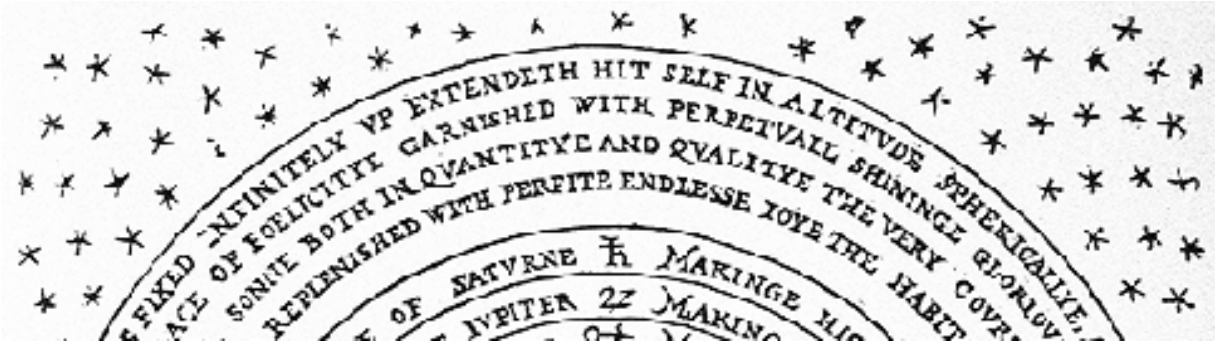


PHY1033C/HIS3931/IDH 3931 : Discovering Physics:

The Universe and Humanity's Place in It

Fall 2016

Announcements

- HW8 posted, due Nov. 10

- Lab 9 due today

- Reading: Chapter 16, pp. 331-39; Chapter 20, pp. 411-18, 425-29, 431-33
Ronalds: Francis Ronald's Electric Telegraph (coursepack)

- Thurs., Nov. 10 4pm after class, NPB 2205:
  Optional film: Relativity pizza party!

Last time

- Coulomb's law of electrostatics: $F = k\, q_1\, q_2 / r^2$

  (another inverse square law, but q = charge can be either + or - $\Rightarrow$ neutral atoms form, prevent most obvious manifestations of electrostatic forces
- History of magnetism: ancient, medieval ideas

  de Magnete, W. Gilbert 1600
- 1600s, 1700s: suspicion that electricity and magnetism were related (lightning reversed ship's compass), but unable to prove in laboratory
- 1820: H.C. Oersted shows that current in wire deflects compass needle ("circular force")

  [Oersted expt with iron filings]

Last time

- André-Marie Ampère:

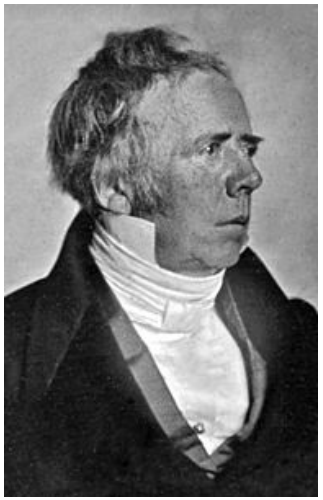
  - there's a force between two parallel current-carrying wires [Ampère expt with 2 wires]

  - a current can magnetize an iron bar

  - permanent magnets must be made of molecules with tiny circulating currents that line up.

- Earth is a permanent magnet due to circulating charged currents in its core

Clicker question



In 1820 Hans Christian Oersted discovered that

A) A current carrying wire orients compass needles along its length

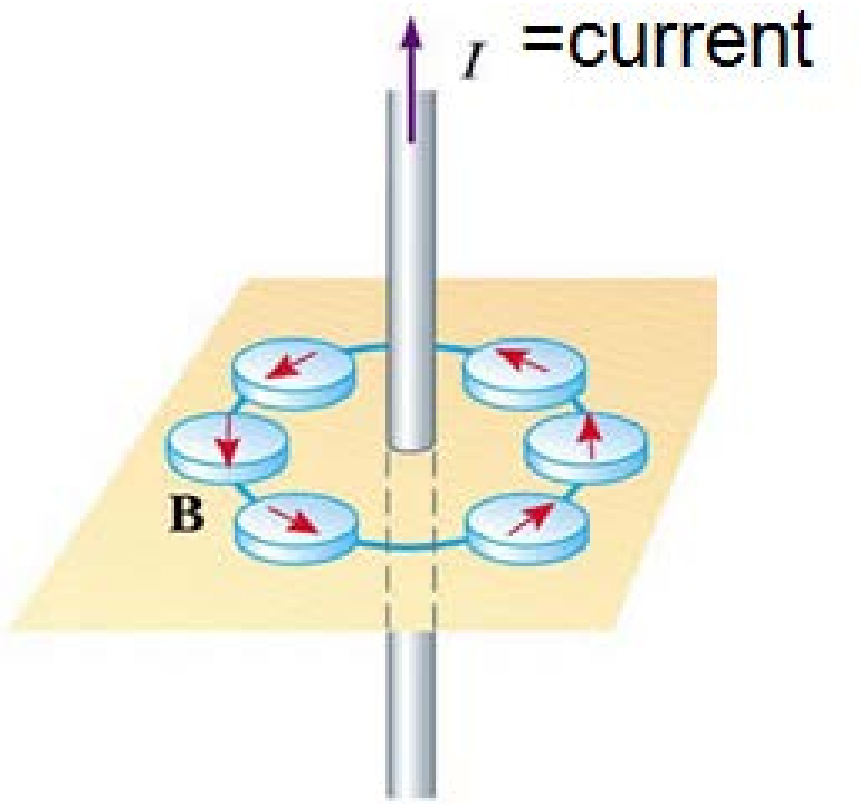
B) A loop of current-carrying wire acts as a compass

C) Electricity and magnetism come from gravity

D) The force on a compass needle acts in circles around a current-carrying wire

E) Electricity can be used to make a motor

Reminder: Oersted expt.



Magnetic effect goes in circles around wire!

Magnetism

Just as we have gravitational forces between two masses and electric forces between two electrically charged objects, there are magnetic forces between two magnetized objects

The "charges" in magnetization are called poles

Magnetized objects have a north pole and a south pole

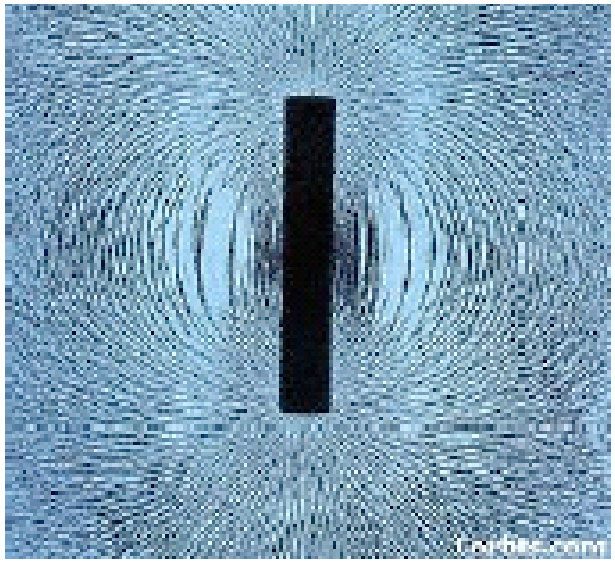
Just like the electric force, the magnetic force can be either attractive or repulsive

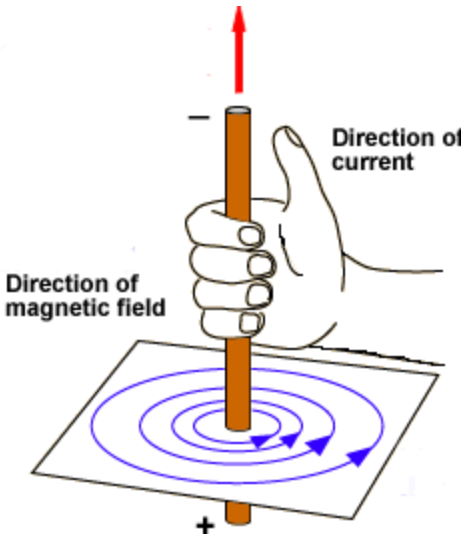
- Poles with the same magnetization repel
- Poles with the opposite magnetization attract

Unlike electric charges, magnetic poles cannot be separated!

Magnetic fields

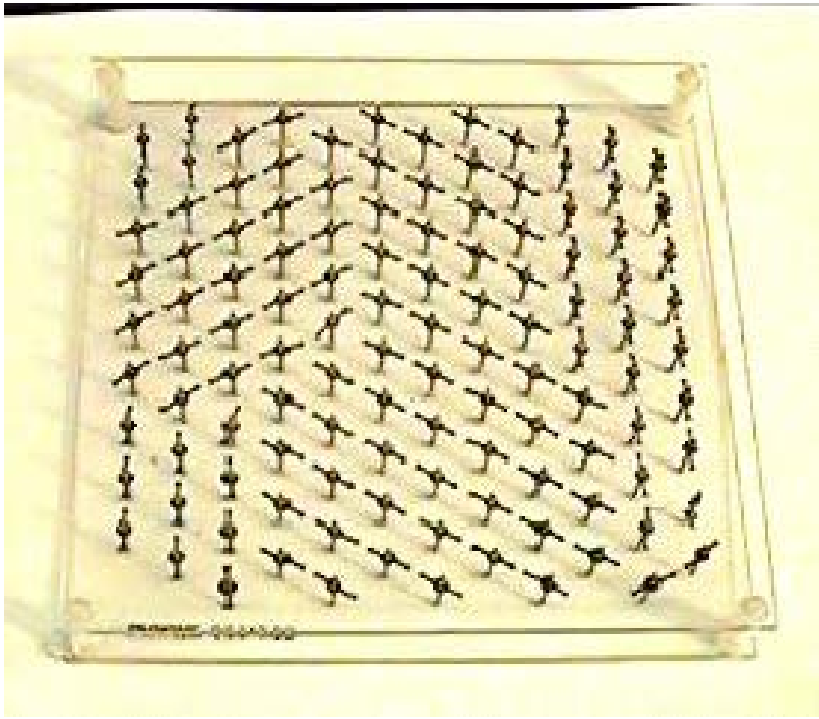
Michael Faraday (1781-1867) imagined lines of a “force field” that extended into space around a magnet.
The “magnetic field” at a point in space provides a force if a magnet or current is placed there





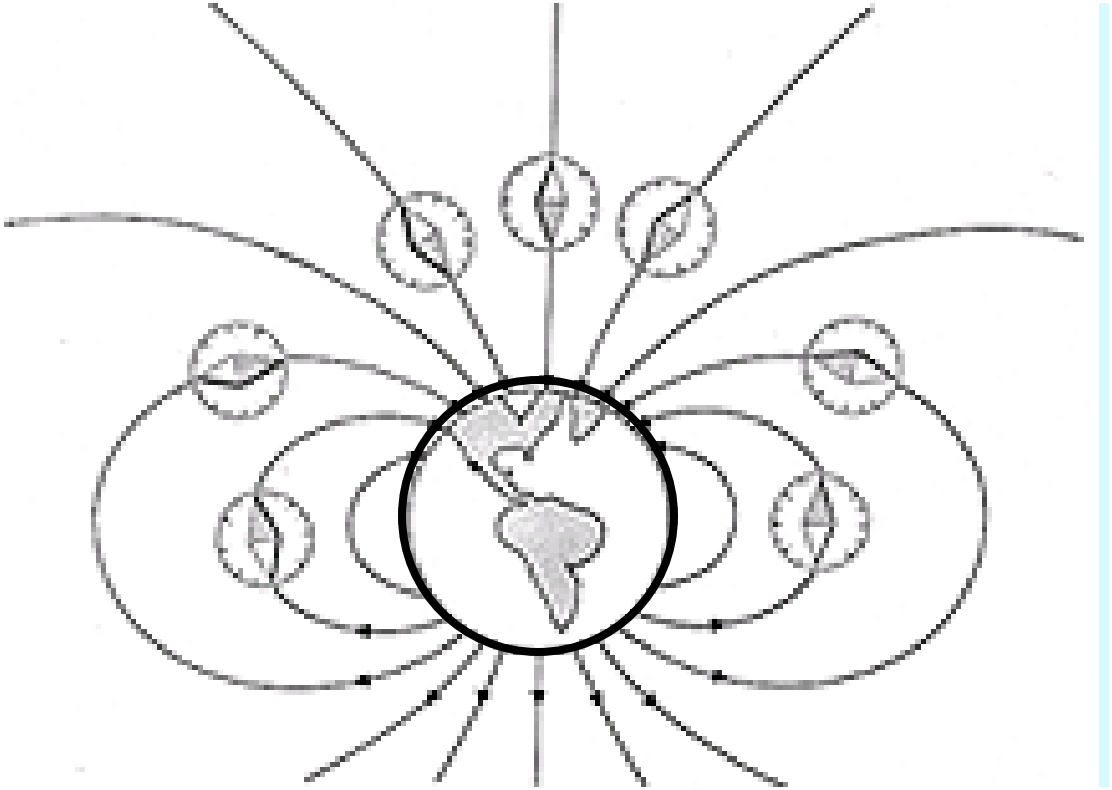
Permanent magnets (e.g. iron)

In some materials each atom has a tiny *magnetic moment* which acts like a tiny bar magnet. These *moments* like to line up with each other, like bar magnets, but sometimes disorder in the material prevents this, and they only line up in a small portion of the sample, called a *magnetic domain.* You can't tell that the material is magnetic inside until you apply a large external field to it, *aligning the domains.* Then you have a good permanent magnet.



The earth is a permanent magnet

Circulating electric currents in central core cause:



…which is why compasses work

Magnetic fields

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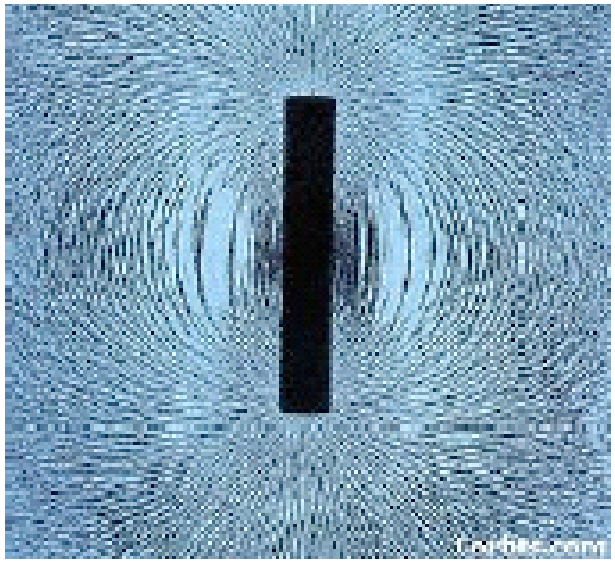
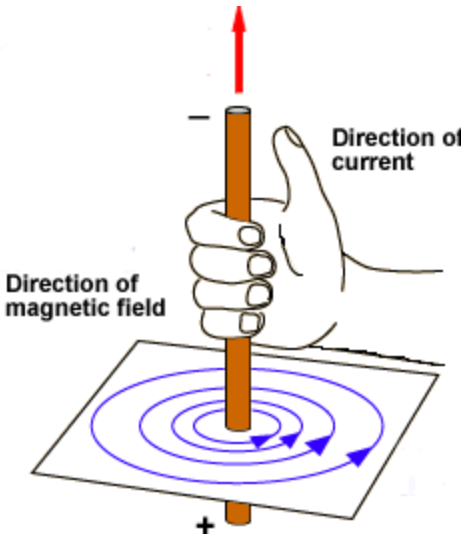
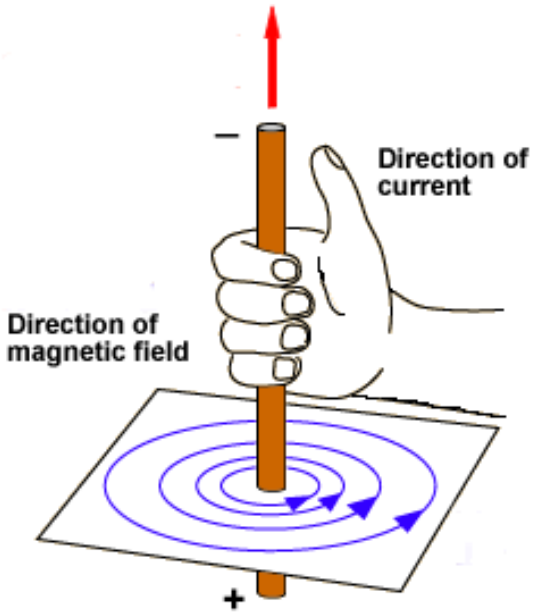
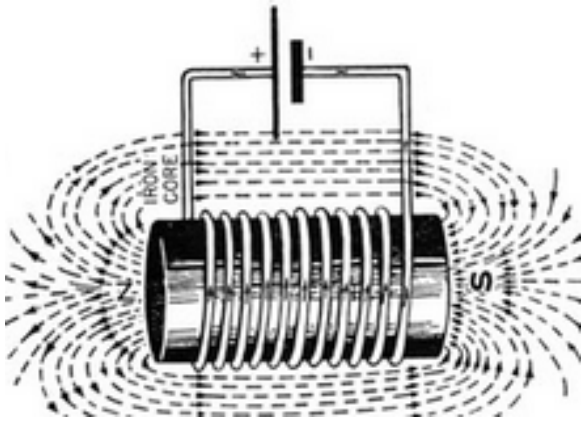




Using electricity to produce magnetism



Oersted



Ampere

Michael Faraday

Faraday asked:

Can we use magnetism to produce electricity?

Before we get to that

Let’s look at some of his other experiments

Faraday's unusual background made it highly unlikely that he would ever learn science

Poor – apprenticed in the bookbinding trade

Sandemanian

Very little education – no mathematics

A couple factors came together to make the unlikely happen

Very intelligent mind

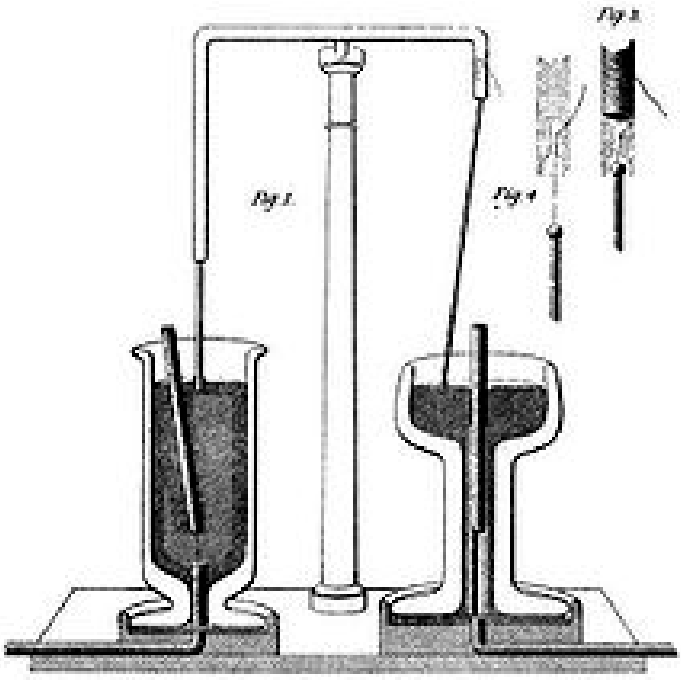
Very industrious

Lucky break

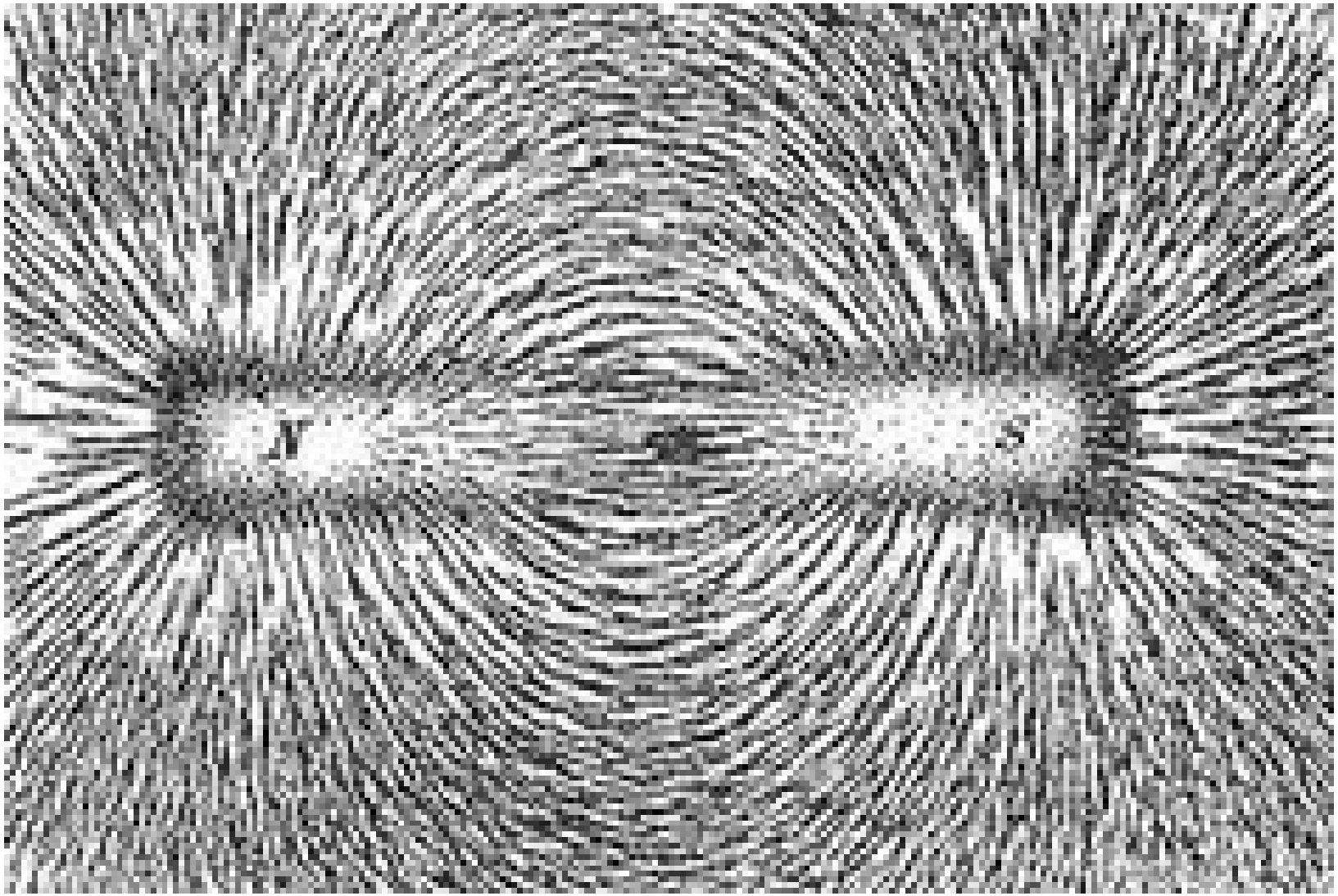
Very soon after he learned about Oersted's experiment he did one of his own

He showed how to use electromagnetism to produce mechanical force

He invented the electric motor



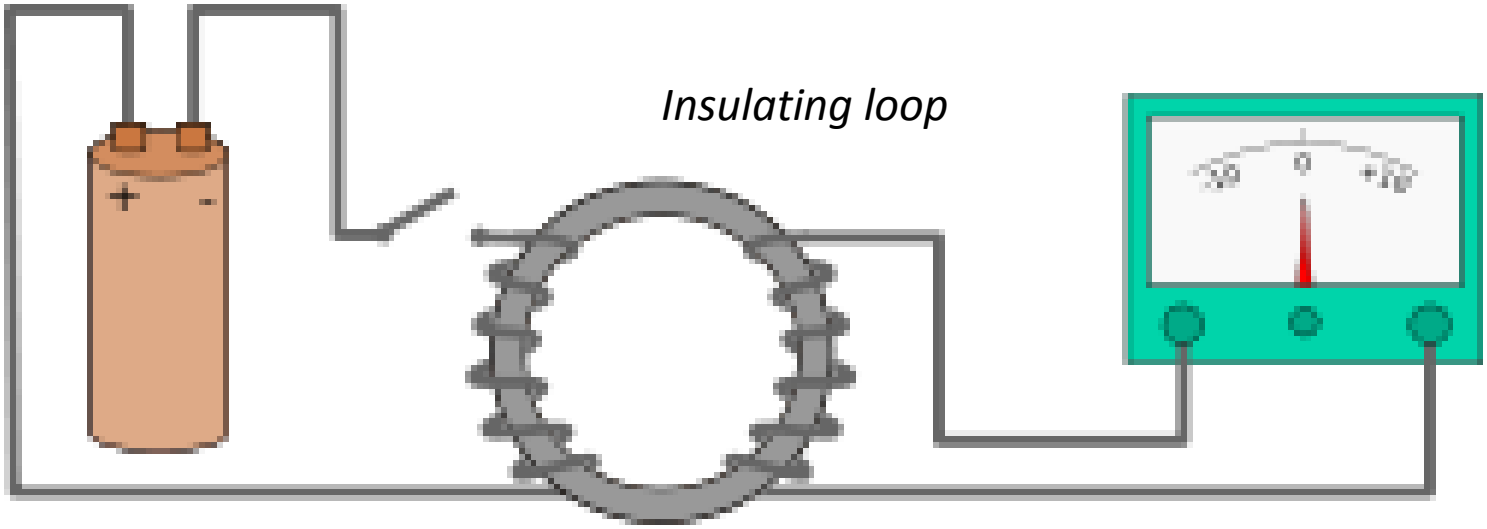
Video: Faraday motor



Faraday’s lines of force

Ten years later he succeeded in his pursuit

Could a magnetic field induce a current in a second wire?

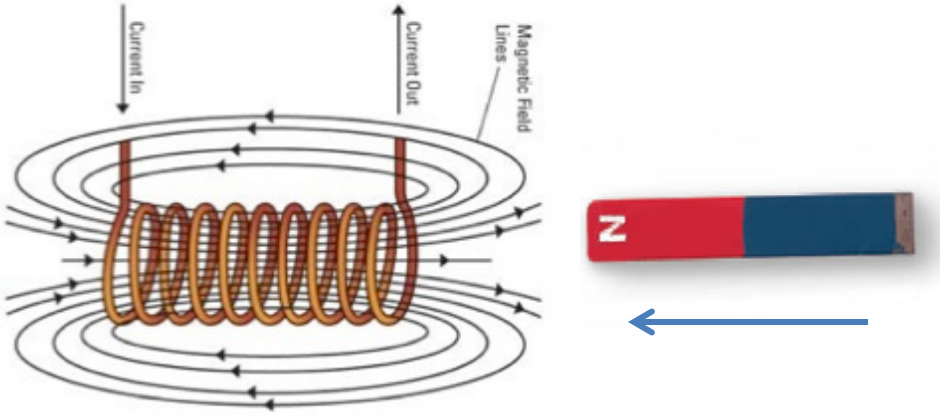


1831

Answer? Yes and no

Faraday realized that magnetism generates electricity whenever the magnetic field changes

Another way to interrupt a magnetic field would be to insert a magnet into a coil



We can show it here

Faraday realized that *cutting the lines of a field* with a magnet generates electricity

Faraday confused many natural philosophers because his non-mathematical way of envisioning things was not what they were used to

Were there really lines of force out there in nature?

How seriously should we take the models we come up with?

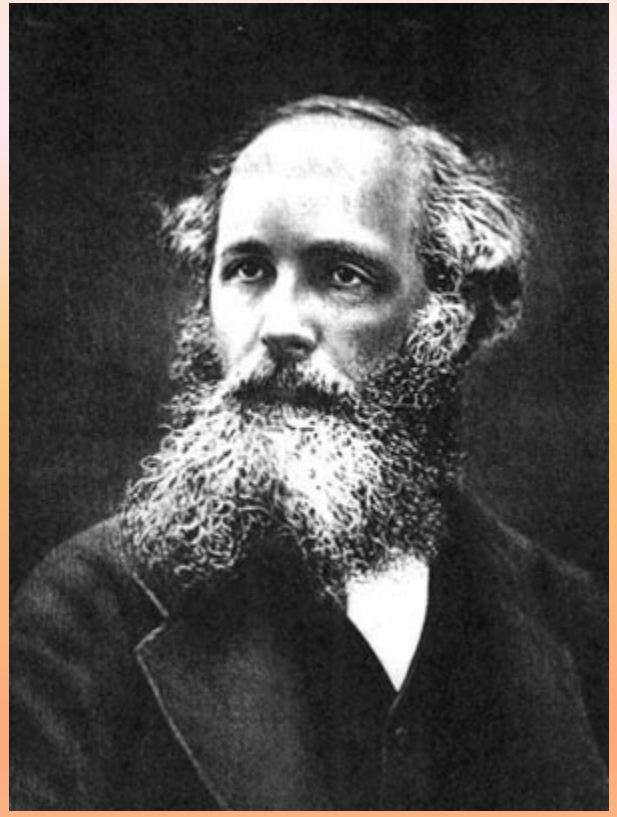
Couldn't deny Faraday's successful discoveries

The question about the status of models soon came up again

How are we to understand the close link between electricity and magnetism?

Faraday had assumed that induced current was transmitted as a wave

But a wave of what? What was it that was waving?

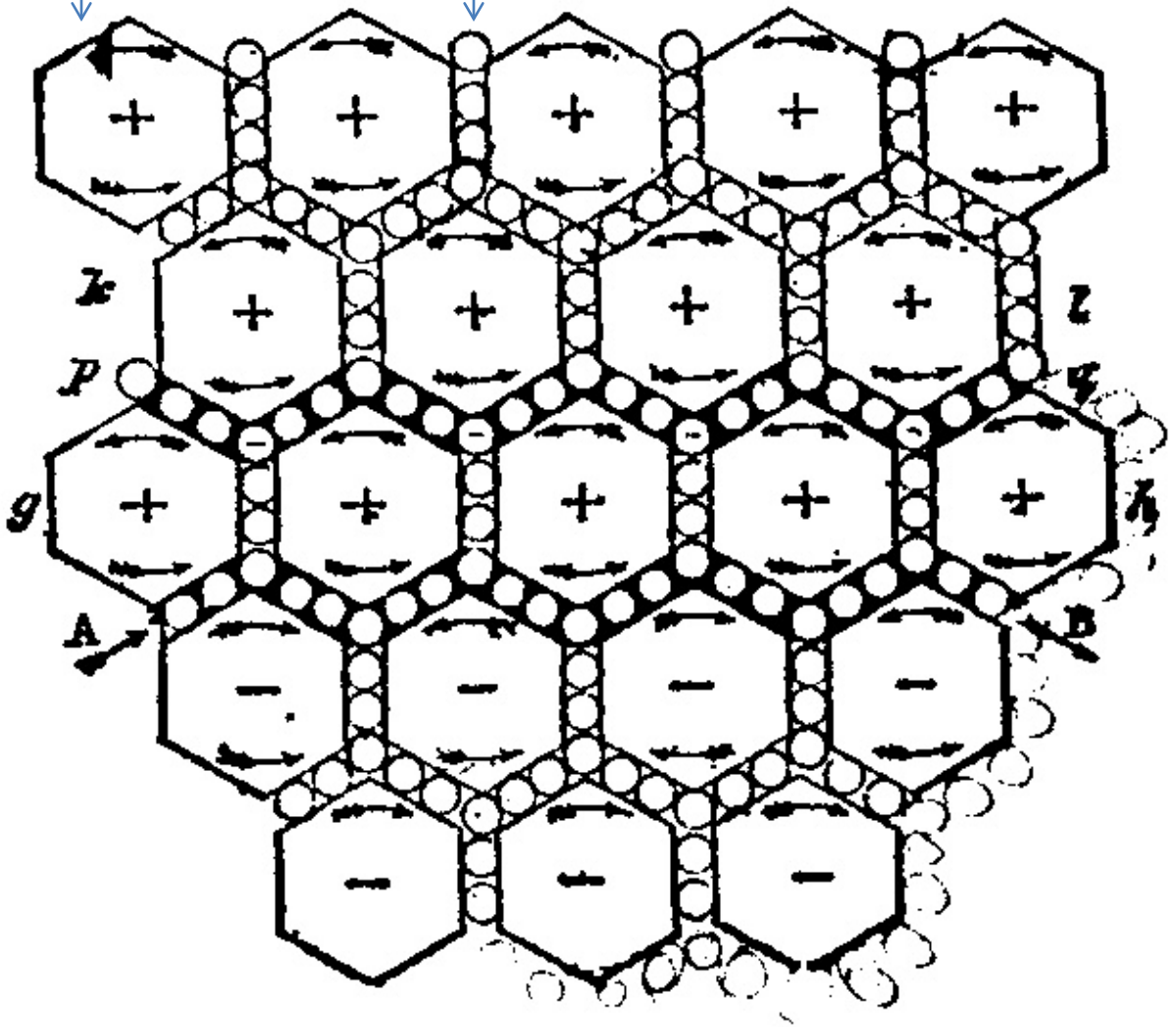


James Maxwell in Scotland in 1865 assumed the answer was: the ether, which was

Everywhere

Magnetic effects

Electric effects



The model shows why changing electricity produces magnetism and vice versa

Maxwell's Equations

$$\nabla \cdot D = \rho$$
$$\nabla \cdot B = 0$$
$$\nabla \times E = -\frac{\partial B}{\partial t}$$
$$\nabla \times H = i + \frac{\partial D}{\partial t}$$

These equations are wave equations:

Electromagnetism is transmitted as waves in the ether in a wire

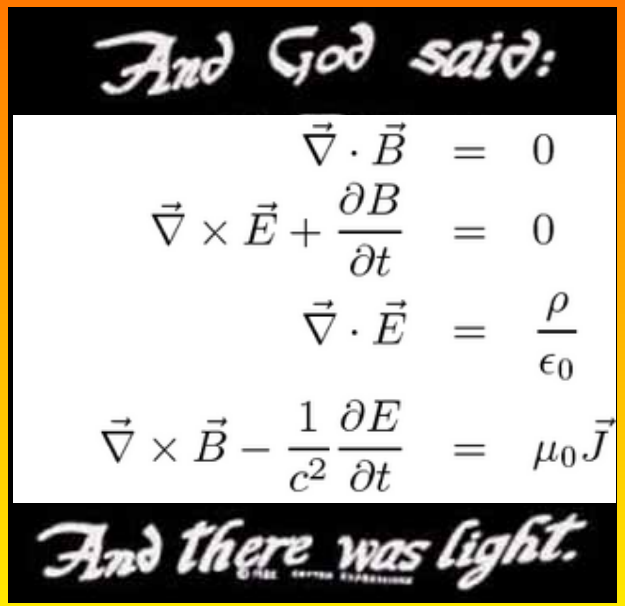
And they reveal an incredible new discovery

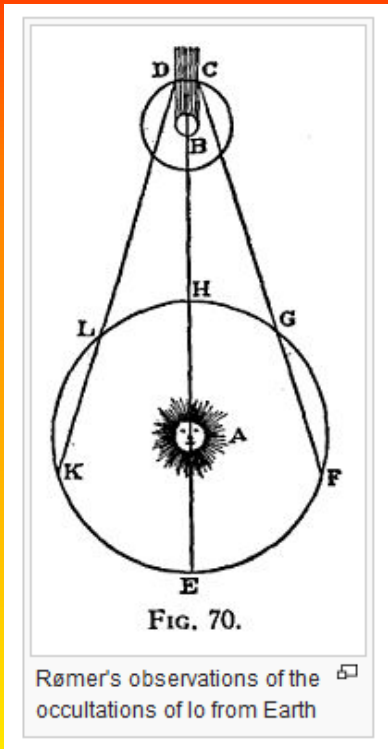
From quantities present in his equations Maxwell was able to calculate the speed with which electromagnetism moves

Turned out to be c, the speed of light (measured by Ole Roemer, 1676!

Light was known to be a wave (Young experiment 1801)

"We can scarcely avoid the inference that light consists of the transverse undulations of the same medium which is the cause of magnetic and electric phenomena" -- Maxwell

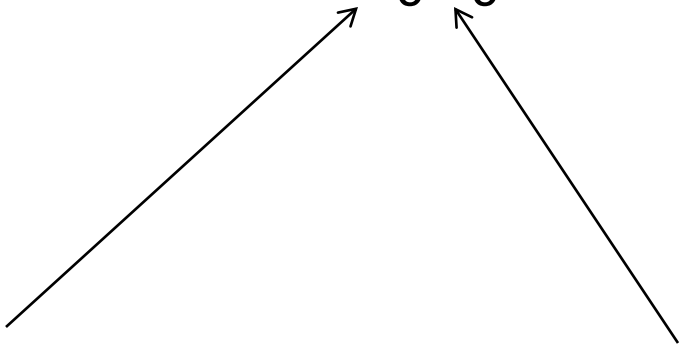




Rømer's observations of the occultations of Io from Earth

What goes into Maxwell's speed of light calculation

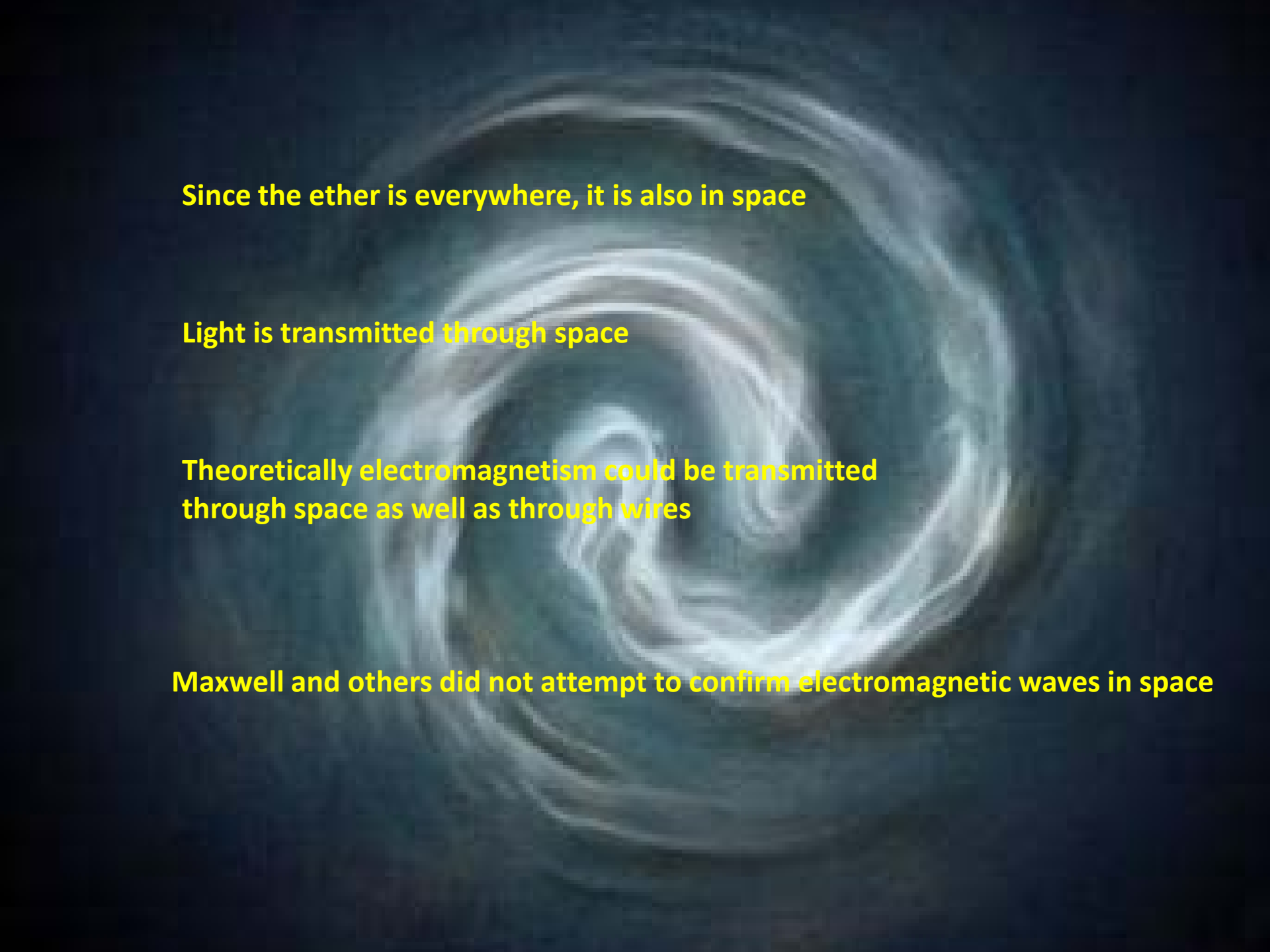
$$c = 1/\sqrt{\varepsilon_0 \mu_0}$$



"dielectric constant of free space"
Related to Coulomb's constant *k*
-- measurable in laboratory

"permeability of free space"
Related to magnetic fields produced by electrical currents
-- measurable in the laboratory

Maxwell substituted these known values and came up with $c=3 \times 10^8$ m/s, speed already known from Roemer measurements (1676). *Fiat lux!*



Since the ether is everywhere, it is also in space

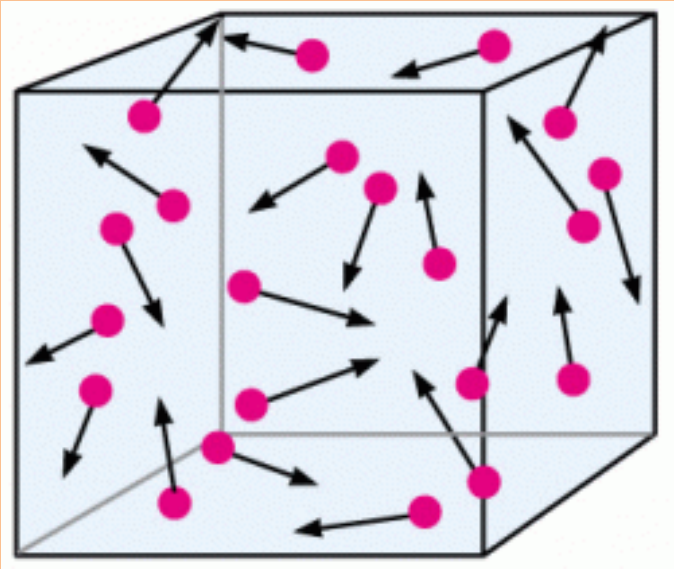
Light is transmitted through space

Theoretically electromagnetism could be transmitted through space as well as through wires

Maxwell and others did not attempt to confirm electromagnetic waves in space

Other developments in physics suggested that models were descriptions of nature “as it really is”

Kinetic theory of gases



Whole age had become confident it was nailing down the truth of nature

John Tyndall

The region of objective knowledge belonged to science alone.

We are closing in on the final truth of nature

We are describing nature “as it really is.”

Second half of the 19th century has been called the “Age of Realism”

Classical physics a good expression of the age

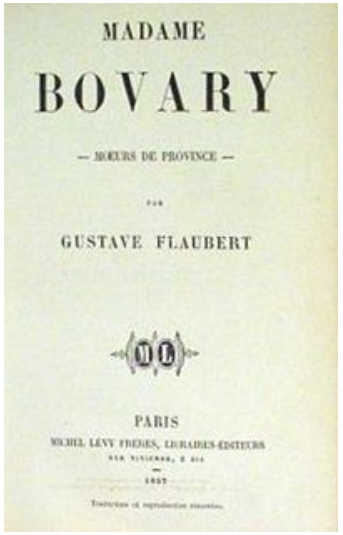
Other developments in science reinforce this attitude

Another side of an attitude is an impatience with idealism

Bismarck's Realpolitik

Realism in art

Realism in literature


MADAME

BOVARY

— MOEURS DE PROVINCE —

PAR

GUSTAVE FLAUBERT

PARIS

As you might guess, the overconfidence that comes with thinking one knows what's really the case can be naive

We'll see it begin to unravel in physics next week