Microwaves to Mobiles

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Where does the story begin?

- The mobile phone seems like a recent phenomenon
- How far back do we go to trace its origin?
  20 years ? . . . 50 years ? . . . 100 years ?

A quick recollection

???

Surely the mobile phone has no link to a comb attracting paper or a magnet attracting nails?

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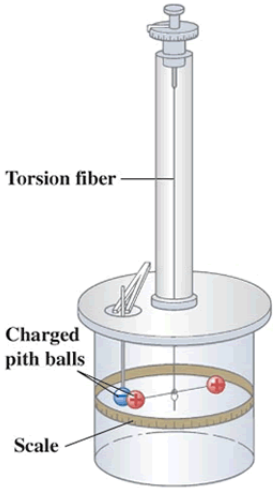
Electric Forces (Electrostatics)

- 1784: Charles Augustin de Coulomb and his predecessors carried out experiments which established the existence of two kinds of charges in matter
- Like charges attract, unlike charges repel
- The mutual force falls off rapidly as the charges are separated

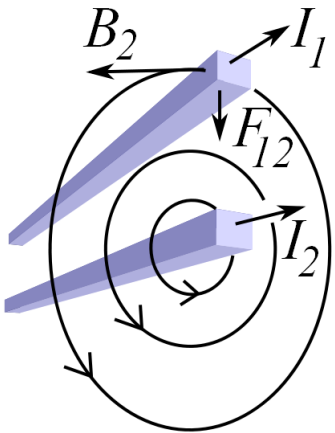


Magnetic Forces (Magnetostatics)

- 1820: Hans Christian Oersted and colleagues showed that wires carrying an electric current affected a magnetic needle
- This force was akin to bar magnets affecting each other
- And this too falls off with increasing separation

Magnetic Forces (Magnetostatics)

- 1849: Andre Marie Ampère established a law describing the magnetic force between two electrical currents
- Currents in the same direction attract, in the opposite direction, repel
- Again, the mutual force falls off with increasing separation



Puzzling observation

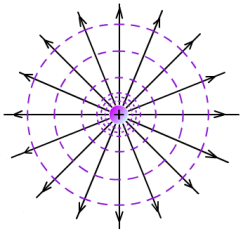
Very Spooky...

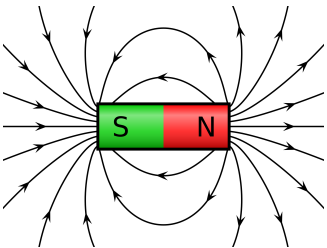
- Action at a distance!
- Reconciliation to non-contact forces

Puzzling observation. . . and its bizarre resolution

Lines of force

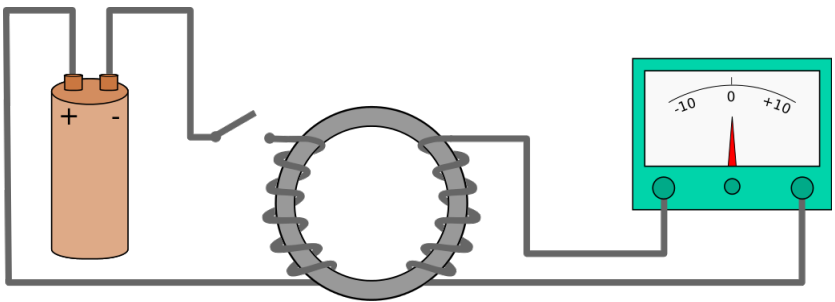
- Visualise imaginary lines in space suggest the forces
- The concept of a field is a leap of imagination that proves to be enormously powerful





Electromagnetic Induction

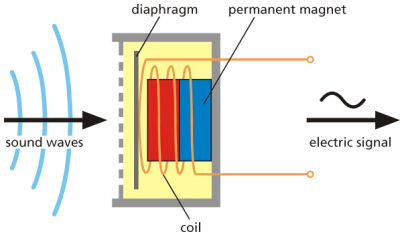
- 1831–32: Faraday and Henry discovered electromagnetic induction

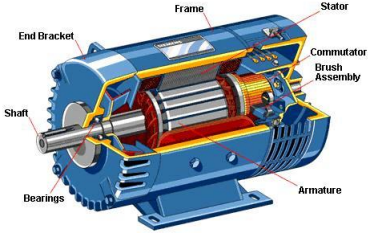


- A magnetic field that changes with time generates a voltage

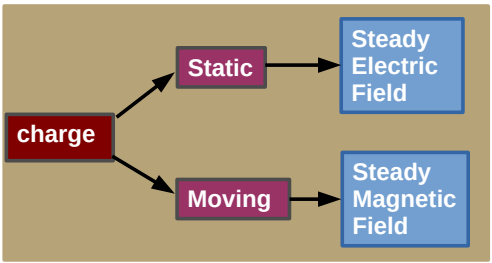
Motive Effects of Electricity and Magnetism

Forms the basis for all electrical generators, motors, electric trains, air-conditioner and refrigerator compressors, speakers, microphones, bells, fans, mixers, cd-drives, hard-disks. . . just about anything that involves motion by using electricity

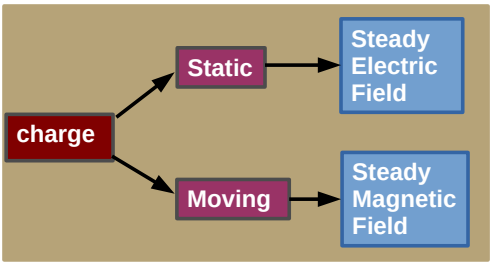


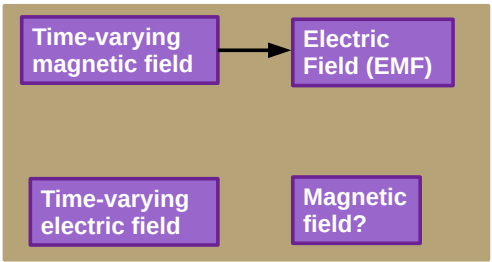


Summary of Developments till 1865 : Stage I

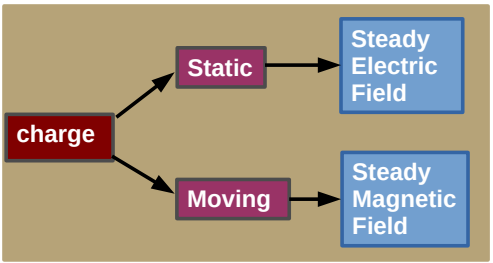


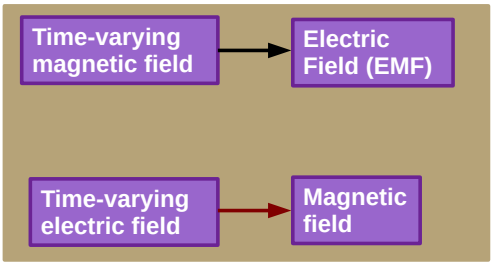
Summary of Developments till 1865 : Stage II





1865 : A memorable year





Maxwell's Critical Insight

- This is how it stood, based on observations...

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} \qquad \text{(Ampère's Law)}$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \qquad \text{(Faraday's Law)}$$

- ...and this is what Maxwell claimed it should be

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...how could this claim be tested?

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Maxwell's Predictions

- A claim can be tested on the basis of the predictions resulting from that claim
- Prediction–1: Disturbance in one field leads to a disturbance in the other field, and vice-versa – *the disturbance is a wave*
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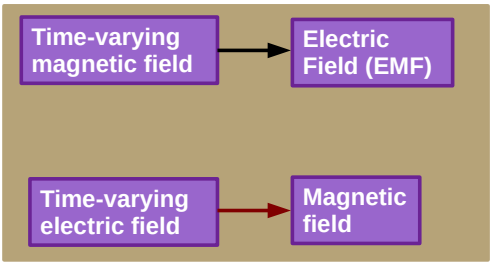

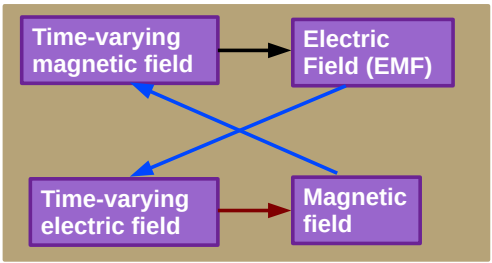

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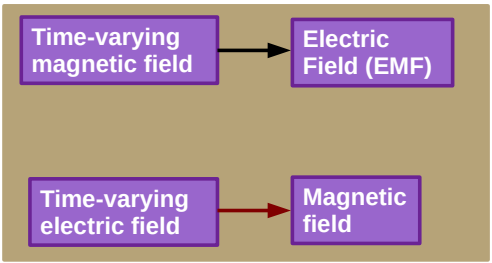

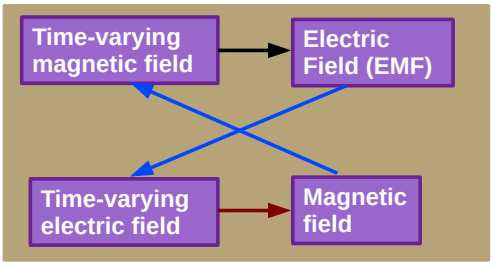

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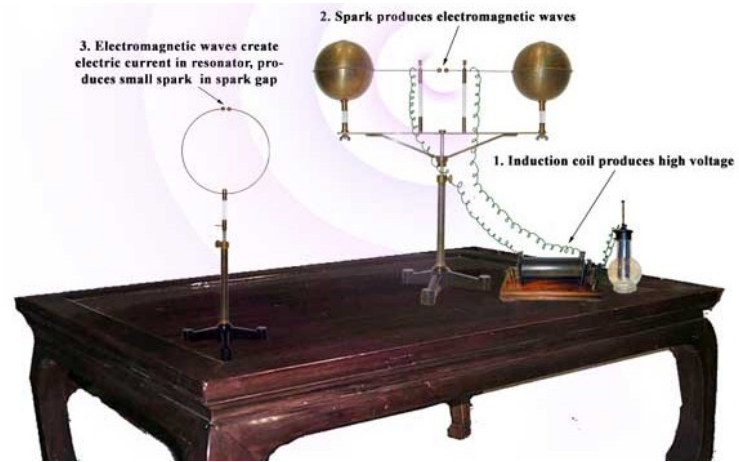
Hertz's Demonstration, 1887



- The big circuit generates a spark in the gap between the spheres
- This causes a spark in the gap of the small circuit even though the two are not in contact!

Electromagnetic Radiation

- Hertz verified Prediction–1
- Hertz sees no 'use' for this work:

  "It's of no use whatsoever . . . this is just an experiment that proves Maestro Maxwell was right – we just have these mysterious electromagnetic waves that we cannot see with the naked eye. But they are there. Ramifications? . . . None, I guess."

- Prediction–2 was verified in due course (*Michelson–Morley Experiment, Special Relativity. . .*)
- A wide variety of electromagnetic radiation was eventually discovered – *radiowaves, microwaves, infrared, visible, ultraviolet, x-rays, γ-rays*

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At the turn of the 19th century

Working through the 18th and 19th centuries we had a complete mathematical theory of electromagnetism.

Maxwell's equations predicted the existence of electromagnetic waves, and their existence was eventually verified.

Microwaves, yes . . . Mobiles, not yet!

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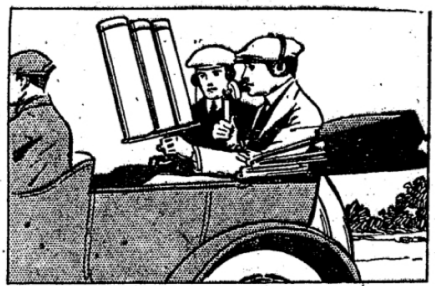
Devices that could transmit and receive electromagnetic signals were being developed



Transmitting and Receiving a Telephone Message in a Moving Motor Car.

- 1920s: Wireless telephone from a moving car to the garage half a kilometer away
- 1940s: Communication using electromagnetic waves progressed rapidly; widely deployed during WW-II
- Also police wireless, navigation, radio and TV broadcasts etc.

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Hertz's Apparatus

- Size: about 1 m
- Range of signal: about 10 m

Current mobile transmitter/receiver

- Size: about 1 cm
- Range of signal: about 1 km

One-hundredth in size
Yet hundred times powerful
What made this possible?

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The next BIG thing

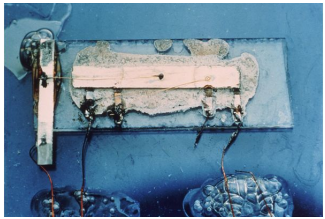
1900–30s:

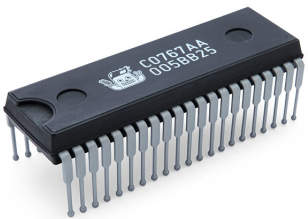
Something dramatic was happening in our understanding of the microscopic world – a theory that could explain the structure and stability of atoms and matter – Quantum Mechanics

This theory explained many things,
. . . but it could not predict how novel materials would change our world

The Semiconductor Revolution

- The key: Controlling the electrical properties of semiconductors by adding miniscule amounts of impurities, or dopants
- 1947: Invention of the transistor by Bardeen, Shockley, Brattain
- 1958: Integrated circuit – building many components on a single chip of germanium (earlier attempts 1949–1952)
- 1980s: VLSI circuits, transistor based memory, electronic data processing
- Micron-sized circuits transformed the world

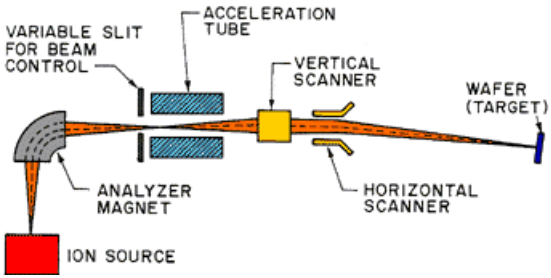




Another Development

How did manipulation of material properties on a tiny scale become possible?

- Ions can be manipulated by EM fields
- We can ‘shoot’ them at desired targets nearly one at a time
- Suitable ions are implanted into silicon – a few thousand ions in a micron sized area
- Millions of diodes and transistors on a finger-nail sized chip



Summary

A smart phone seems like a recent phenomenon, but we can recognise stages of fundamental research which feed into it

- Development of the theory of electromagnetism
  - Maxwell's prediction of electromagnetic radiation
  - Hertz's demonstration of electromagnetic radiation
- Development of Quantum Mechanics
  - Explanation of many puzzling observations
  - But a failure to predict how it would influence the development of novel materials
- The semiconductor revolution
  - Greatly assisted by ion accelerator physics techniques

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Summary

- Electromagnetism and Quantum Mechanics are pillars of Physics
- Both are success stories of pursuit of knowledge, driven by curiosity
- None of the heroes of these stories had societal ‘uses’ in mind
- Yet we revel in the beneficial fallouts of their work
- Can we then afford to ignore fundamental research?