The Information Explosion

The Early Years
The 1800’s

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Chapter 1

The Early Players

The Early Players

-In the early 1800’s we had Newton’s
  - Three laws of physics (F=mA) and
  - Calculus.

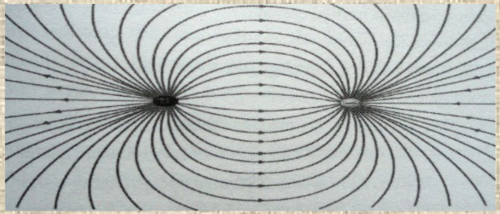
-Don’t have
  -3D partial differential equations.
  -vector calculus.

-Schools didn’t teach electrical engineering.
  -There wasn’t any to be taught.

-Technically educated people became professors
  -Not practitioners.
  -Incentive for business didn’t exist.

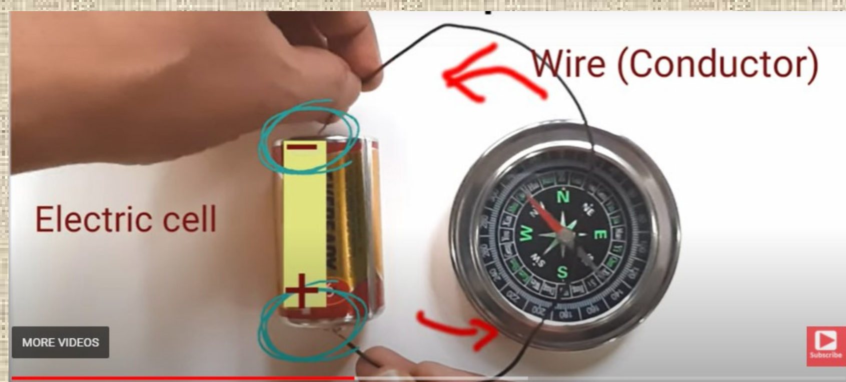
-But we did have batteries and Leyden jars.

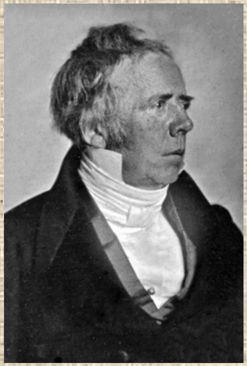
-All have names we now commonly spell with small letters.

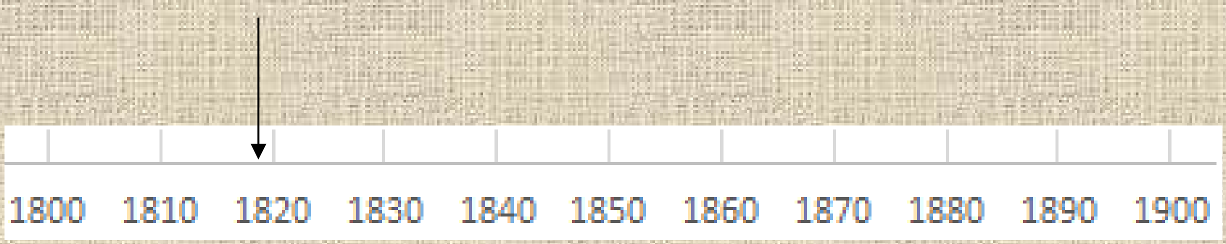


The Early Players
H.C. Oersted (1777-1851)

-1819. Discovers that electric currents create magnetic fields.
-The *first connection* between electricity and magnetism.
-Galvanometer developed as a result.







The Early Players
Andre Ampere (1775-1836)

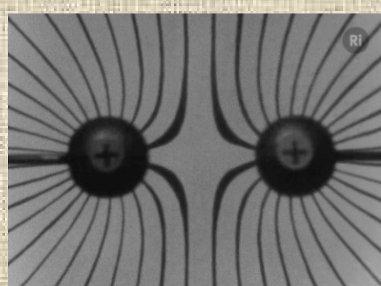
-1820. Hears of Oersted's work. Begins working on developing the relationship.

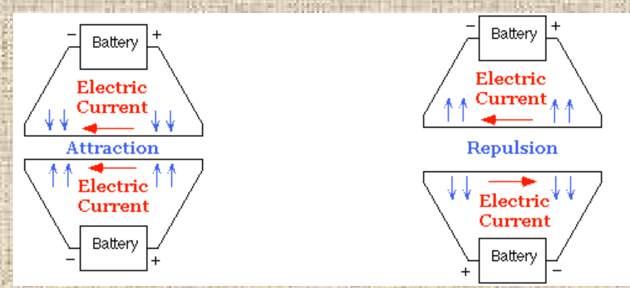
-Physics professor. Advocate of "Action at a distance."

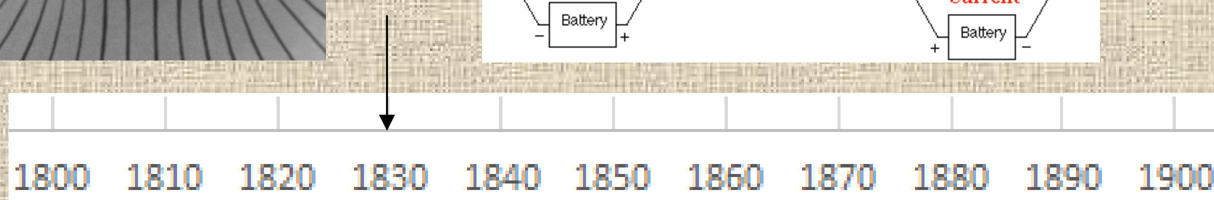
- -Did not believe in existence of fields as a force.
- -Did not develop the mathematical relationship.

-Finds that a wire carrying electric current can repel or attract an adjacent wire also carrying a current (a magnetic field), but with no magnet involved.

- Constant current relationship but Ampere's Law involves a changing current.



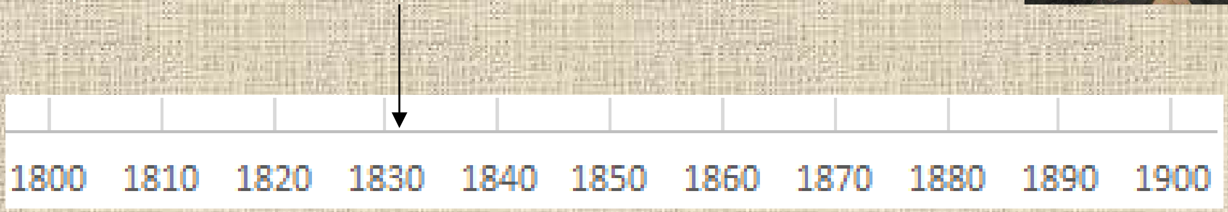




The Early Players
Carl Gauss (1777-1855)

-German mathematician who developed relation between *static* fields and sources.
-Separate laws for electric and magnetic fields.
  -Like charges repel; unlike charges attract.
  -It is impossible to create an isolated magnetic pole.
-Establishes statistical distribution laws, including one for uncorrelated noise which is used all the time.
-1845 letter expresses deep trouble over "action at a distance."

What is flux? Invisible lines of force with calculable magnitude and direction.

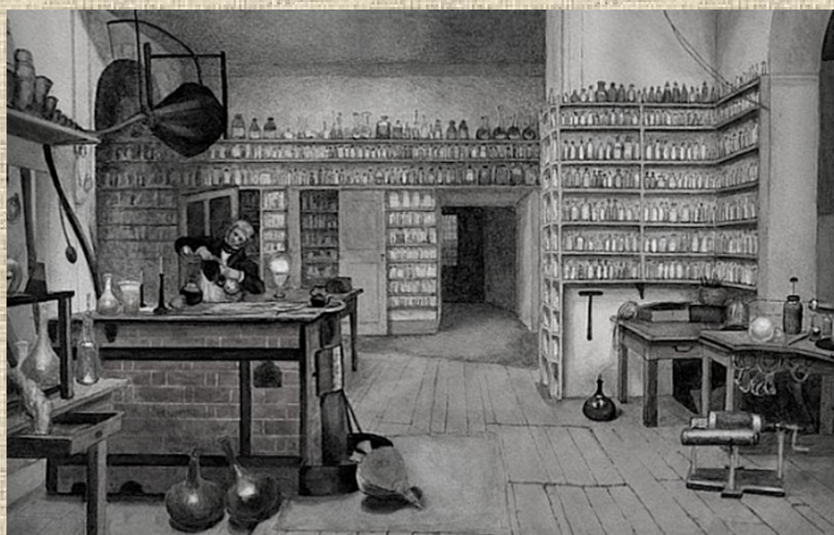


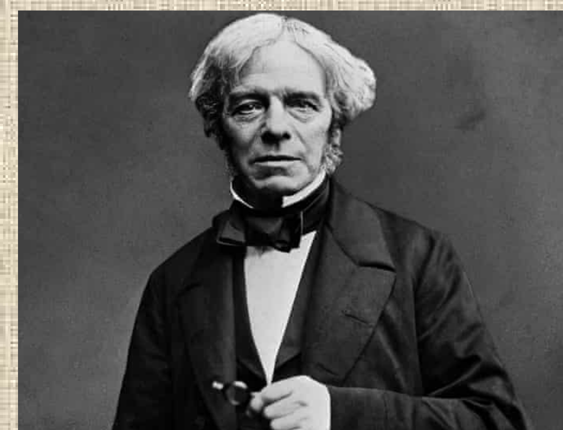
Michael Faraday (1791-1867)

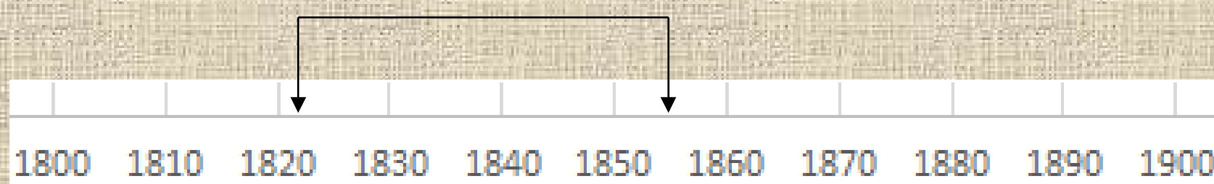
-Grammar school educated, yet one of most influential scientists in history.

- Humble person. Totally non-mathematical. Unable to express his theories mathematically.

-Logic in experiments forms basis for electromagnetic theory.

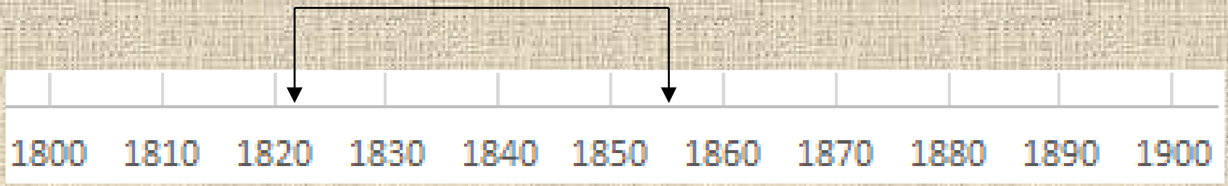






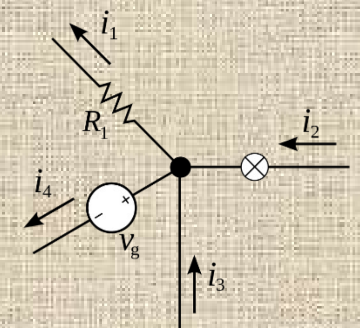
Michael Faraday (1791-1867)

- Until 1812. Apprentices as bookbinder.
- 1813-1825. Assistant to Sir Humphry Davy.
- 1821. Produces mechanical motion via permanent magnet and electric current.
- 1833. Lecturing professor at Royal Institution in London.
- Discovers transformer action, motors, and generators.
- Prime Minister once asks if his experiments have any useful purpose. Replies “At present I don’t know, but one day you will be able to tax them.”
- Views fields as lines of force => controversial at the time.
- Meets Maxwell. Has many conversations with him in London.

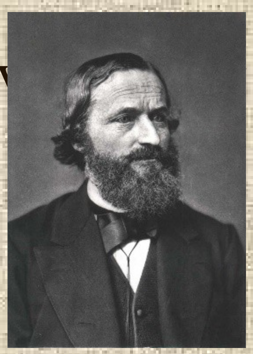


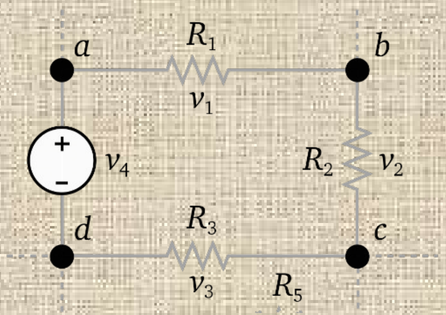
Gustav Kirchhoff (1824-1887)

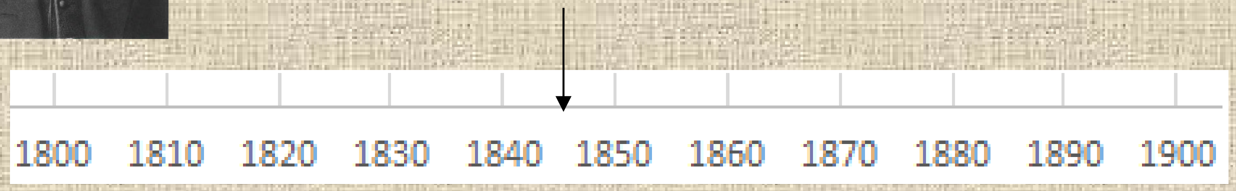
- German professor.
- Formulates his circuit laws in 1845.
    - Generalizes work of Ohm.
    - Corollaries to Maxwell's Equations.
- KCL: sum of currents into a node = 0



- KV voltages around a closed loop = 0





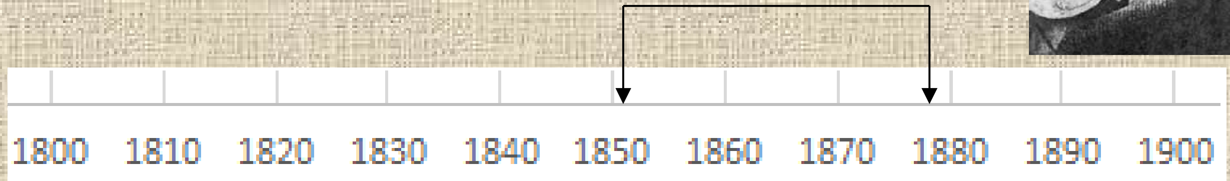


Chapter 2

The Integrator

The Integrator
James Clerk Maxwell (1831-1879)

-Scottish family Fellows of the Royal Society.
-Presents first paper at age 14. Professor at age 25.
-Dies from cancer at age 48.
-First paper after school is on Faraday's concept of lines of force.
-Initially little attention paid to him since fields were controversial.
-Describes new concepts in mathematical terms.
-Introduces vectors and partial differential equations.
-1860 -Speed of light first measured by others.
-1861 -Discovers light similar to electricity and magnetism.
    -Has velocity, frequency, and wavelength.
-Derives speed of light mathematically from Faraday's Law. Light doesn't just travel at the speed of EM waves => It is an EM wave.



The Integrator
James Clerk Maxwell (1831-1879)

-Works mostly on EM concepts from 1851 until his death in 1879. Publishes his full 20 equations in 1873.

$$p' = p + \frac{df}{dt}, \qquad P = \mu\left(\gamma\frac{dy}{dt} - \beta\frac{dz}{dt}\right) - \frac{dF}{dt} - \frac{d\Psi}{dx},$$

$$q' = q + \frac{dg}{dt}, \qquad Q = \mu\left(\alpha\frac{dz}{dt} - \gamma\frac{dx}{dt}\right) - \frac{dG}{dt} - \frac{d\Psi}{dy},$$

$$r' = r + \frac{dh}{dt}, \qquad R = \mu\left(\beta\frac{dx}{dt} - \alpha\frac{dy}{dt}\right) - \frac{dH}{dt} - \frac{d\Psi}{dz}.$$

$$P = kf, \quad Q = kg, \quad R = kh.$$

$$e + \frac{df}{dx} + \frac{dg}{dy} + \frac{dh}{dz} = 0$$

$$\frac{de}{dt} + \frac{dp}{dx} + \frac{dq}{dy} + \frac{dr}{dz} = 0.$$

$$P = -\varrho p, \quad Q = -\varrho q, \quad R = -\varrho r.$$

$$\mu\alpha = \frac{dH}{dy} - \frac{dG}{dz}, \qquad \frac{d\gamma}{dy} - \frac{d\beta}{dz} = 4\pi p'.$$

$$\mu\beta = \frac{dF}{dz} - \frac{dH}{dx}, \qquad \frac{d\alpha}{dz} - \frac{d\gamma}{dx} = 4\pi q',$$

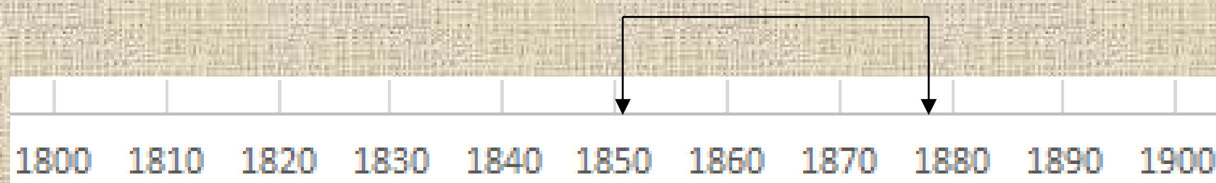
$$\mu\gamma = \frac{dG}{dx} - \frac{dF}{dy}, \qquad \frac{d\beta}{dx} - \frac{d\alpha}{dy} = 4\pi r'.$$

Builds on the work of Gauss, Ampere, and Faraday for a *unified* EM theory.

Despite the vectors and the partial differential equations, the math still not sufficiently advanced to state relationships clearly.

Not the Maxwell's Equations seen today.

Prelude to Einstein's General Relativity.



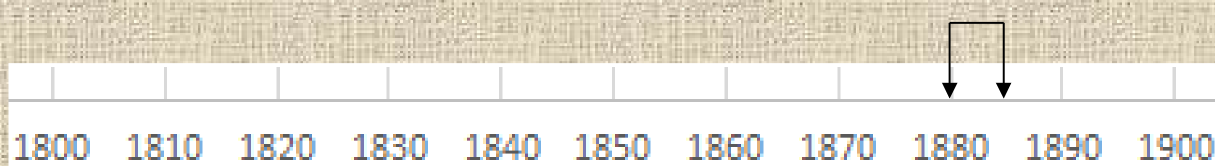
Chapter 3

Aftermath of the Publication

Aftermath of the Publication

-After Maxwell's death, his ideas lay dormant for years.
-2 reasons:
-Germany has more scientists, and the state had long supported their work. Further, the industrial revolution was in full swing and the two countries were joined on a collision course.
-Most scientists believed Newton's laws were inalienable;
-Force reactions were immediate; not delayed, -Invisible forces such as fields do not exist in nature.
-"Action at a distance" is the prevalent theory.

-But Germany does pick up the gauntlet. Heinrich Hertz challenged to prove whether Maxwell was right and Newton wrong.
-Are fields a real force of nature?



Aftermath of the Publication

-1876. Capacitors born. Leyden jars used until wax paper capacitors invented. Not useful in RF transmitters yet.

-Circuit theory starts to mature.

-Capacitors defined: $i(t) = C \cdot \frac{dv(t)}{dt}$

-Inductors defined: $v(t) = L \cdot \frac{di(t)}{dt}$

-Now we can

-Describe anything we want a circuit component to do.

-Build them to some kind of standard.

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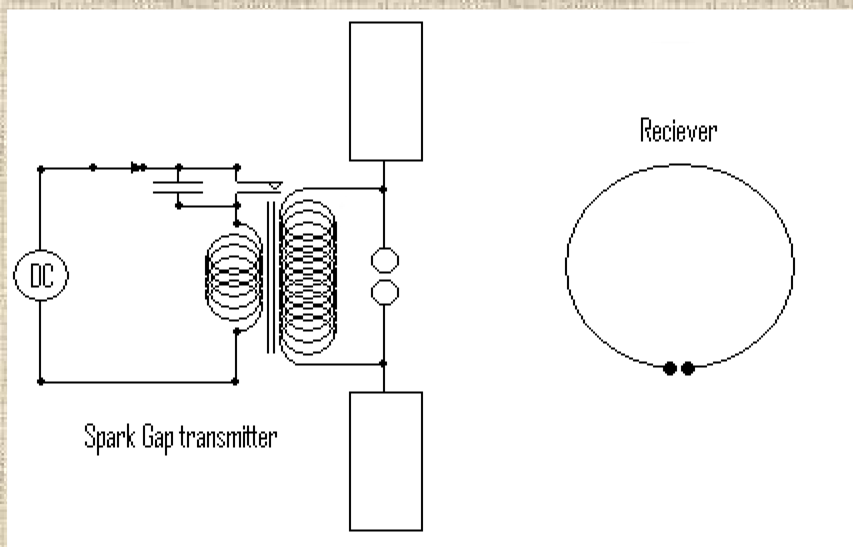
Chapter 4

Coming of Age

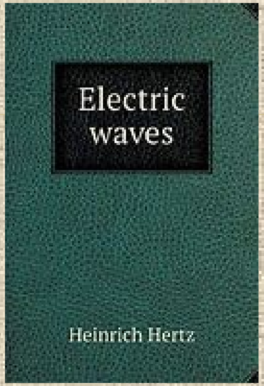
Coming of Age
Heinrich Hertz (1857-1894)

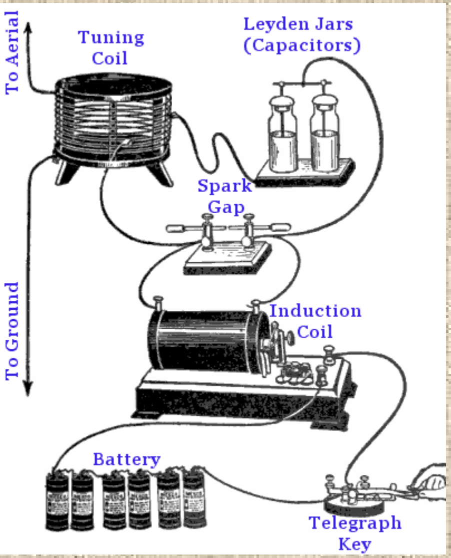
-1879. Helmholtz offers a prize to anyone who can prove Maxwell right or wrong, and offers it to Hertz, who declines. Nothing happens.
-1886. Hertz builds spark gap transmitter and simple ring receiver. Detects spark at receiver across the room. The genie escapes the bottle.

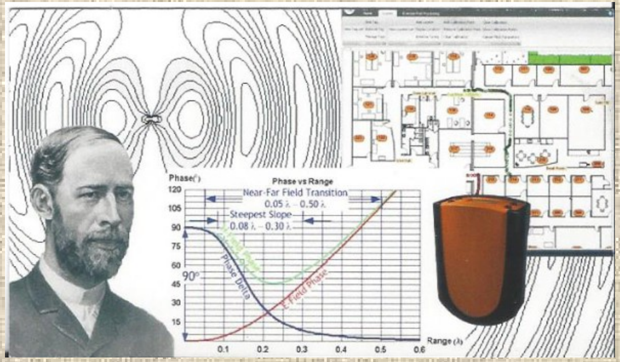


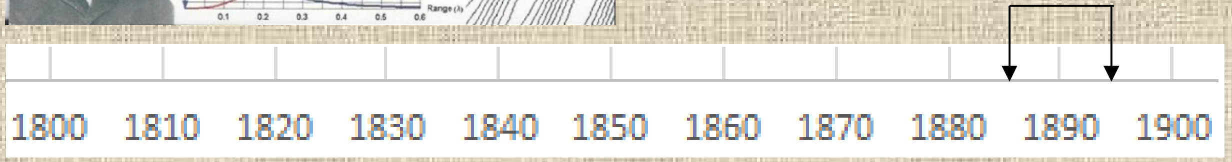
Coming of Age
Heinrich Hertz (1857-1894)

- Did Hertz know how to tune the coil with the Leyden jars?
- How did he know how long to build the antenna?
- How could he detect a VHF response?
- How could he see a spark lasting just a few nsec?
- 1886-1889. Accomplishes most of his work/experiments.
- 1892. Publishes Electric Waves.
- Book describes behavior of E and M fields in the “near field” which was used by Q-Track.
- 1894. Dies from medical complications, age 36.





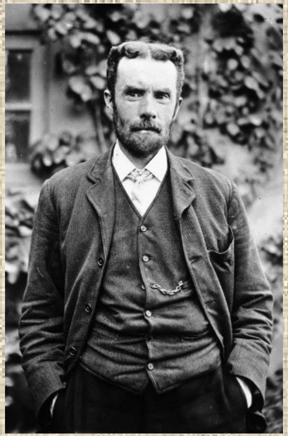


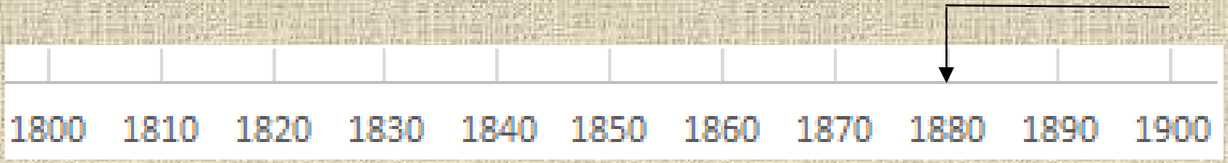


Coming of Age
Oliver Heaviside (1850-1925)

- Lives on the charity of others for his entire life (except for a few weeks). Never works a job. Minimal formal education, age 16. Solely self taught.
- At odds with the scientific establishment for most of his life (namely the British undersea cable works).
- 1873. Introduced to Maxwell’s treatise.
- 1880. Patents the coaxial cable.
- 1882. Helps develop what is now known as transmission line theory – the telegrapher’s equations.
- 1884. Recasts Maxwell’s 20 equations with new math as the 4 equations we now know.

  -Invents new techniques for solving differential equations, such as divergence and the curl.





Coming of Age
The Equations Maxwell Never Saw
The Work of the Uneducated Heaviside

1. $\nabla \cdot \mathbf{D} = \rho_V$

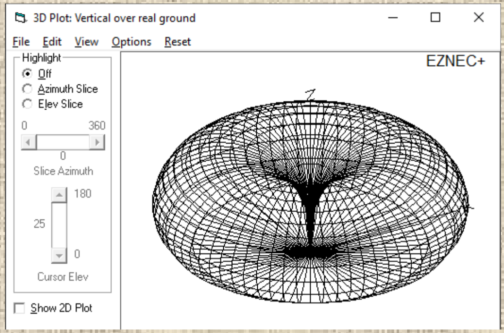
2. $\nabla \cdot \mathbf{B} = 0$

3. $\nabla \times \mathbf{E} = -\dfrac{\partial \mathbf{B}}{\partial t}$

4. $\nabla \times \mathbf{H} = \dfrac{\partial \mathbf{D}}{\partial t} + \mathbf{J}$

1. Gauss' Electric Law
Static fields; use divergence.
2. Gauss' Magnetic Law

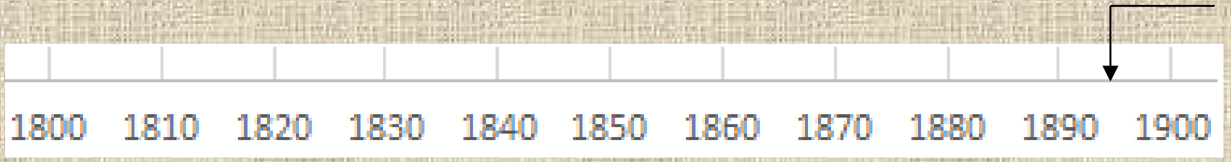
3. Faraday's Law
Changing fields; use curls.
4. Ampere's Law



D and E related by permittivity.
B and H related by permeability.

Coming of Age
Guglielmo Marconi (1874-1937)

- We call him an engineer but he was minimally educated with no scientific background.
- Takes off on his pursuit of a wireless business upon hearing of the death of Hertz in 1894.
- Pursues business opportunities rather than merely the science.
- Turns a lab experiment into a useful communication system not long after age 20.
- Invents many useful components himself.
- Achieves greater distances via concepts he reads about but doesn't understand.
- Applies for many patents early on.



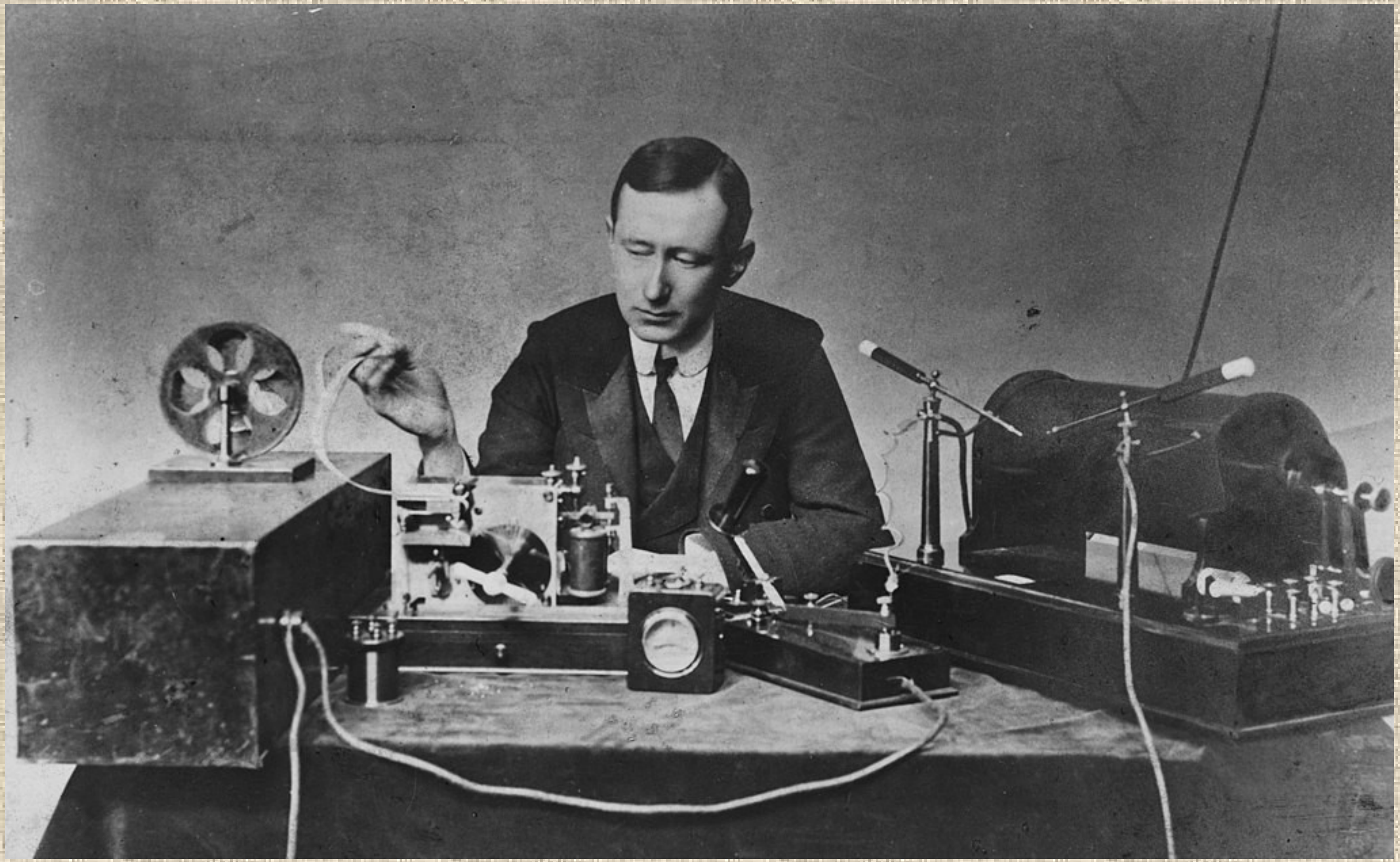
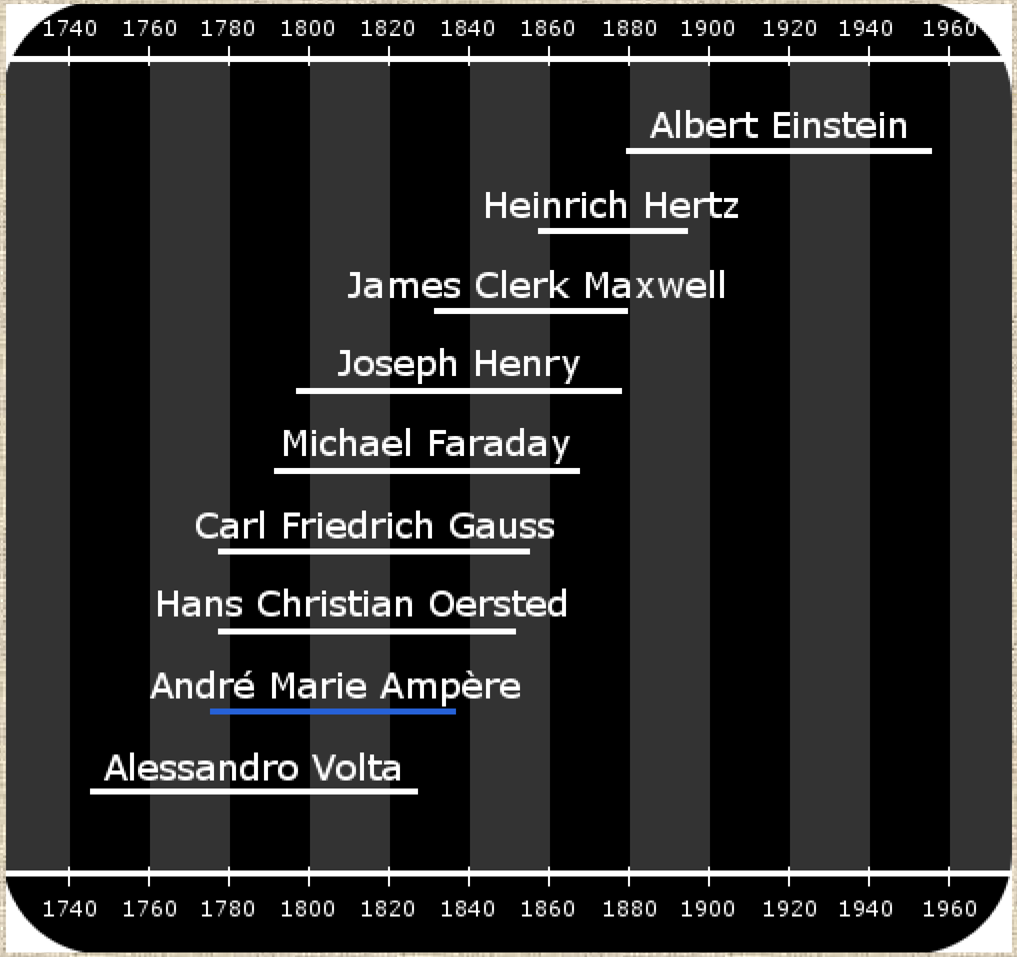


Photo taken in 1890’s


1740 1760 1780 1800 1820 1840 1860 1880 1900 1920 1940 1960
Albert Einstein
Heinrich Hertz
James Clerk Maxwell
Joseph Henry
Michael Faraday
Carl Friedrich Gauss
Hans Christian Oersted
André Marie Ampère
Alessandro Volta
1740 1760 1780 1800 1820 1840 1860 1880 1900 1920 1940 1960

Maxwell's Equations

1. Gauss' Law for Electric: $\oint \vec{E} \cdot \overrightarrow{dA} = \frac{Q}{\varepsilon_0}$

   The integral of the outgoing electric field over an enclosing volume equals the total charge inside.

2. Gauss' Law for Magnetism: $\oint \vec{B} \cdot \overrightarrow{dA} = 0$

   A magnetic field does not diverge since there are no magnetic monopoles.

3. Faraday's Law: $\oint \vec{E} \cdot \overrightarrow{dl} = \frac{d\Phi_B}{dt}$

   The closed path integral around a wire gives the total voltage around the circuit, which is generated by a varying magnetic field through the circuit.

4. Ampere's Law: $\oint \vec{B} \cdot \overrightarrow{dl} = \mu_0 \left(I + \frac{d}{dt} \left(\varepsilon_0 \cdot \int \vec{E} \cdot \overrightarrow{dA} \right) \right)$

   The closed path integral around a wire gives the total magnetic force around the circuit in terms of the current through the circuit plus any varying electric field through the circuit.

The History Of Maxwell's Equations (sacredheart.edu)

$$v = \sqrt{\frac{1}{\mu_0 \varepsilon_0}} = 3E8\ m/sec$$