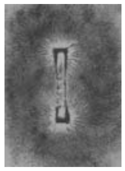
Electromagnetism and the Æether

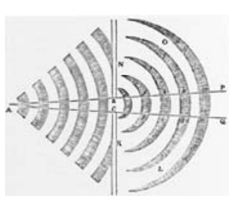


Light

- What is it?
  - According to Newton, Light is a stream of particles (i.e., hard bodies), just as matter was composed of particles.
  - Even in Newton's day, alternate theories proposed that light was some sort of *wave*, and was not like matter at all. (E.g., Huygens, Leibniz, Goethe).
- Is there a way to decide between waves and particles?

Newton's demonstrative diagram to show that light must be particulate

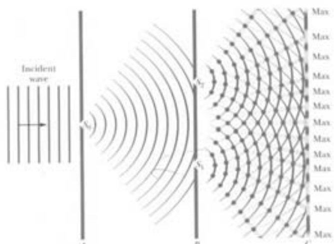
- A diagram from the *Principia* to show what light *would* do if it was a wave phenomenon.
  - According to Newton, it does not do this, so it must be particles.



Thomas Young's Crucial Two-Slit Experiment

- Thomas Young (1773-1829)
  - English physician
  - Interested in investigating the nature of light, primarily from the point of view of perception.
  - Young re-opened the debate by showing that Newton's "experiment" was flawed.

Young's 2-Slit Experiment, 2



- Young's (actual) experiment, showing interference patterns, characteristic of wave phenomena.

The Wave Theory

- Augustin Fresnel, a French engineer, developed a mathematical theory of light based upon a wave model. It accounted for Young's experimental data.

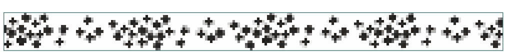
Waves of what?

- If light was a wave phenomenon, what is it that was “waving”?
  - The Newtonian mechanist world view assumed that the constituents of the universe were tiny particles moving through *empty* space.
  - What is the meaning of waving particles?

Kinds of waves

- There are two basic patterns of wave motions:
  - Longitudinal, where the wave is in the same direction that the wave front moves.
  - Transverse, where the wave crests and troughs are in a direction perpendicular to the motion of the wave front.

Longitudinal waves



- Particles can form wave patterns by bunching up together and spreading apart on a periodic basis.
- Sound waves are longitudinal waves, formed by molecules of air being alternately compressed densely together and spread thinly apart.
- Fresnel and Young expected that light would consist of longitudinal waves, making it possible that they were in fact particles, but formed wave patterns.

Transverse waves

- Transverse waves are typical of fluids. The familiar model is wave motion on the surface of a body of water. The waves are represented by differences in the depth of the water, seen as crests and troughs. The wave moves up and down as the wave travels outward.

A complication…

- Unfortunately, while both longitudinal and transverse motions were waves, some of the characteristics of light only made sense if light was conceived as a transverse wave – like waves of water.
- This did not fit the model of particles in empty space.

The problem of speed

- There was an additional problem:
- The speed at which a transverse wave propagates depends on the rigidity of the material.
- Light clearly travels very fast indeed.
- Therefore waves of light must be caused by the vibration of a very rigid body – a solid.

Non-empty empty space?

- Maybe the Newtonian model of particles in empty space is not correct.
- Maybe space is not empty at all, but is completely filled with some rigid substance capable of vibrating.
  - Note the rise of the Parmenides/Aristotle worldview.
  - Note also the *ad hoc* nature of this hypothesis.

Enter the Æther

- As a medium to carry light waves, one could propose an invisible, otherwise undetectable, medium that everything is situated in.
- Call this the ***æther***. The term had been around since Aristotle.
  - It was the name often given to his “fifth element.”

Properties of the Æther

- In order to fit the mathematical model that described the behaviour of light, the æther had to be:
  - Solid
  - Rigid
  - Rarefied (i.e., very thin), since everything passed through it effortlessly.

Two other problem phenomena

- In addition to the mysteries of light, two other categories of phenomena presented challenges to the mechanist viewpoint:
  - Electricity
  - Magnetism
- Like light, both of these seemed to work over "empty" space, and called up that troublesome notion, *action at a distance.*

Electricity

- Electricity was the scientific toy of the late 18^{th} and early 19^{th} centuries.
  - Devices were made to build up static electric charges and use them to attract or repel materials or to give shocks.
  - There appeared to be two kinds of electricity, produced by different materials. Objects charged with the same kind of electricity repelled each other while those charged with different kinds of electricity were attracted to each other.

Franklin: only one kind of electricity

- The American, Benjamin Franklin, argued that electricity was all of one kind, but had polarity, like magnetism.
  - An extra kind of one electricity could be neutralized by an equal amount of the other.
  - Franklin said it was all the same thing but came in *positive* and *negative* amounts.

Lightning is electricity, too.

- He also demonstrated that lightning was just a discharge of electricity by attracting a lightning bolt with a kite attached to a battery during a thunderstorm.
  - Amazingly, he was not killed by the lightning.

The inverse square law

- In France, Charles Coulomb devised an instrument to measure electric charges.
- He determined that the strength of an electrical force over space diminished proportionately to the square of the distance.
- This was also a feature of the force of *magnetism.*
  - It is also characteristic of the *gravitational force.*

Naturphilosophie

- *Naturphilosophie* (philosophy of nature) was a movement in philosophy in Germany in the 19th century that sought to find unity in nature via a single unifying force that would account for everything.

Experimental support for *Naturphilosophie*

- In Denmark, Hans Christian Oersted showed that an electric current could move a magnet.
- In Britain, Michael Faraday, found that moving a magnet could start an electric current flowing.
  - Maybe they were all the same thing, somehow.

Maxwell's synthesis

- James Clerk Maxwell (1831-1879), Scottish mathematical physicist.
- Maxwell found a way to account for the phenomena of electricity, magnetism, and light itself, in a single sytem of wave equations.

Maxwell's wave equations

- Maxwell's systematic treatment accounted for the experimental results of Oersted, Faraday, and Coulomb as interactions of wave motions.
- Maxwell's system implied that there was some medium causing the waves.
  - Hence the concept of the æther became entrenched as a necessary concept in physics.

Absolute space and time

- Newton's universe was a large (potentially infinitely large) empty box with fixed places in it.
  - A Euclidean space.
- Time flowed on evenly at a constant rate without regard to any events whatsoever.

Relative space and time

- We have no direct contact with absolute space and time. We only can detect relative space and time.
  - Relative space and place is determined with reference to other identifiable things, e.g. position in the solar system, place in a room, etc.
  - Relative time is measured by change of some reference system, e.g.
    - The apparent motion of the Sun, Earth, Moon, etc.
    - The change of position of hands of a clock.
    - The aging of a living thing.

Absolute and relative motion

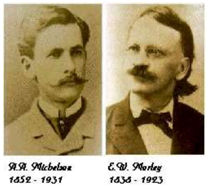
- Relative motion is change of place relative to some frame of reference, taken as fixed.
  - E.g., motion within a room, with reference to the walls.
  - Motion of the planets, with reference to the Sun.
- Absolute motion is virtually undectable.

The stationary æther

- If space is truly empty and we can only detect motion of things in it relative to some other frame of reference, which may itself be moving, then there is no way to determine absolute motion.
- But, the æther is supposed to fill all of space and therefore not be moving.
  - So motion relative to the æther would be the same as absolute motion in the universe.

Michelson and Morley

- In the 1880s, two physicists, Albert A. Michelson and Edward Morley, working in Cleveland, Ohio, thought they had found a way to measure the motion of the Earth through the æther.

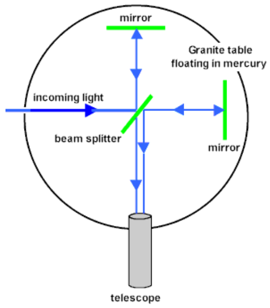


The Michelson-Morley Experiment

- If light is a wave disturbance of the æther, then the speed that it travels through the æther will be constant, but it will appear to be different, relative to the Earth, because the Earth is moving through the æther.
  - If a light wave is shot out from a place on the Earth in the same direction that the Earth is moving through the æther, it will seem to go slower than one shot out at right angles, because the Earth will be keeping pace with it.

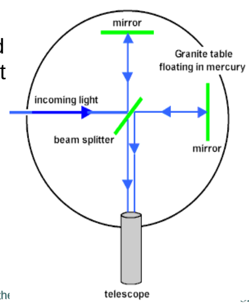
Michelson-Morley, 2

- Michelson and Morley devised an apparatus to shoot light off in a particular direction, then using a half-silvered mirror, deflect some of that light off at a 90 degree angle.



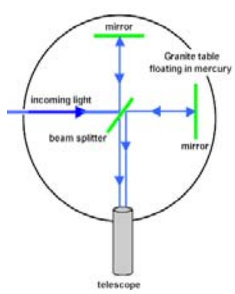
Michelson-Morley, 3

- Both the light rays continuing straight and those deflected at right angles would then be bounced off mirrors to return to their point of divergence, and then recombined to head together to a receiving instrument.



Michelson-Morley, 4

- The point of the experiment is that if the apparatus is moving through the æther, then one pathway will take longer than the other, because the apparatus is moving along too.



Michelson-Morley, 5

- The difference would show up as an interference pattern when the light rays recombined.
- The experimenters of course did not know which way the Earth was moving through the æther, but they set up their apparatus so that it could rotate into many different positions.
- When they found the greatest interference pattern, they would know which way the Earth was moving, and from the size of the interference bands, could calculate the speed of the Earth through the æther.

Michelson-Morley, 6

Michelson's & Morley's actual apparatus, the *interferometer*.

- An animated re-creation of the Michelson-Morley Experiment, showing the expected results for different speeds and directions of the Earth through the æther.

Michelson-Morley, 7

- What they expected to find:
  - They want to calculate *v*, the speed of the Earth through the æther.
  - After rotating the interferometer to find the maximum distance, they will have two measures,
    - *t* = the time required for light to travel back and forth over a path stationary in the æther.
    - *t'* = time taken to travel the same path when it is moving parallel to the æther.

Michelson-Morley, 8

- They already have a measure, *c*, for the speed of light.
- They can calculate that the relationship they are measuring will satisfy this equation:

$$t = t'\sqrt{1 - v^2/c^2}$$

- After measuring *t* and *t'* Michelson and Morley would be able to solve this equation for *v*, the speed of the Earth through the æther.

Michelson-Morley, 9

- The shocking result:
  - After many trials and measurements made at different angles and different rotations of the interferometer. They found no difference at all in the interference patterns.
  - That is, according to their measurements, $t = t'$

Michelson-Morley, 10

- The implication:
  - If $t = t'$ the solution of the equation

$$t = t'\sqrt{1 - v^2/c^2}$$

for *v*, the speed of the Earth through space, is zero.

- It seemed inconceivable that after Copernicus, Galileo, Newton, etc., that experiment would show that the Earth is motionless in space!

Explaining Michelson's and Morley's negative result

- Consider the logical structure of the theory behind their experiment:
  - *H* = The æther is motionless in the universe and the Earth moves through it.
  - *T* = Light will appear to travel at different speeds when measured by instruments travelling at different speeds through the æther. (That is, in different directions on Earth.)
  - *H* implies *T* (If *H* is true, so is *T*.)

Modus Tollens at work

- Here we have *H* implies *T* , but *T* is false (light does not appear to travel at different speeds in different directions).
- If *T* is false, *modus tollens* says that *H* is false.
- But *H* is a complex statement involving many assumptions of its own.
  - What is it about *H* that is false?

Possible explanations

- Maybe the Earth really is motionless and it is the heavens that move. (Back to Aristotle and Ptolemy!)
- Maybe the Earth drags the æther around with it.
- Maybe *H* is correct after all and the experiment is set up incorrectly, or the measurements were made sloppily.

Response of the scientific community

- No one seriously considered that maybe Copernicus was wrong all along!
- Those who believed the experiment had been done correctly tended to favour the explanation of the æther being dragged around near the Earth.
- Most just concluded the Michelson & Morley had been careless.

An *ad hoc* solution

- Two physicists, George FitzGerald in Ireland and H. A. Lorentz in Holland, proposed an even more bizarre way out:
  - They suggested that the interferometer actually shrinks its size in the direction of its motion through the æther, by just enough to make the change in speed undetectable.
  - The shrinkage would be by a factor of

$$\sqrt{1 - v^2/c^2}$$

And yet another possible way out…

- The whole premise of the Michelson-Morley experiment depends upon the existence of the æther as a stationary medium that fills the universe.
  - Yet while the æther makes sense of electromagnetism and seems a necessary concept, it has never actually been detected by any direct measurement. Assuming that it existed solved other problems, but was it justified?

Positivism and Ernst Mach

- Just then, in the last decades of the 19th century, a new way of thinking about scientific concepts was being discussed by philosophers and scientific theorists: *positivism.*
- A leader of the positivist movement was the Austrian physicist Ernst Mach.
- Mach argued that if a scientific concept could not be independently verified by experiment then it did not belong in a scientific explanation.

Mach's target

- Among the targets of Mach's positivist views were explanatory theories that supposed the existence of underlying objects, forces, concepts, etc., that could be defined but not measured.
  - For example, in psychology, the notions of thoughts, feelings, and the will.
  - In physics, it would also apply to the concept of the æther.