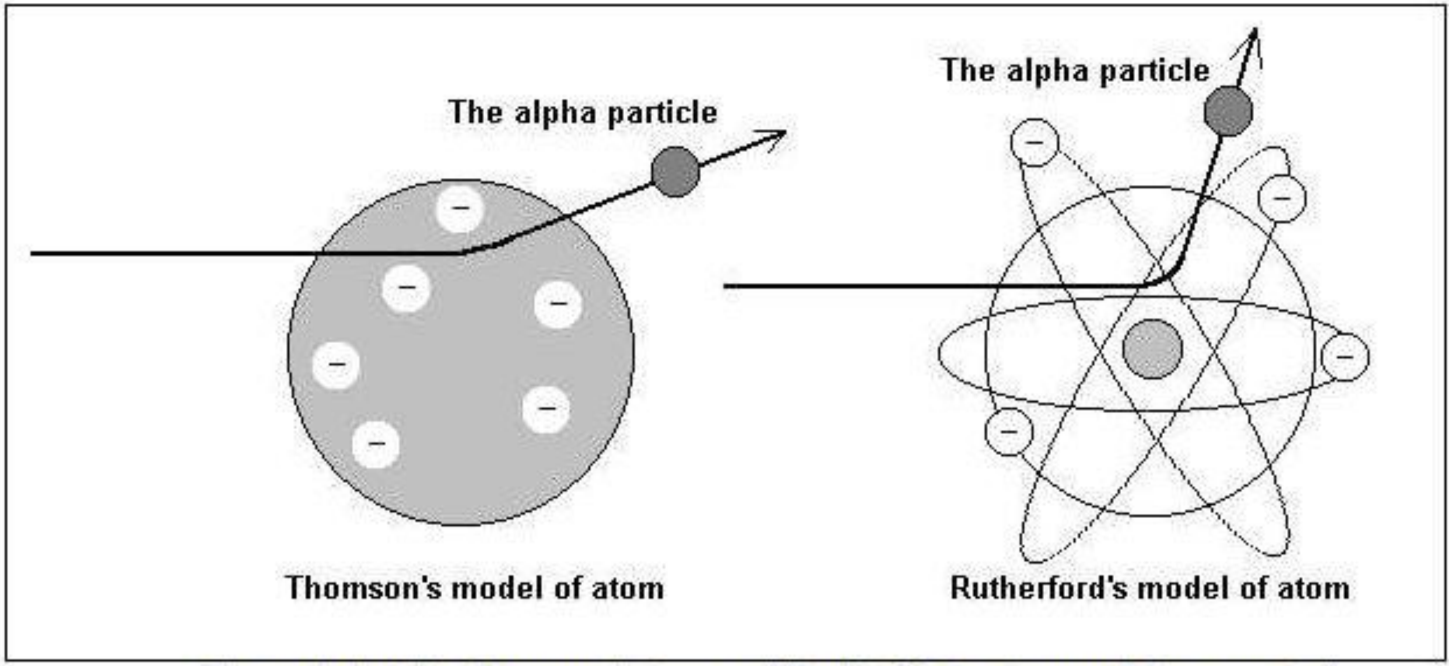
- **Rutherford's Atom**
  - concentrated mass and positive charge at the nucleus
  - electrons roam empty space around the nucleus



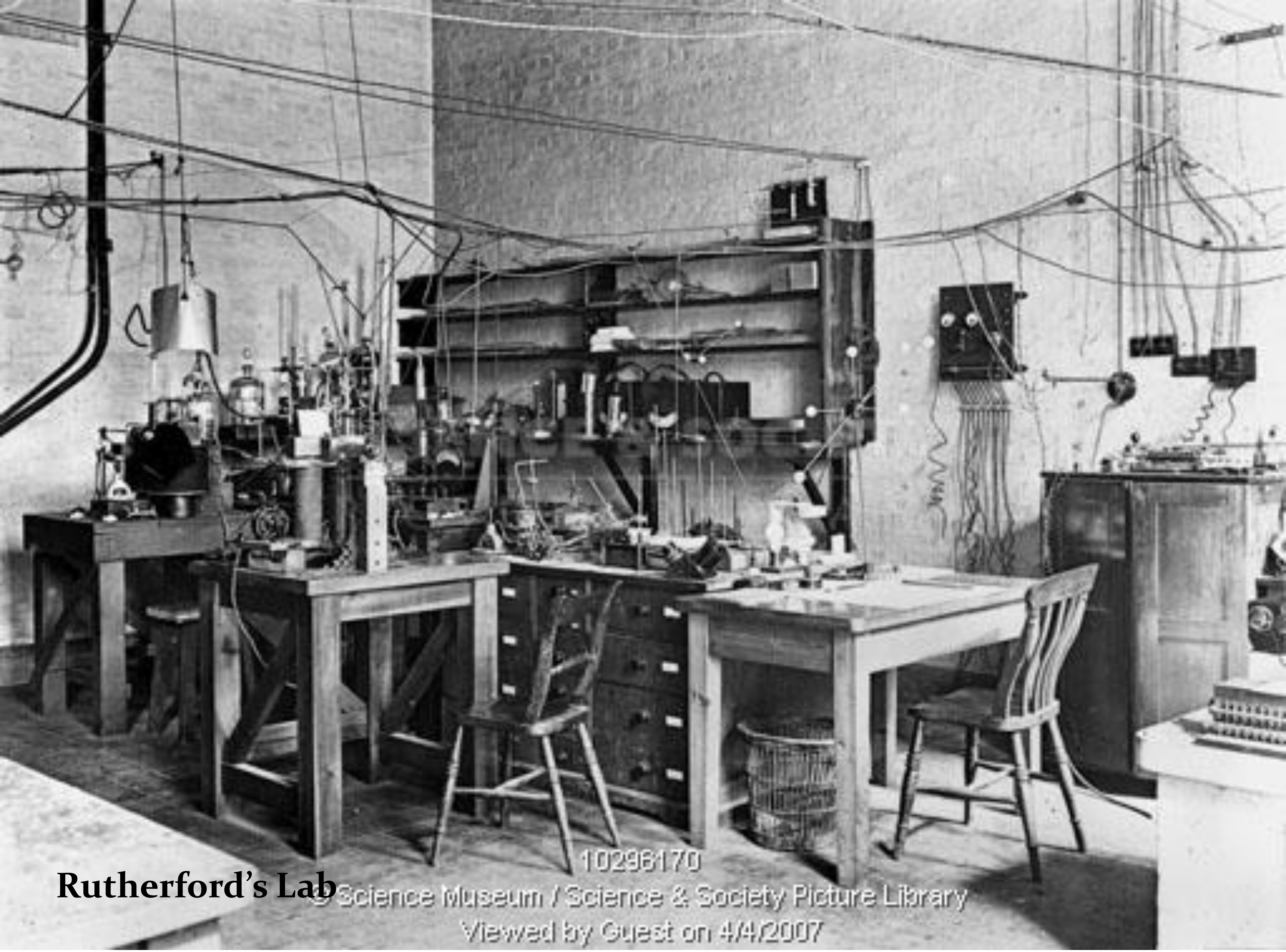
Rutherford’s atomic model



The Rutherford's atomic model. The electron circulating on the orbit around the nucleus with the velocity v is attracted by it with the force F



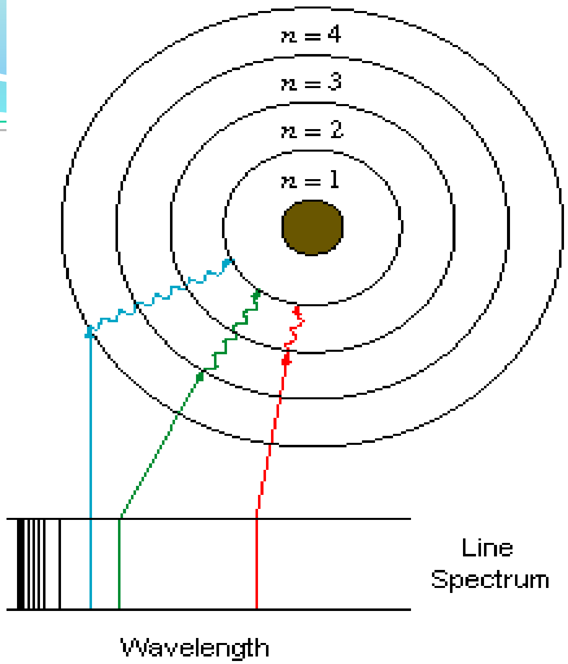
The models of the Thomson's atom and Rurtherford's atom; and the expected aberrations of alpha particle in both cases.

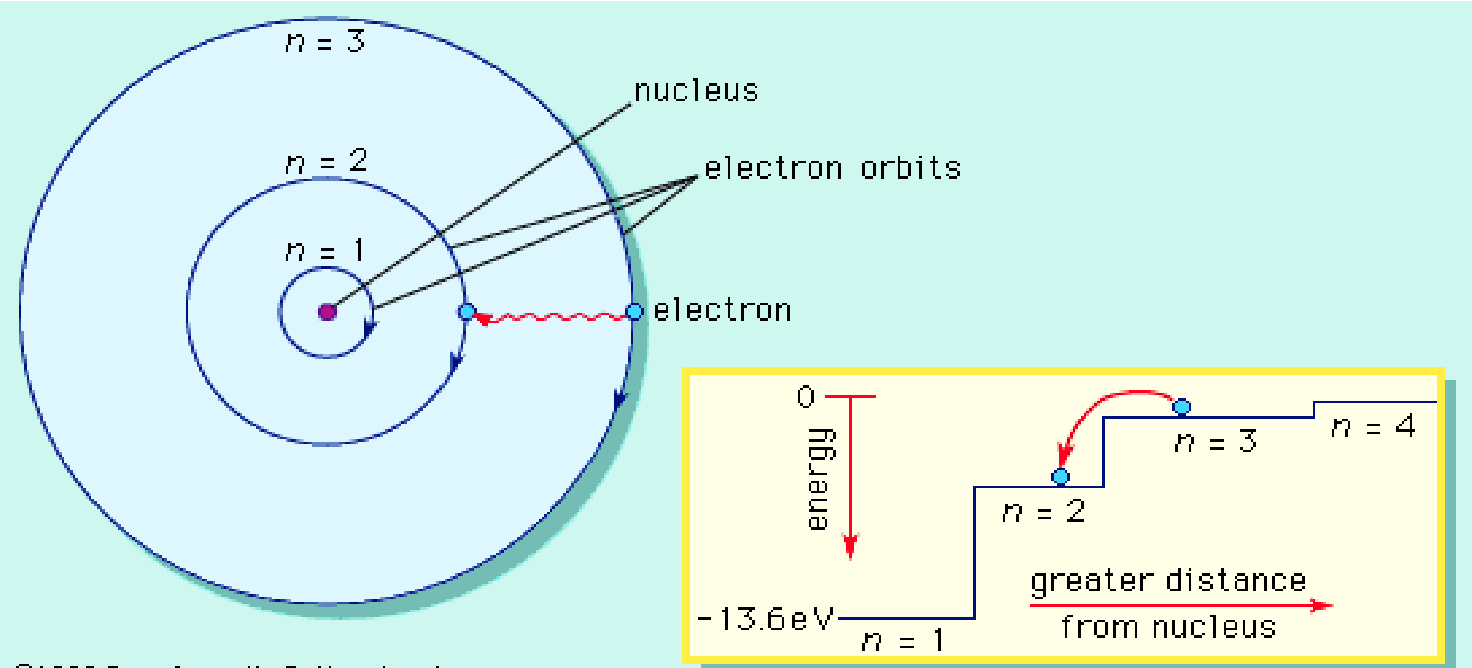


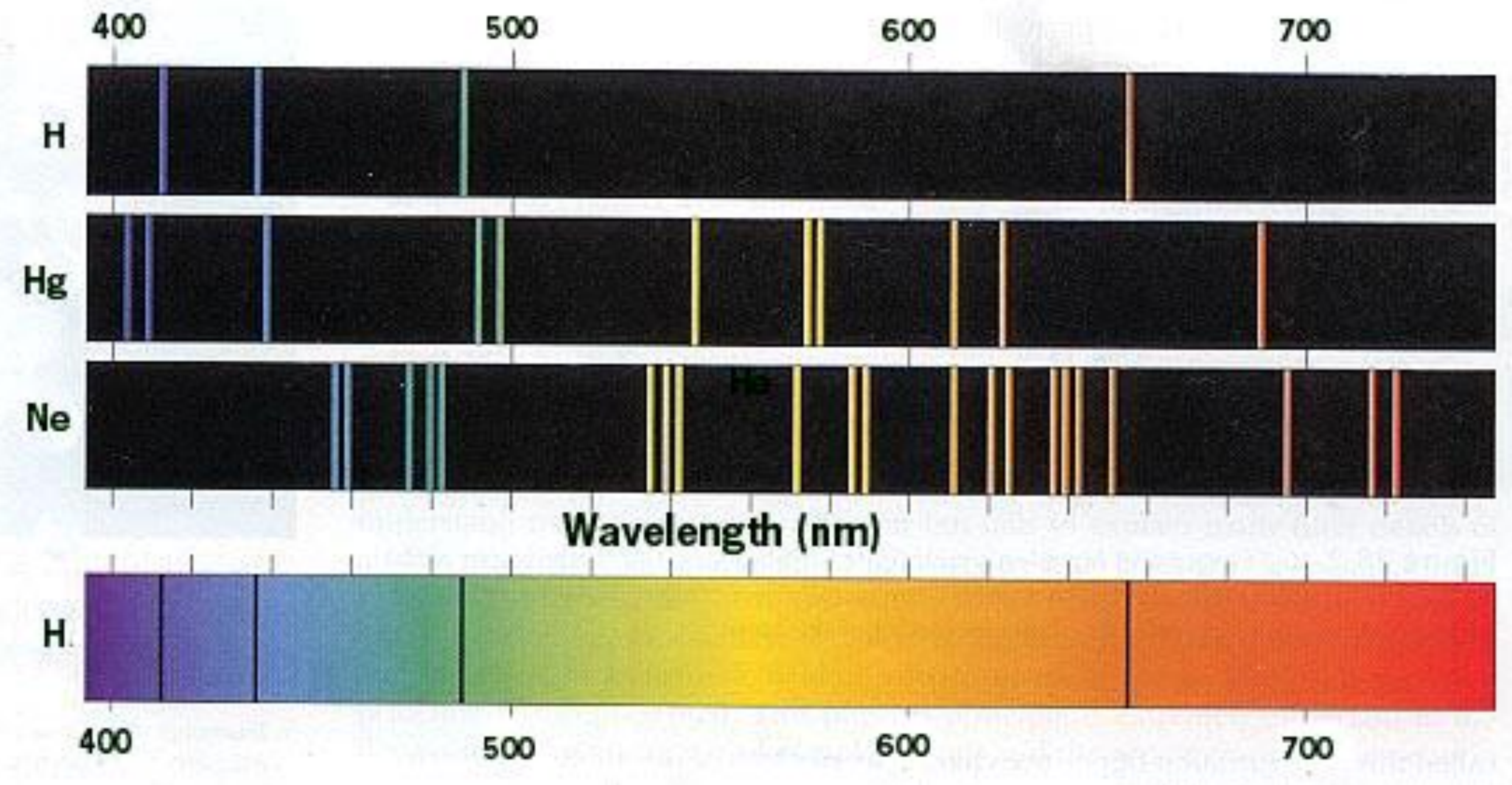
Rutherford’s Lab

Niels Bohr suggested that the electrons orbiting the central nucleus could only release their energy in distinct packets of energy, each with a distinctive frequency.

The electrons orbiting the nucleus were not radiating continuously, they did so at particular frequencies.

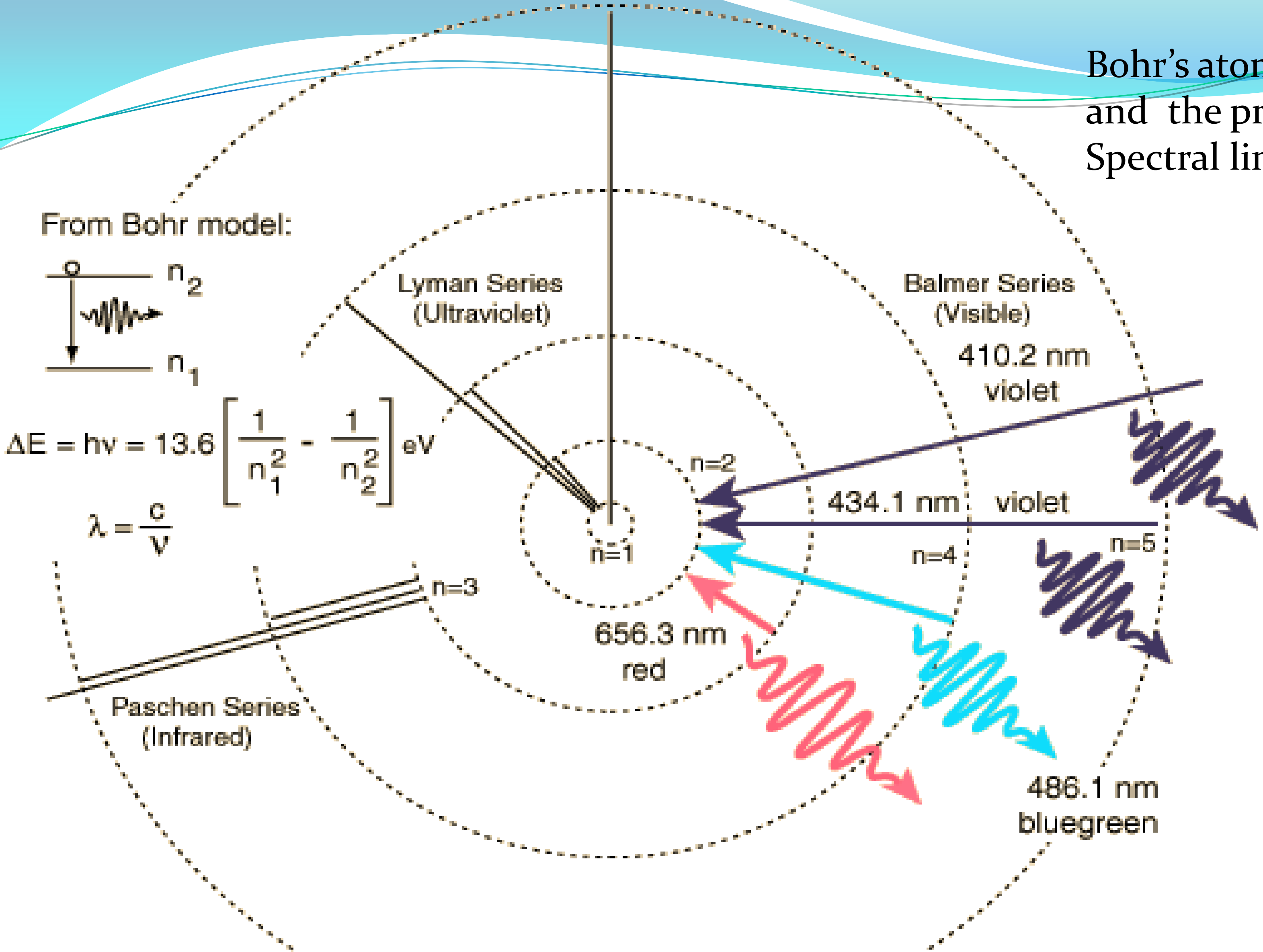


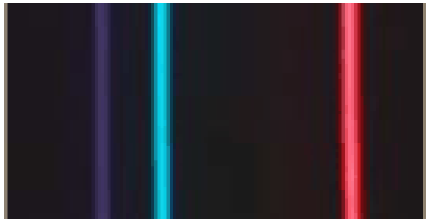


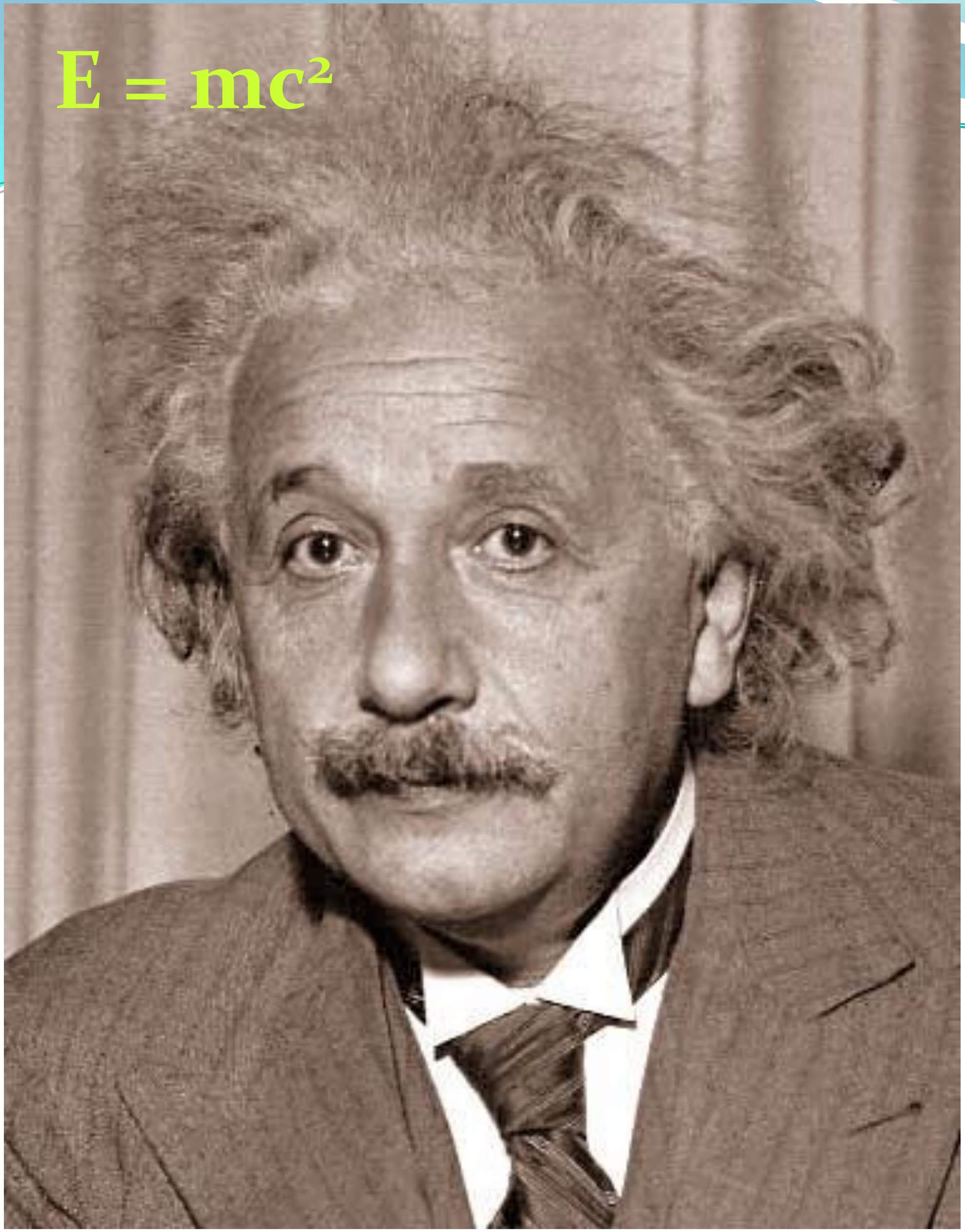


Atoms in heated gases ***emit*** and ***absorb*** light of certain wavelengths. Shown above are three *emission* spectra and one *absorption* spectrum.

Bohr's atomic model and the production of Spectral lines







Albert Einstein (1879-1955) was a German physicist whose theories of relativity forever changed scientific approaches to space, time, and gravity. Einstein was awarded the Nobel Prize for physics in 1921. After Hitler came to power in 1933, Einstein fled Nazi Germany, eventually taking a post at the Institute for Advanced Study at Princeton University in New Jersey, where he remained for the rest of his life.