Heinrich Hertz (1857 - 1894) Discovery of Radio Waves 1887

Static Electricity

- Thales of Miletus (624 – 526 BC)
  - Two pieces of amber rubbed with wool or two pieces of glass rubbed with silk would repel each other.
    - We now know that the amber removes electrons from the wool and becomes negatively charged.
    - Similarly, the glass becomes positively charged, having given up electrons to the silk.
  - Also, the amber would be attracted to the glass and the wool to the silk.

Static Electricity

Triboelectric Series

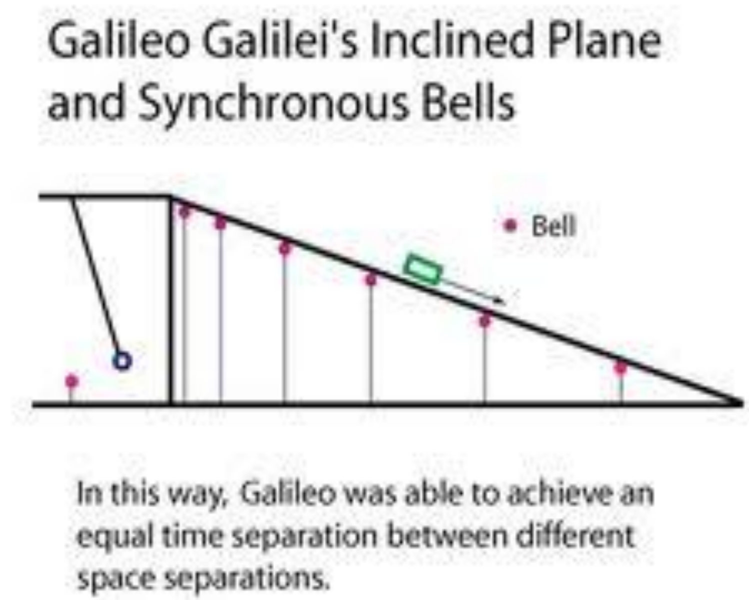
Negative	Conductor or Insulator
Silicone rubber	Insulator
Polyethylene	Insulator
Saran	Insulator
Synthetic rubber	Insulator
Brass/silver	Conductor
Nickel/Copper	Conductor
Hard rubber	Insulator
Steel	Conductor
Cotton	Insulator
Paper	Insulator
Aluminum	Conductor
Silk	Insulator
Wool	Insulator
Nylon	Insulator
Glass	Insulator
Positive	Conductor or Insulator

Magnetism

- Thales of Miletus (624-526 BCE)
- Described the lodestone
- China in 100 BCE used the magnetic compass.
- By convention, the direction of a magnetic field (S -> N) is indicated by a compass needle.

Galileo Galilei (1564 – 1642)

- One of the earliest "scientists", dared to "tinker with nature", rather than merely observing it.
- Observed moons of Jupiter, and supported the Copernican hypothesis.



Isaac Newton (1642 – 1727)

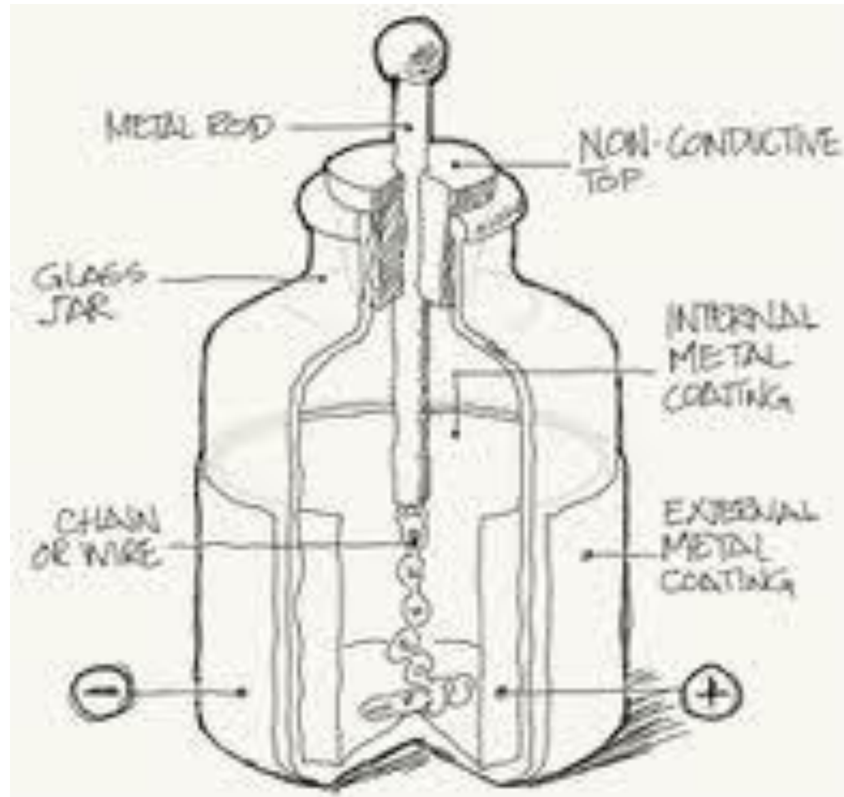
- Invented calculus to describe gravitation.
- Demonstrated that white light is a mixture of colours.
- Postulated that light is a stream of corpuscles.
- Invented the Newtonian telescope.

Static Electricity

- 1663 – The earliest friction machines rubbed a glass sphere against wool.
- 1733 – Charles Francois du Fay (1698 – 1739) postulated that there were two kinds of electrical fluid – vitreous and resinous

Static Electricity

- 1733 – The Leyden jar invented in Holland could store charges from generators.
- Spurred much research into static electricity.

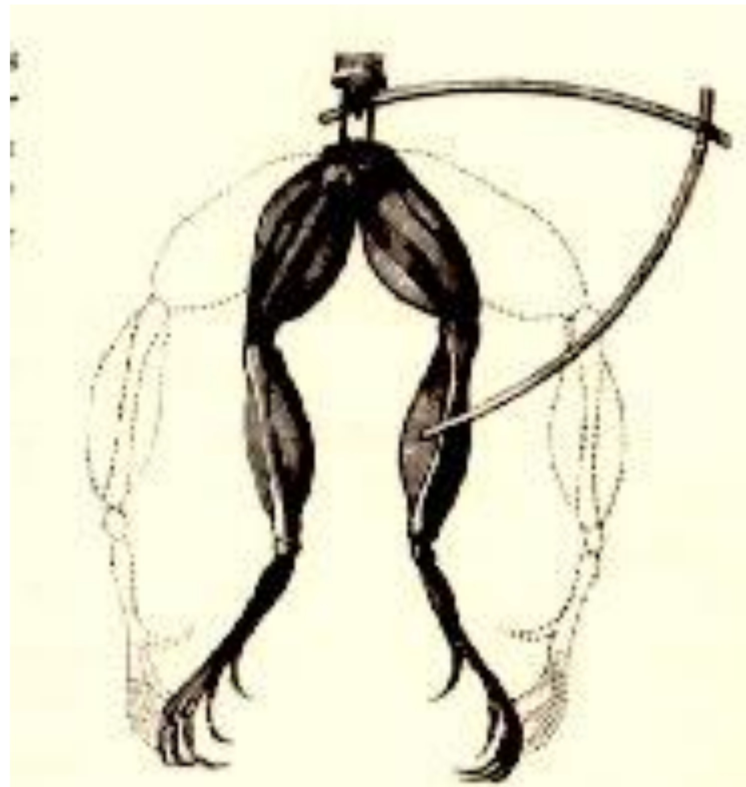


Static Electricity

- Benjamin Franklin (1705 - 1790)
- 1751 - Lightning was static electricity
- Arbitrarily defined Vitreous as "positive"
- Resinous, "negative"
- Theory of charge conservation

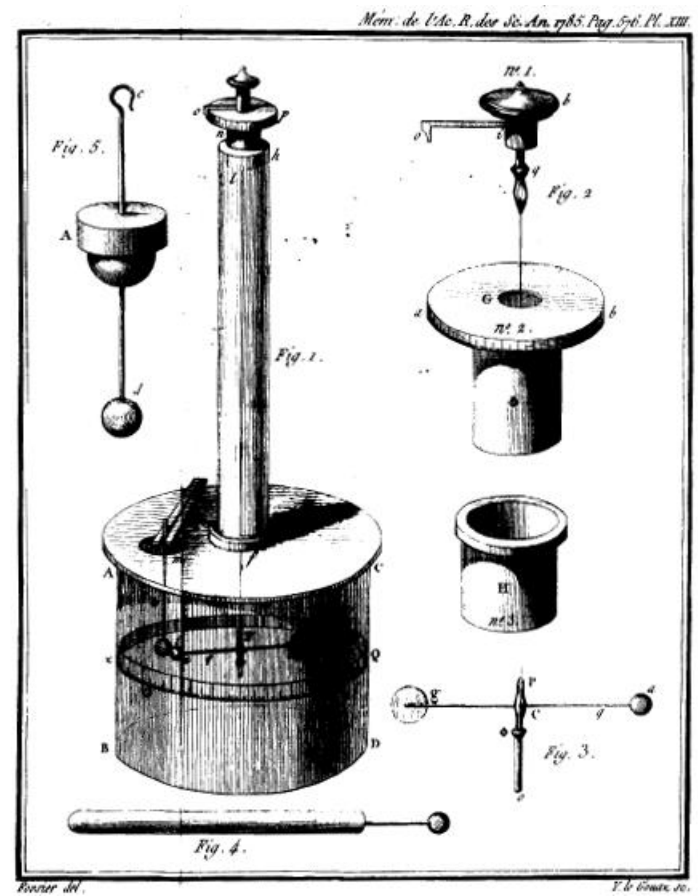
Static Electricity

- Luigi Galvani (1737–1798)
- 1770 - Discovered that static electricity from a Leyden jar could make frog’s legs twitch.
- Electrical basis of nerve impulses, known as “animal electricity”



Static Electricity

- Charles Augustus de Coulomb (1736-1806)
- 1785 - Inverse square law for electrostatic repulsion and attraction of charged bodies
- We now know that one Coulomb ≈ 1.6×10^{19} electrons



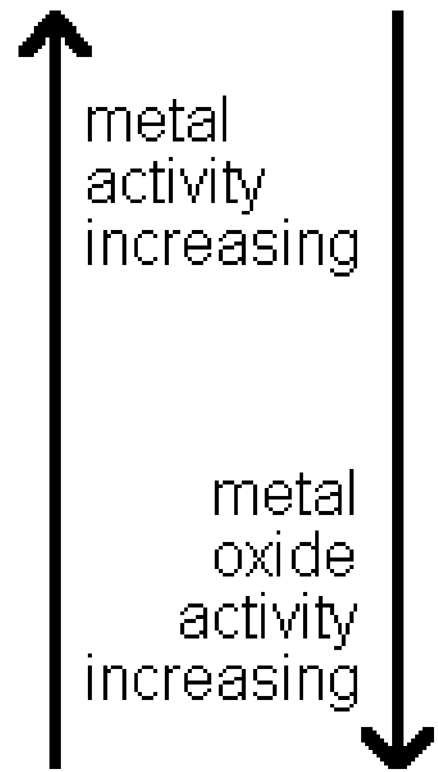
Electricity

- Alessandro Volta (1745-1827)
- 1780 – Difference between charge and tension (C = Q/V)
- Discovered that dissimilar metals could twitch frog's leg muscles.
- 1800 - Invented the Voltaic pile that could produce direct current.

Volta’s Battery was Zinc and Copper

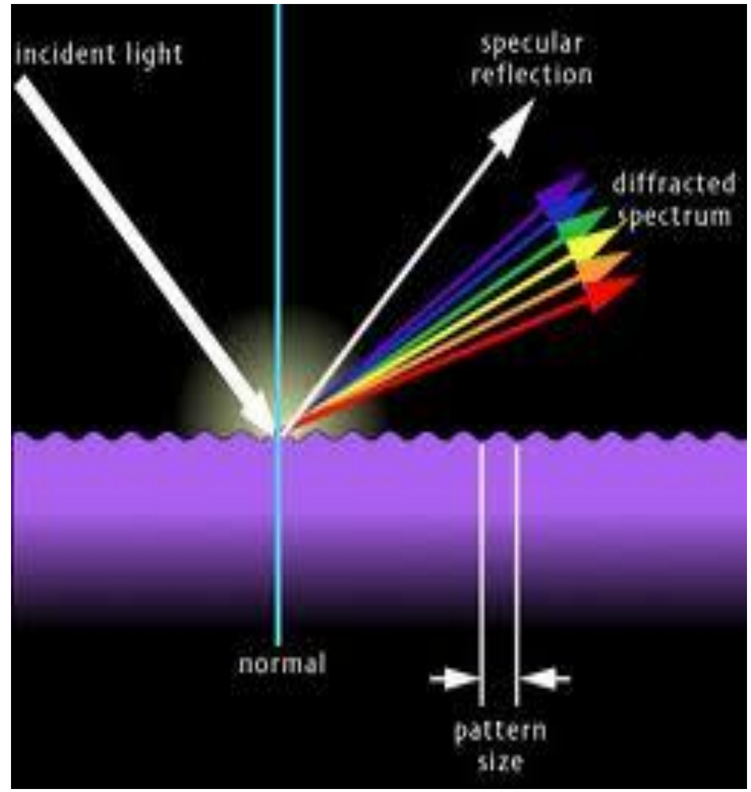
electro-chemical series

Potassium	-2.92
Calcium	-2.87
Sodium	-2.71
Magnesium	-2.37
Aluminium	-1.66
Zinc	-0.76
Iron	-0.44
Tin	-0.14
Lead	-0.13
Hydrogen	0.00
Copper	+0.34
Silver	+0.80
Mercury	+0.85
Gold	+1.68



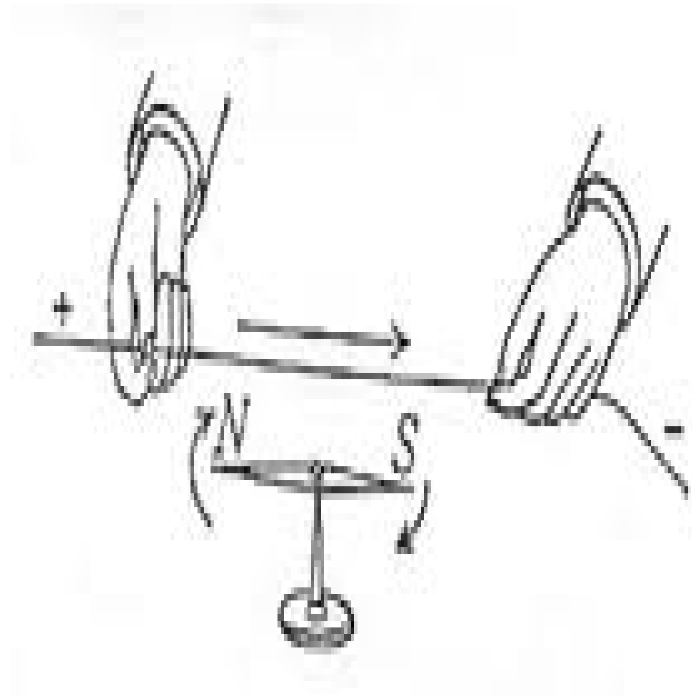
Light

- 1802 - Young (1773-1829) Wave theory of light passing thru a slit.
- 1816 Arago (1786-1853) Demonstrated that light was transverse waves and could be polarized.
- 1818 – Fresnel (1786-1827) Mathematical theory of light diffraction as waves.



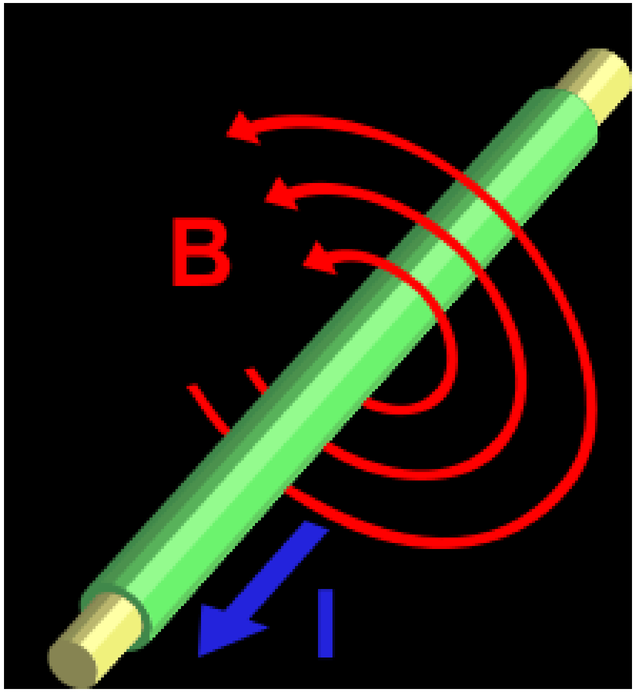
Electromagnetism

- Hans Christian Oersted (1777-1851)
- 1800 – Discovered the link between electricity and magnetism.
- By convention, current flow (arrow) is opposite to electron flow.
- Compass-north points in the direction of magnetic field (RH Rule)



Electromagnetism

- Schweigger (1778-1857)
  - 1820 – invented the galvanometer.
- Ampère (1775 - 1836)
  - 1826 – Experimentally determined the force between two current-carrying wires.
  - Mathematical relationship between current, distance and magnetic field strength.

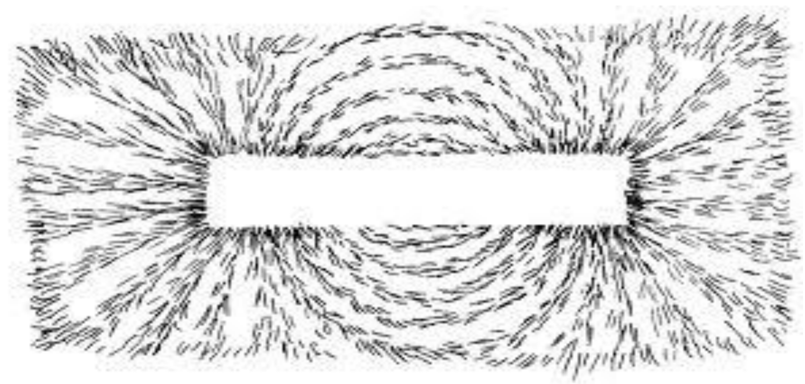


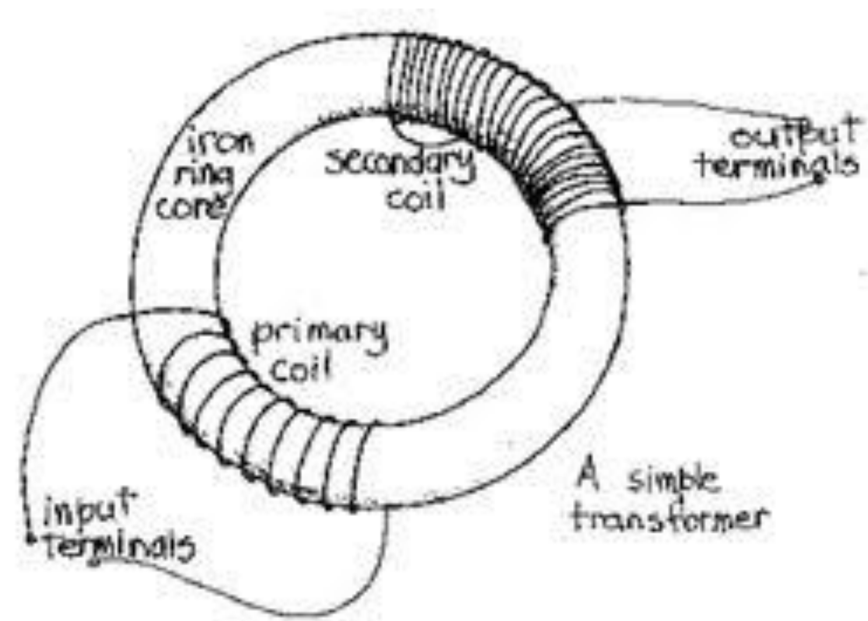
Electricity

- 1827 – Gustav Simon Ohm (1789-1854) asserted a firm relationship between static electric and "voltaic cell" current effects.
- Concept was not taken up immediately because static charge was known to reside on a surface.
- Proposed an analogy between heat flow and current flow (Ohm's Law).

Electromagnetic Induction

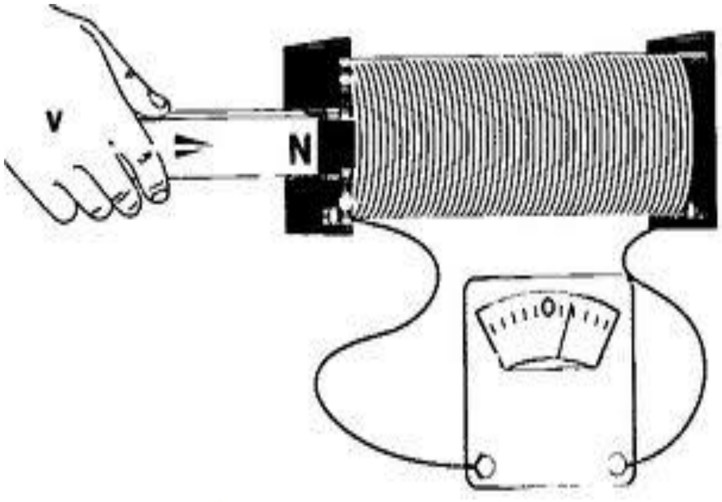
- Michael Faraday (1791-1867)
- Concept of electric and magnetic fields
- A changing electric current in one coil creates a changing magnetic field that can create a changing electric current in another coil.

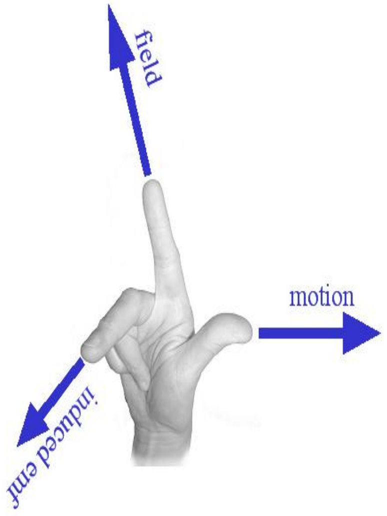




Electromagnetic Induction

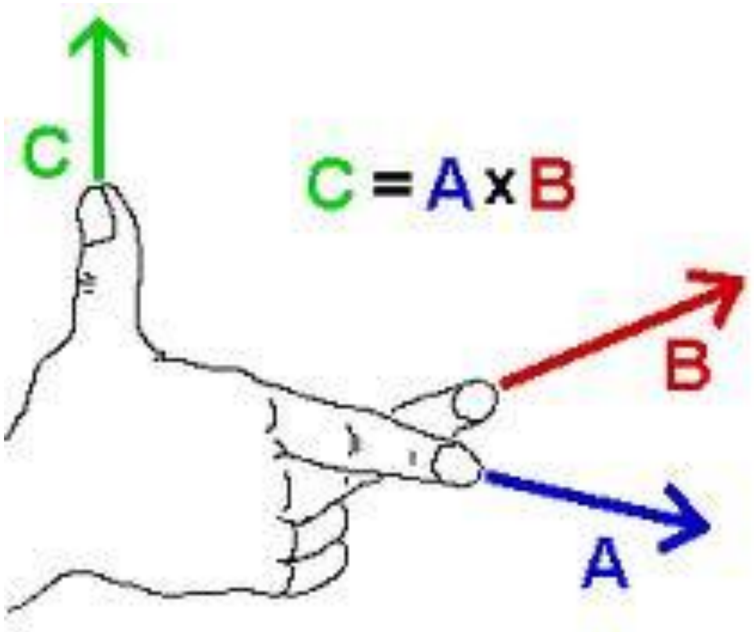
- Michael Faraday (1791-1867)
- 1831 – Electromagnetic Induction
  - Moving magnet induces a changing electric field in a wire.
  - A wire moving in a stationary magnetic field develops an induced electric field.





Electromagnetic Conventions

- C = A “cross” B
- F = qv X B or F = iL X B
- Magnetic Field points from South to North
- Electric field direction is from plus to minus, as is direction of current.
- Today, we know that electron flow is opposite to current.



Twenty Years of Research

- 1835 – Gauss (1777-1835)
  - Law relating electric field to enclosed charge.
- 1840 – Joule (1818-1889) and, independently Helmholtz (1821-1894), determined that electricity is a form of energy.
  - 1843 – Joule – Mechanical equivalent of heat.
- 1851 – Neumann (1798-1895) law of electromagnetic induction $E = L\, di/dt$

James Clerk Maxwell (1831-1879)

- 1855-1864 – In a series of papers, combined Ampère’s (modified), Gauss’s, Faraday’s and Neumann’s laws into a set of 9 simultaneous field equations.
- Described how electric and magnetic fields are generated and affect each other.

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

James Clerk Maxwell (1831-1879)

- In Maxwell's equations:
  - ϵ_0 is the electric permeability of free space
  - μ_0 is the magnetic permeability of free space
  - These constants had already been measured.
- Maxwell also derived a wave equation.
- He believed that light was electromagnetic.
- We now know that visible light is just a small portion of the electromagnetic spectrum.

James Clerk Maxwell (1831-1879)

- 1873 - Maxwell calculated that the velocity of propagation of an electromagnetic disturbance, in a non-conducting medium, should be equal to 1/sq.rt.($\epsilon\mu$), where ϵ and μ are the electric and magnetic permaeabilities of the medium.
- The calculation turned out to be reasonably close to the then known speed of light.

James Clerk Maxwell (1831-1879)
(Excerpt from 1873 *Treatise*)

787.] In the following table, the principal results of direct observation of the velocity of light, either through the air or through the planetary spaces, are compared with the principal results of the comparison of the electric units :—

Velocity of Light (mètres per second).		Ratio of Electric Units.	
Fizeau	314000000	Weber	310740000
Aberration, &c., and Sun's Parallax	308000000	Maxwell	288000000
Foucault	298360000	Thomson	282000000.

It is manifest that the velocity of light and the ratio of the units are quantities of the same order of magnitude. Neither of them

James Clerk Maxwell (1831-1879)

- 1873 *Treatise* - Hypothesized that light was an electromagnetic disturbance.
- Work was accepted in Edinburgh but not well understood on the continent, where two other competing electrodynamics theories were being debated.
- As a student, Heinrich Hertz (1857-1894) had read Maxwell's papers but only later on recognized their full significance.

Herman von Helmholtz (1821-1894)

- Studied interactions between open circuits but failed to develop a consistent theory.
- 1847 - Suggested that the discharge from a Leyden jar was oscillatory.
- As a student, Hertz worked under Helmholtz.
  - Looked, unsuccessfully, for kinetic energy in the electric current (analogous to water flowing in a pipe). Actually, the average electron speed in a 22 ga. wire carrying one Ampere is 0.4 mm/sec.

Heinrich Hertz (1857-1894)

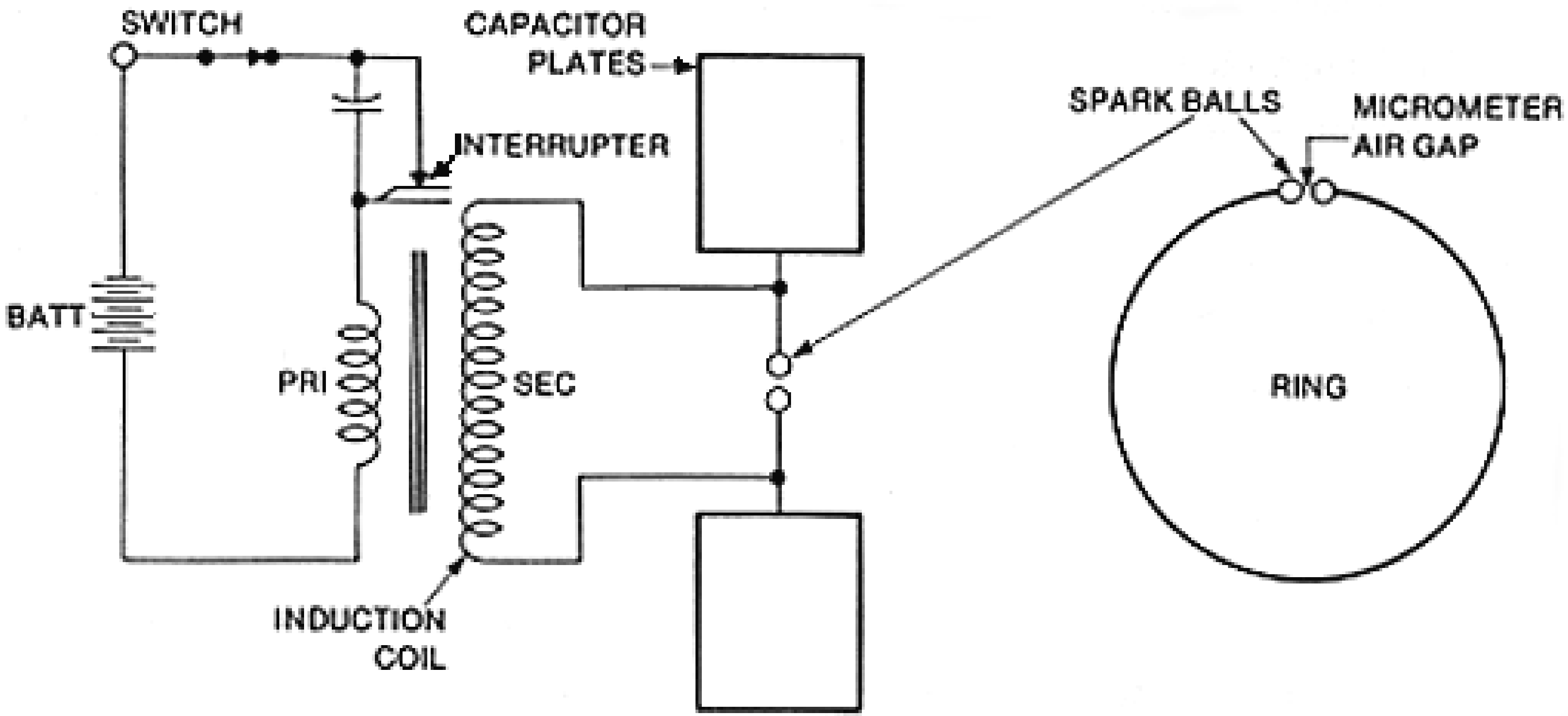
- 1885 – Newly-appointed Physics Department Head at Karlsruhe Institute.
  - Had his own lab, a small workshop and some staff, but as a scientist, worked alone.
  - At Helmholtz’s suggestion, started to investigate electromagnetic high fequemcy effects between adjacent conductors and coupled circuits.
  - Was not looking for evidence of electromagnetic radiation.

Heinrich Hertz (1857-1894)

- Experimented with open induction coils, spiral inductors and parallel wires.
- Achieved “rapid” oscillations of 50 MHz. by replacing the Leyden jar with lower-capacitance metal spheres, 30 cm. in diameter, and by connecting them with a short wire, interrupted by a spark gap.
- Sparks indicated the presence of EM energy.
- He had invented the world’s first dipole antenna.

Heinrich Hertz (1857-1894)

(final configuration, after much trial and error)



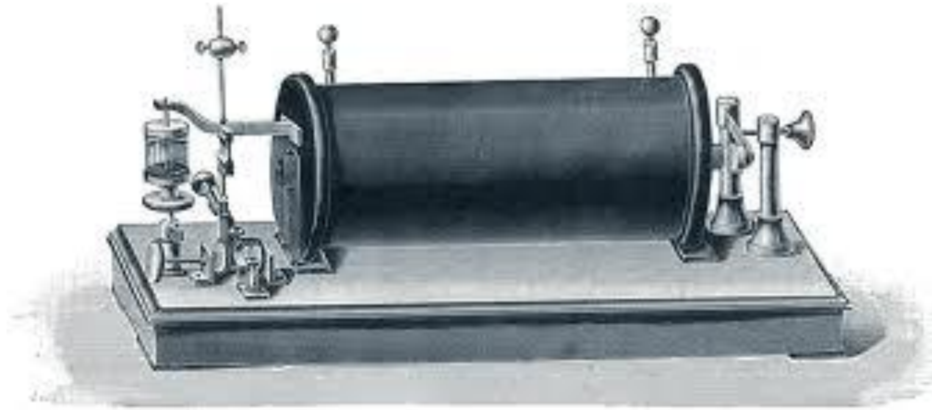
Heinrich Hertz (1857-1894)

- Sparks don’t generate radio waves. They are equivalent to rapid on-off switches.
- Accelerated electrons radiate. An interrupted DC, or an AC current is required.
- 0.25 cm. antenna gap has a breakdown voltage of ≈ 20 KV. As the voltage drops due to radiation and circuit resistance, air ionization keeps the current surging back and forth between the two halves of the dipole. The process eventually stops until a new charge can be applied from the induction coil.

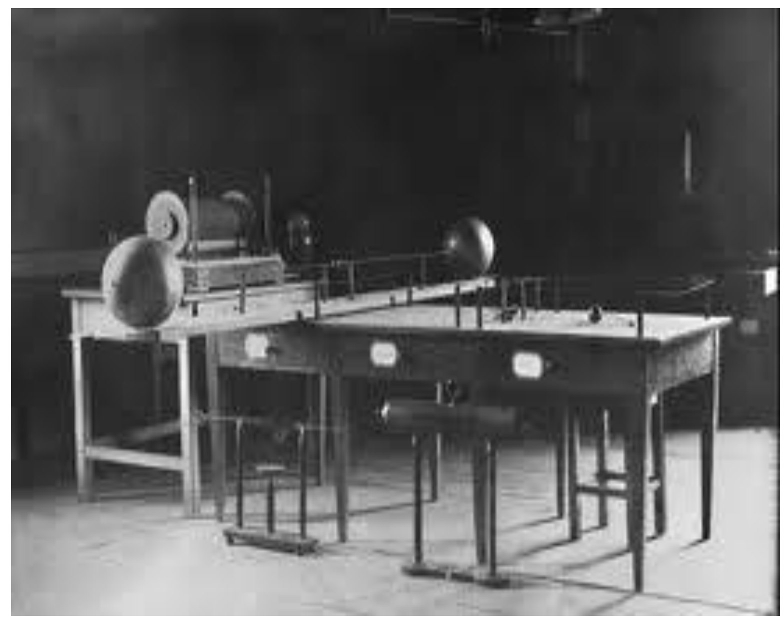
Heinrich Hertz (1857-1894)

- Took over a year of persistence to get the wire lengths, capacitances, distances and orientations optimal, and to begin to understand some of the theory.
- Hertz had to work in a darkened room while adjusting the receiving antenna spark gap, because the sparks were barely visible.
- Once he knew that the effect spanned more than a few tens of centimeters, he began to suspect that he was producing EM radiation.

Heinrich Hertz (1857-1894)



- Apparatus included a battery-powered Rhumkorff coil, to develop high voltages.
- The receiving antenna had a micrometer-adjustable spark gap.
- Antenna gap distance measured the effect's strength.

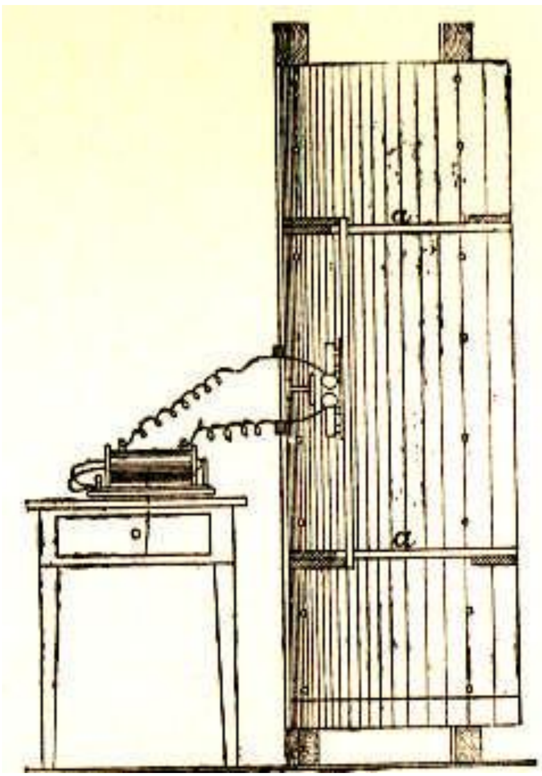


Heinrich Hertz (1857-1894)

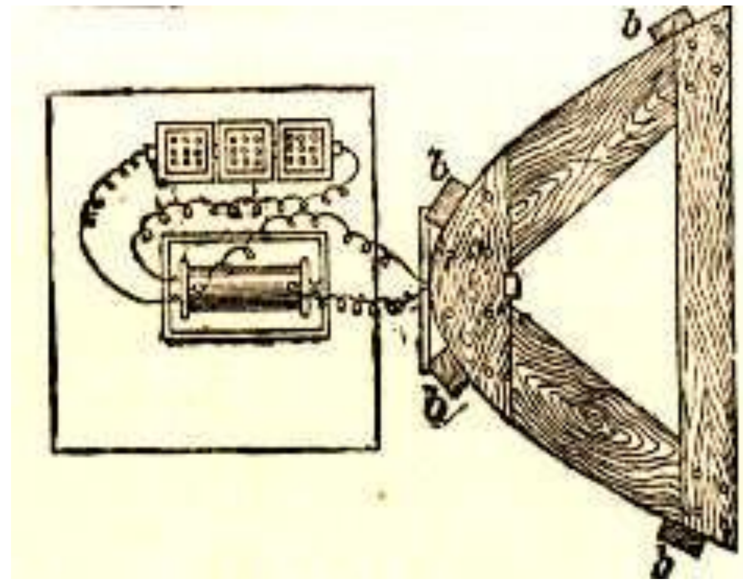
- Hertz increased the frequency to ≈ 500 MHz. and was able to move the receiving antenna back and forth and detect nodes and peaks.
- He found that metal sheets could reflect the radiation. With a parabolic reflector, he was able to set up standing waves in the lab.
- He was able to demonstrate refraction through a prism of pitch.
- He showed that radio waves were polarized and behaved like light.

Heinrich Hertz (1857-1894)

- Reflector, from side

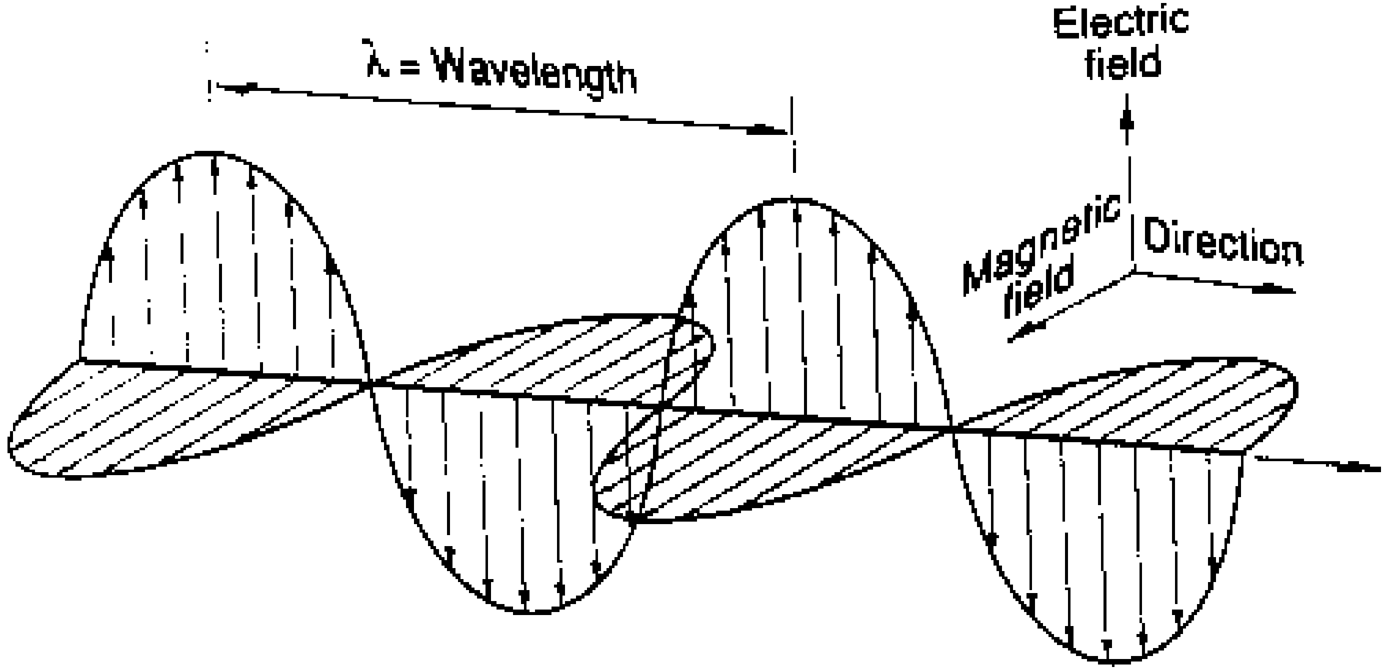


- Reflector, from above



Heinrich Hertz (1857-1894)

- **E** -> d**B**/dt and **B** -> d**E**/dt



ELECTRIC WAVES

BEING

RESEARCHES ON THE PROPAGATION OF ELECTRIC
ACTION WITH FINITE VELOCITY
THROUGH SPACE

BY

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AUTHORISED ENGLISH TRANSLATION

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IN THE UNIVERSITY OF GLASGOW, AND FELLOW OF ST. PETER'S
COLLEGE, CAMBRIDGE

London
MACMILLAN AND CO.
AND NEW YORK
1893

After Hertz, the Electron

- 1892 – Hendrik Lorentz (1853-1928) – Electricity is due to charged particles.
  - Lorentz force : $\mathbf{F} = q\,[\mathbf{E} + (\mathbf{v} \times \mathbf{B})]$
- 1895-1897 – J. J. Thomson (1856-1940) Discovery of the electron.
  - In a series of three experiments, showed that cathode rays were negatively charged, could be bent by passing between oppositely charged plates and could be bent by a magnetic field.
  - Determined the charge to mass ratio of the electron

Guglielmo Marconi (1874 – 1937)

- 1894 – First experiments with spark-gap transmitter.
- 1895 – 2.4 km. transmission
- 1897 – Morse code 6 km
- 1902 – First well-documented trans-atlantic communication.

ON THE ELECTRODYNAMICS OF MOVING BODIES
By A. Einstein June 30, 1905

- It is known that Maxwell's electrodynamics—as usually understood at the present time—when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena. Take, for example, the reciprocal electrodynamic action of a magnet and a conductor. The observable phenomenon here depends only on the relative motion of the conductor and the magnet, whereas the customary view draws a sharp distinction between the two cases in which either the one or the other of these bodies is in motion.

Our Story Never Ends