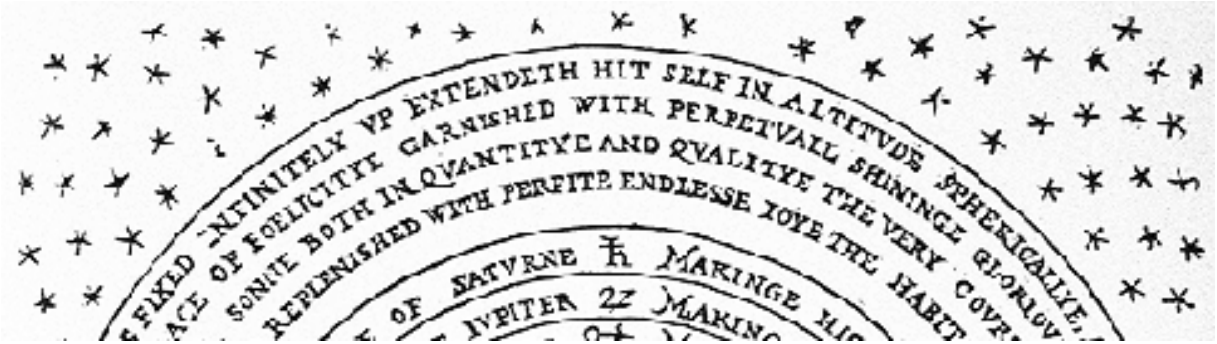


PHY1033C/HIS3931/IDH 3931 : Discovering Physics:

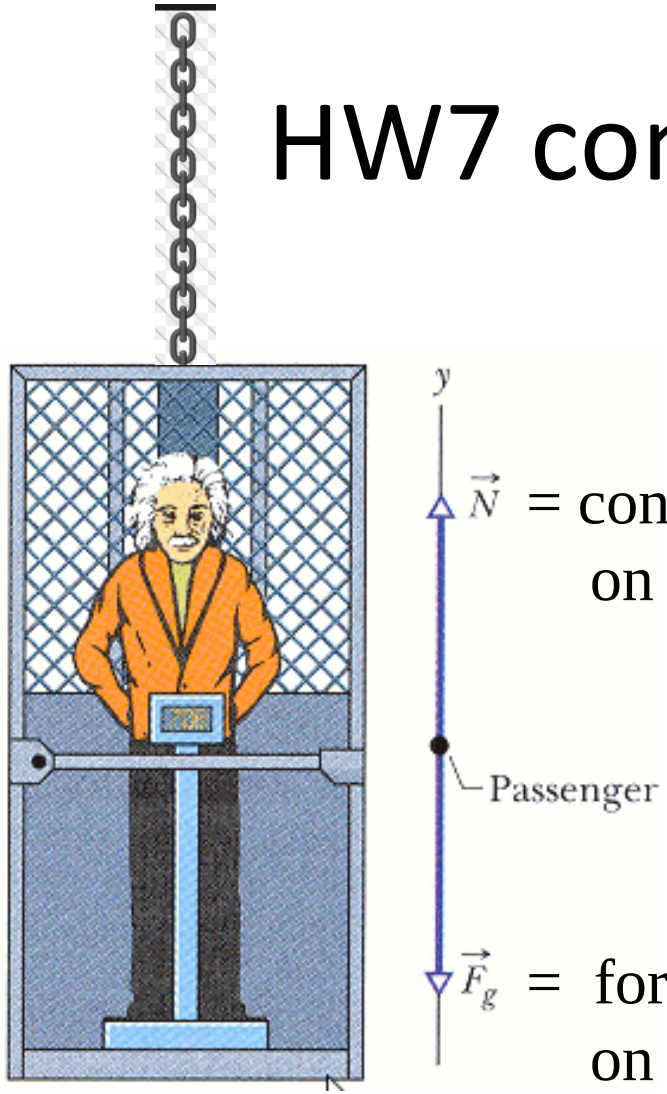
The Universe and Humanity's Place in It

Fall 2016

Announcements

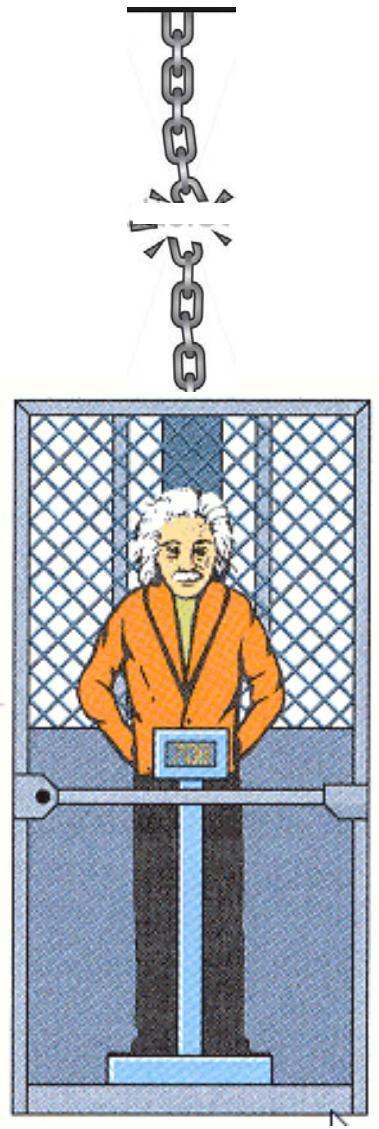
- HW 8 due today HW9 posted, due Nov. 15
- Reading: Chapter 21, to p. 447
  Look at Michelson-Morley simulator!
- Thurs., Nov. 10 4pm after class, NPB 2205:
  Optional film: Relativity pizza party!
- HW 7 remarks: Newton's elevator

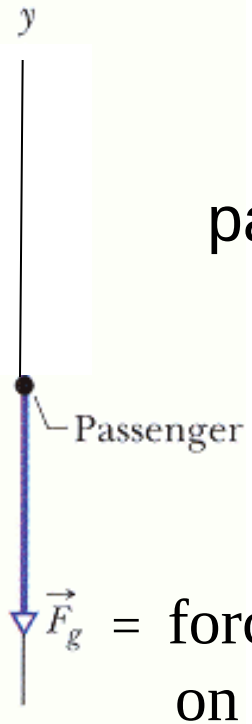
HW7 comments



At rest, forces cancel, scale reads normal weight, W=N

HW7 comments

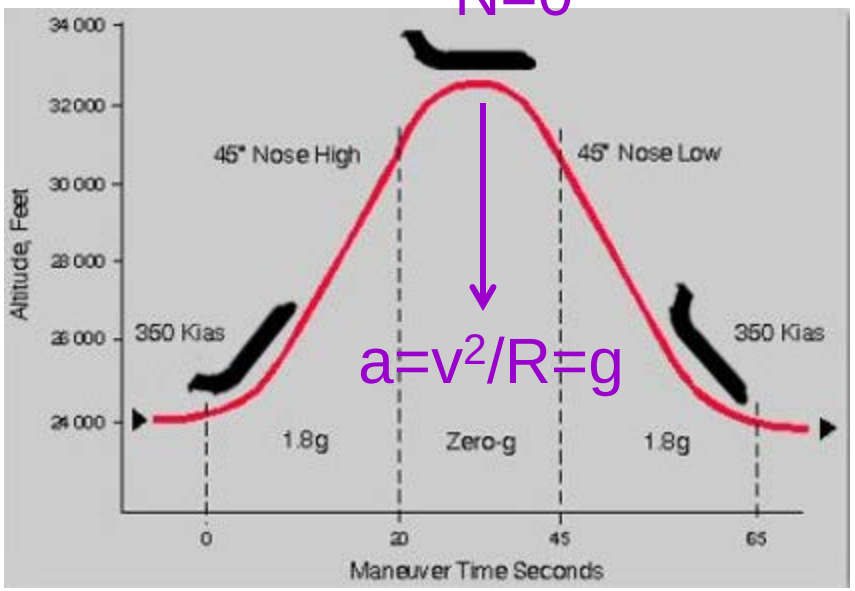




chain breaks:
passenger is weightless!
scale reads zero

$a_y = -g = -10\ m/s^2$ for all objects!
scale force on passenger N = 0

NASA's "vomit comet"



Happy birthday!

Lise Meitner
Nov. 7, 1878

- discovered nuclear fission 1939

Marie Curie
Nov. 7, 1867

-discovered elements radium, polonium
-theory of radioactivity

Go to lunch question: name 4 women scientists from 15th-19th centuries besides Galeazzi and describe their achievements.

Last time

- Saw how Faraday used electric current to produce mechanical motion in the Faraday motor
- He later tried to pick up electricity from one wire in a separate wire located in the magnetic field around the first wire
- Succeeded in getting only spurts of electricity when circuit was closed or opened
- Concluded that changing the magnetic field induced electricity in the second wire
- Showed how inserting a magnet into a coil of wire induced a current in the wire

- Demos! 2nd try

Clicker question

Michael Faraday, attempting to show that a current in one wire could induce a current in a nearby one, noticed

A) an electric charge was accumulated on the 2nd wire

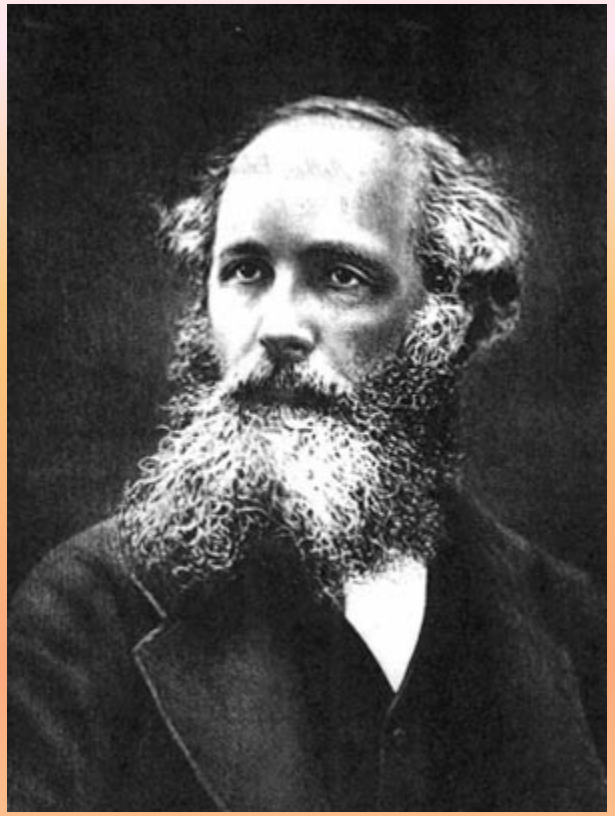
B) A current in 2nd wire was induced only when he opened or closed the switch

C) His hair stood on end

D) The 2nd wire pointed always to the north pole

E) The 2nd wire experienced a force tending to curl it into a loop

Question for 19th century scientists: light is a wave (Young 1801). What is the medium carrying the wave?



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

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

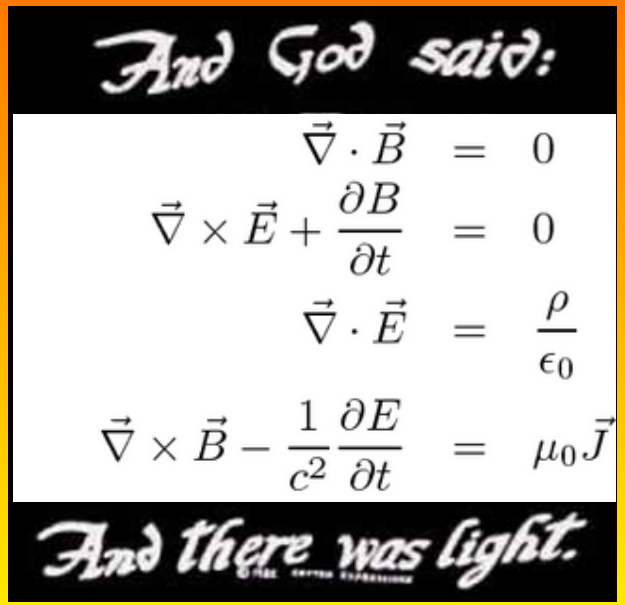
And they reveal an incredible new discovery

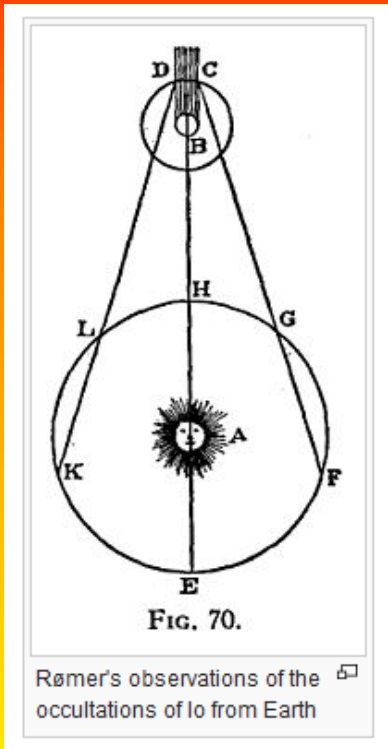
From quantities present in his equations Maxwell was able to calculate the speed with which electromagnetism moves

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

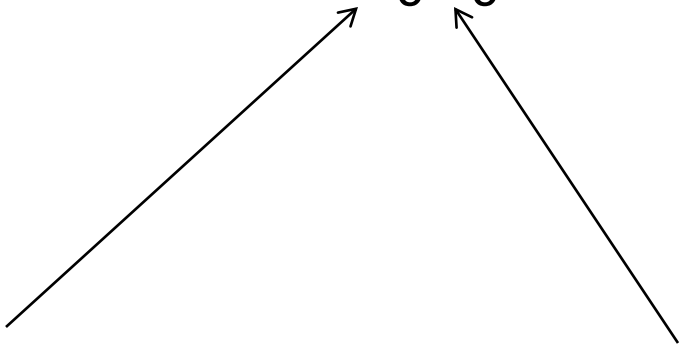




Rømer's observations of the occultations of Io from Earth

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 was thought to be everywhere, it was also in space

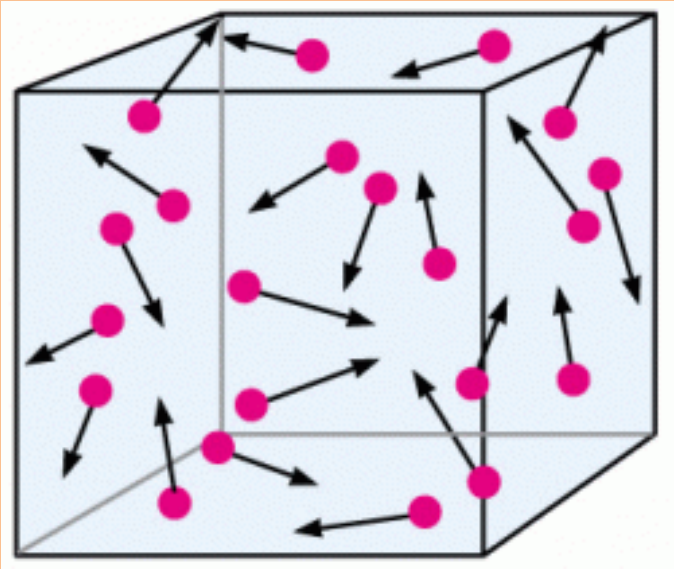
Light is transmitted through space

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

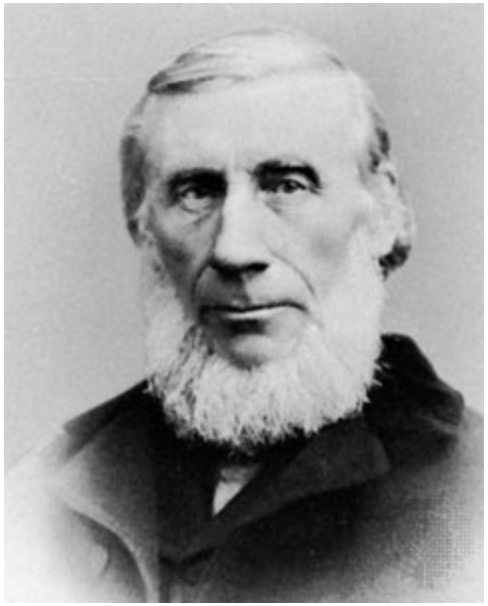
Maxwell and others did not attempt to confirm electromagnetic waves in space

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



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.”

John Tyndall
(Irish physicist, 1820-1893)

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

Classical physics a good expression of the age

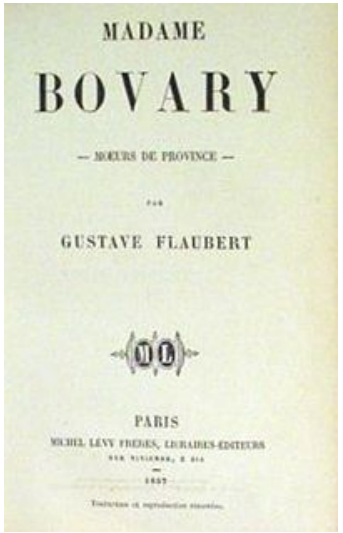
Other developments in science reinforce this attitude

Another side of an attitude is an impatience with idealism

Bismarck’s Realpolitik

Realism in art (Gustave Courbet)

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

Now we'll see it begin to unravel

Context of Michelson-Morley experiments (1881,1887)

Late 19th century: period where scientists have a successful theory of mechanics and the solar system (Newton), as well as heat & energy. Attitude characterized by

a) *Realism*: Confidence that physics has captured nature "as she really is" -- complete description of objective reality possible

b) *Determinism:* Belief in a precise description of cause and effect. *In principle,* we can calculate everything!

Pierre-Simon Laplace (1814):

"*We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed, if this intellect were also vast enough to submit these data to analysis, it would embrace in a single formula the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes.*"

Context of Michelson-Morley experiments (1881,1887)

Science *and* technology timeline

- Understanding of light as electromagnetic wave (Maxwell, 1865)
- Reliable submarine telegraph cable 1866
- Periodic table of elements (Mendeleev, 1869)
- Discovery of cathode rays (Crookes, 1875)
- Telephone (Bell, 1876)
- Phonograph (Edison, 1877)
- Light bulb (Edison, 1879)
- Discovery of radio (electromagnetic) waves (Hertz, 1887)

Confidence that all would soon be understood

Albert Michelson (1852-1931)

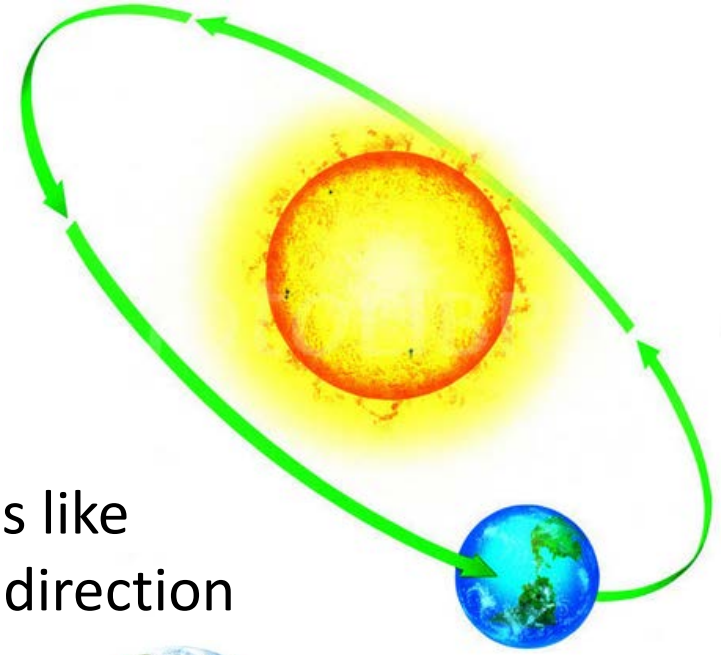
- Son of Polish immigrant who came to California for gold rush
- Early research on interferometry and laboratory measurements of speed of light, at US Naval Academy and Case School (now Case Western)
- Spent career attempting measurements of the earth's velocity with respect to the *ether* – medium supporting *electromagnetic waves*

Ether

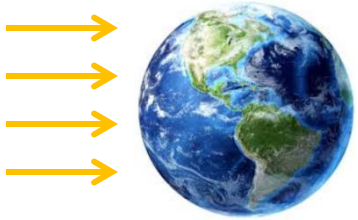
- Logic (faulty): light is transported to us over vast distances from the stars. Light is a wave. Therefore there must be a medium, filling all of space, which supports light waves the way air supports sound waves.
- Light goes very fast, so the ether must be very *stiff*.
- Yet things moving through it experience *no resistance*!

Ether

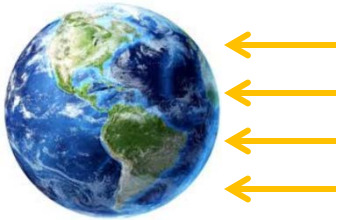
The Earth moves through the ether



So from our perspective, the ether is like a wind blowing past us. The wind's direction should be opposite in winter

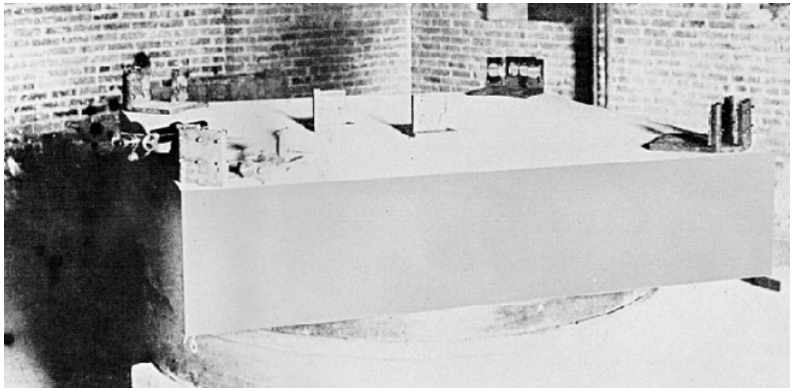


and summer,

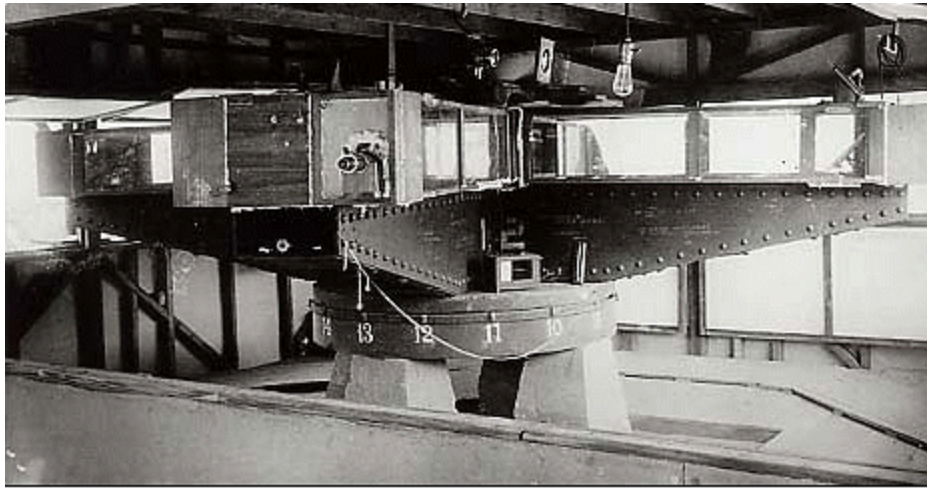


and this difference should be detectable!

Michelson-Morley (1887,…) experiment (actual)

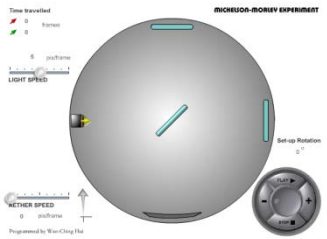


1887 Case School



Morley and Miller's 1905 Interferometer
Sited at high altitude, Mount Wilson, California
Photo: Case Western Reserve Archive

and simulated:

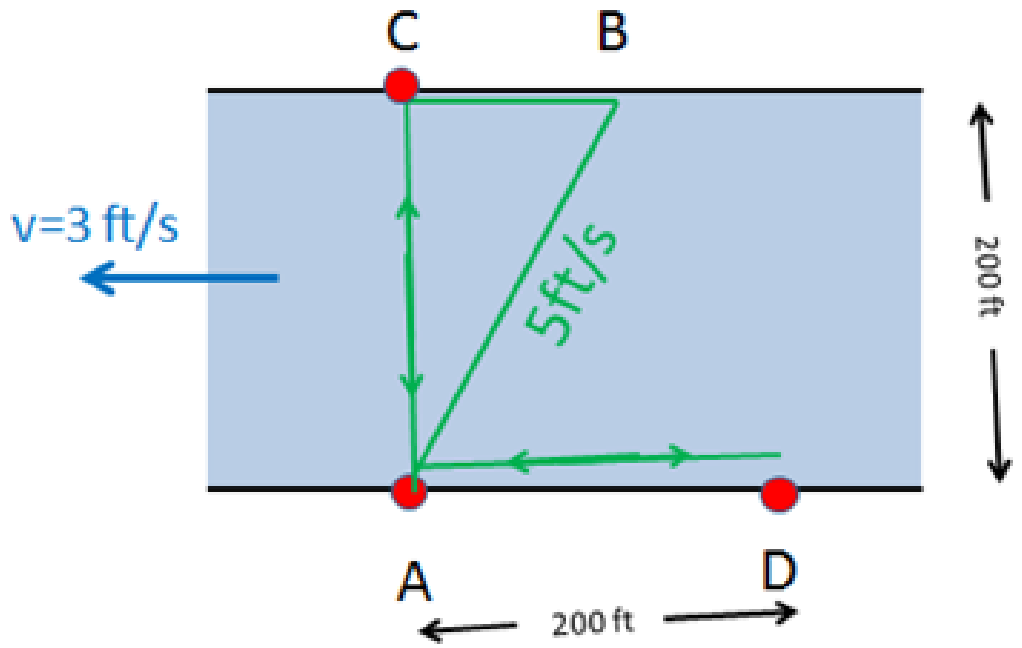


http://galileoandeinstein.physics.virginia.edu/more_stuff/flashlets/mmexpt6.htm

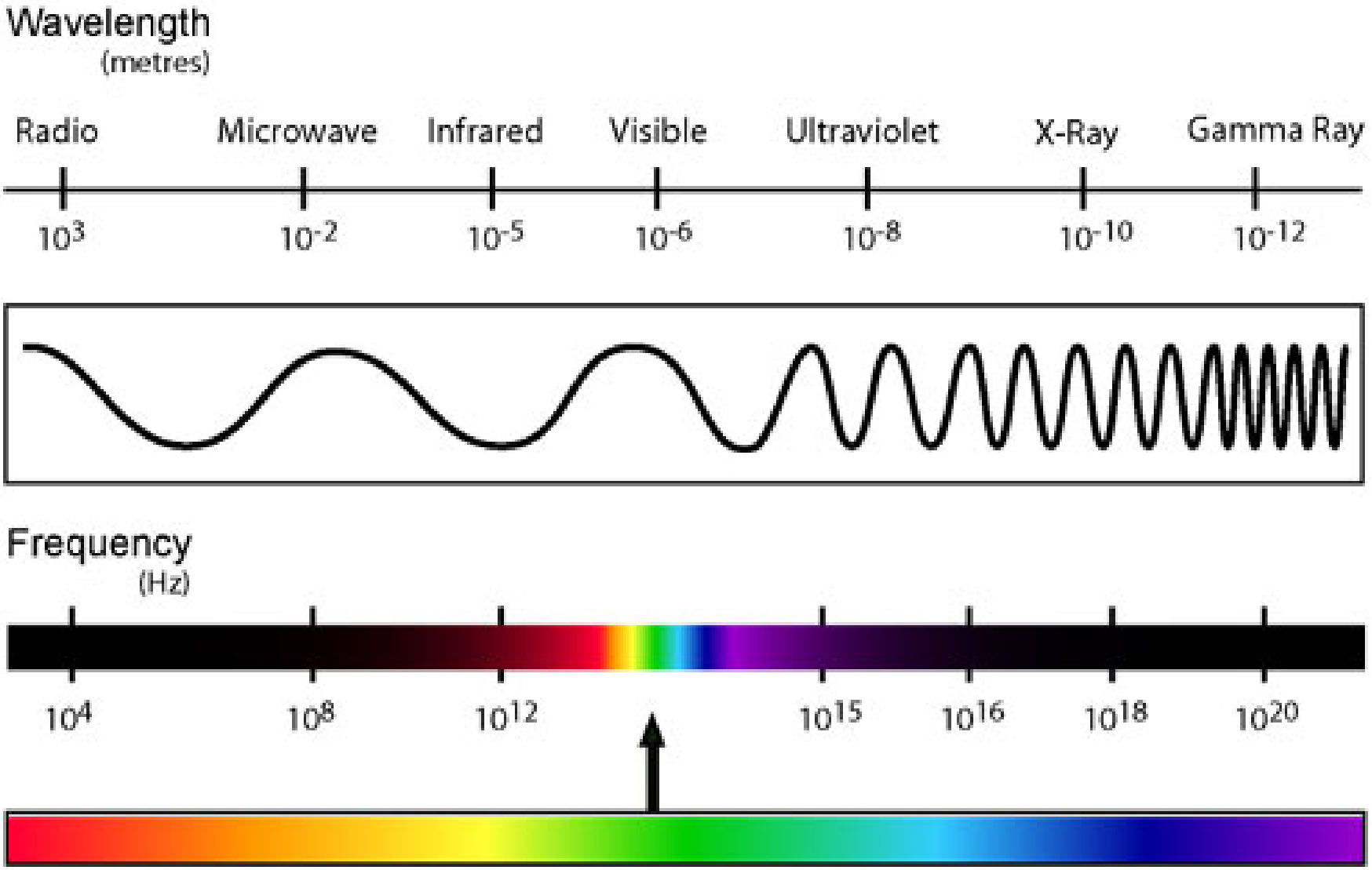
Why is there a difference in arrival time of wave crests if an ether wind exists?

Analogy: swimming in a current

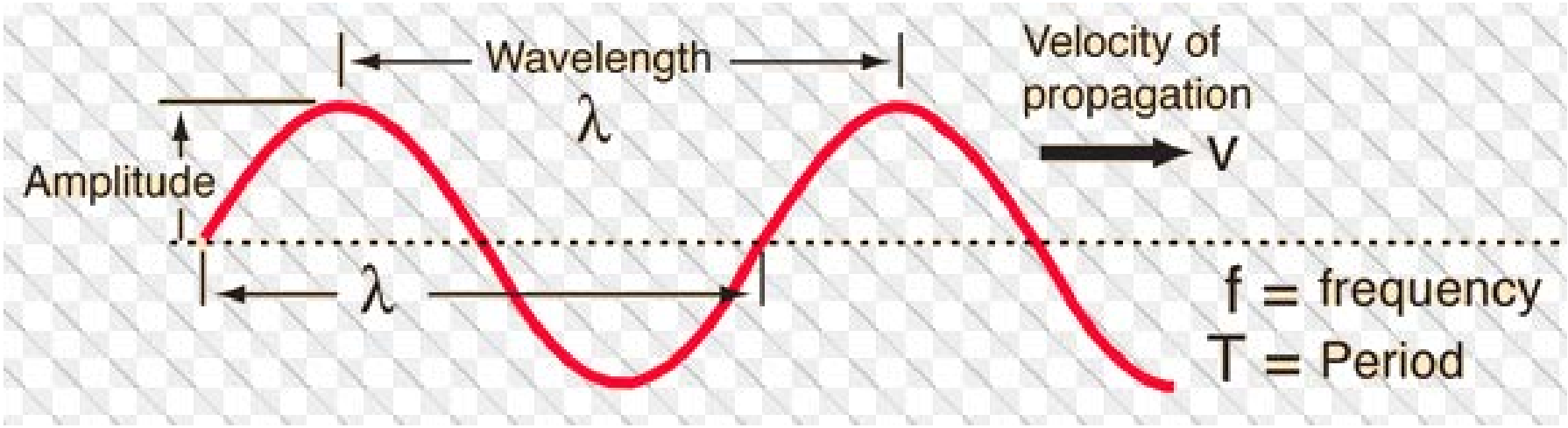
HW9



THE ELECTRO MAGNETIC SPECTRUM



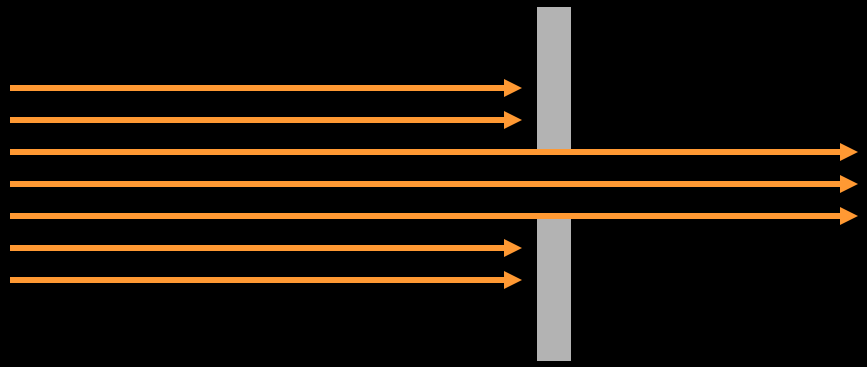
Wavelength and Frequency



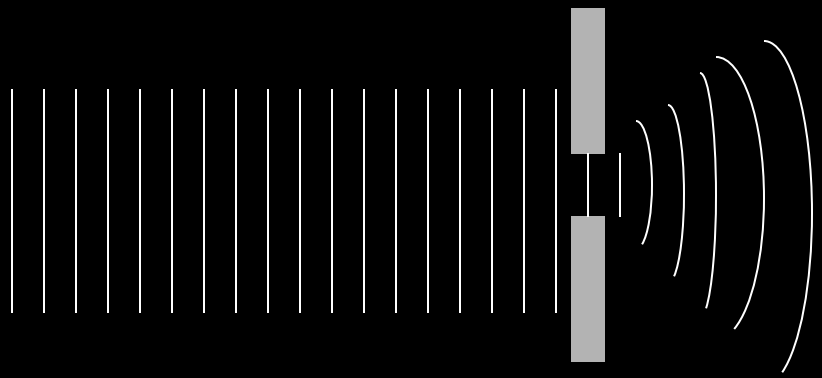
$$v = f\lambda$$

How do we know empirically that light is a wave (not a ray or a “corpuscle”)?

ray picture



wave picture



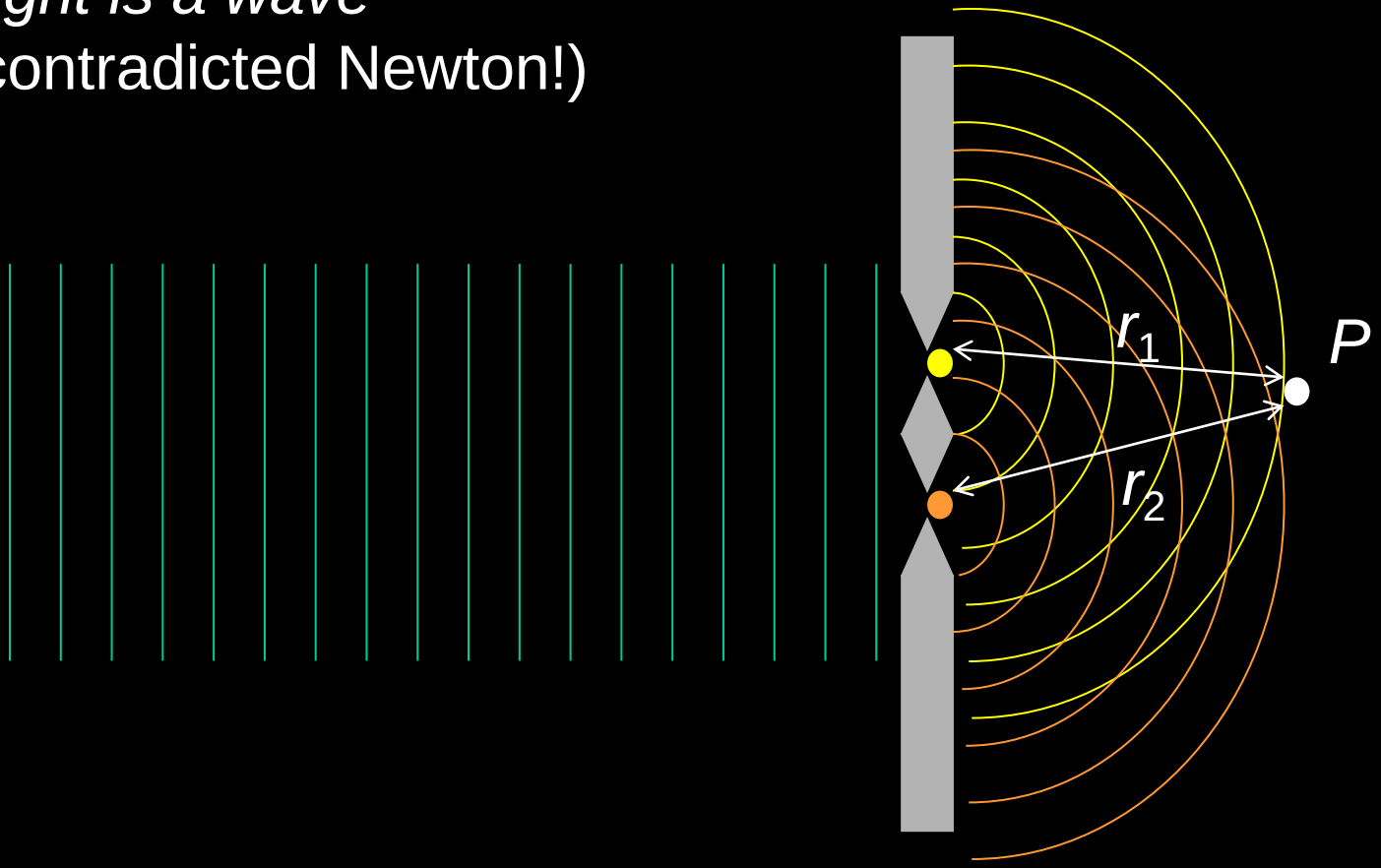
Waves diverge after going through small holes (Huygens)

Two-Slit Interference

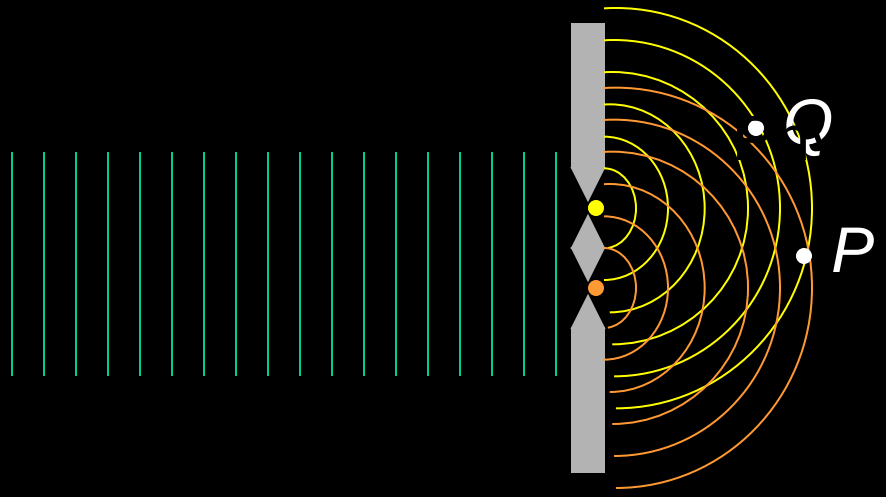
Thomas Young (1773 – 1829):

Light is a wave

(contradicted Newton!)

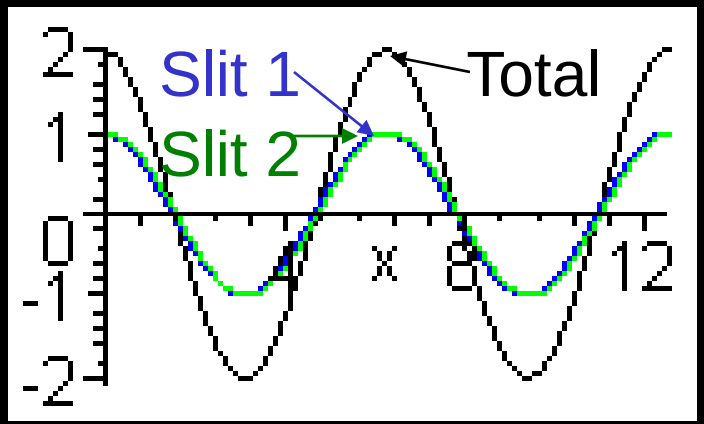


Interference

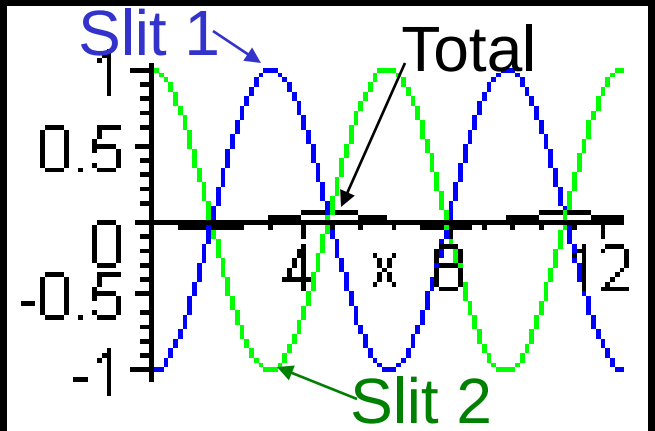


like water!

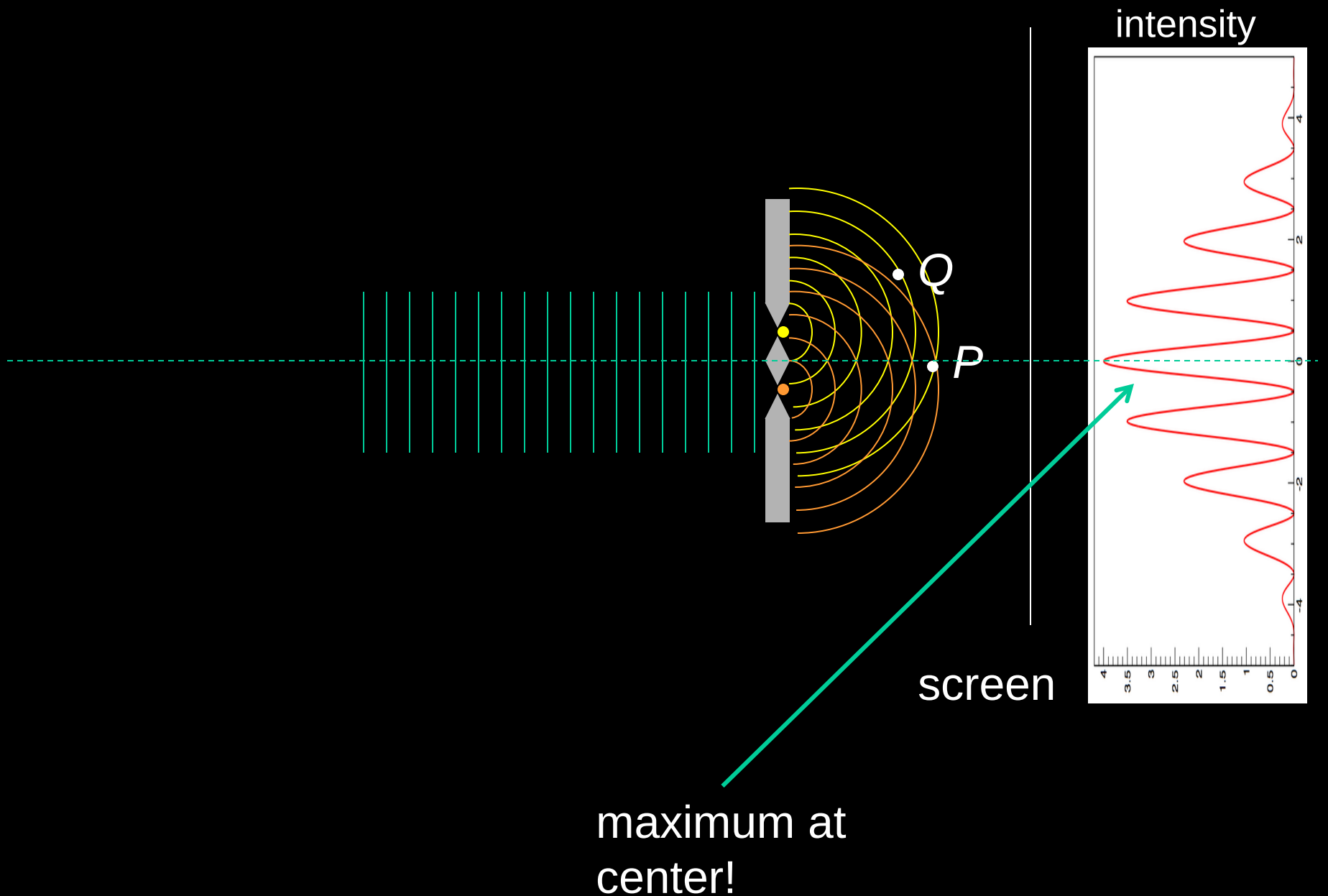
At point *P*, the crests from one slit line up with crests from the other slit
Constructive interference



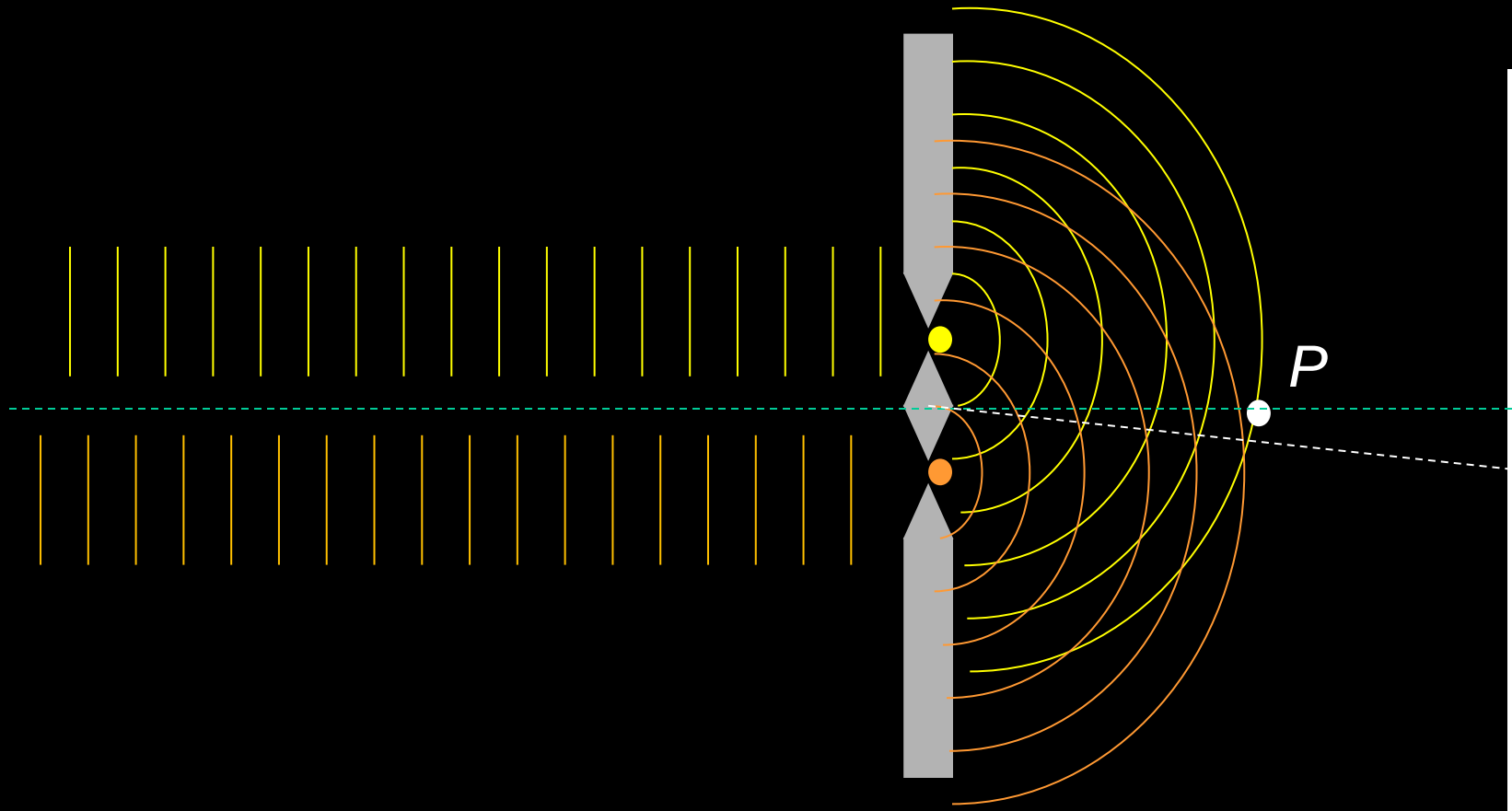
At point *Q*, the crests from one slit line up with troughs from the other slit
Destructive interference

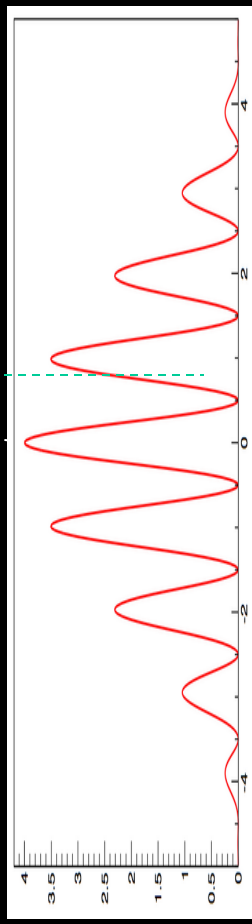


Two-slit interference pattern



You can tell when one light beam is a little behind the other, because the pattern shifts!





such a device is an “interferometer”

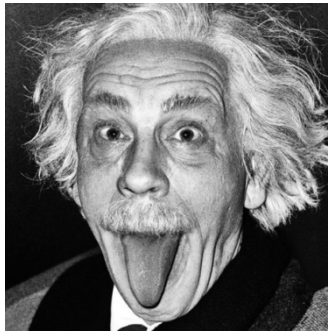
Result of the experiment(s) by Michelson

Zero. Zip. Nada.

Michelson was not happy. Problem: if there's no ether, what is waving? And with respect to what do we measure the speed of light, c?

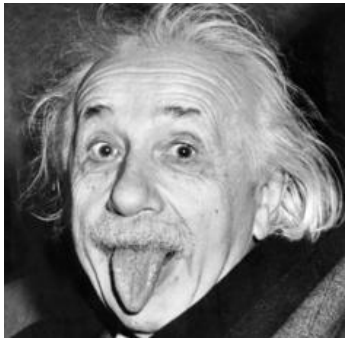
He tried for the rest of his career to refine his experiments, and never accepted that the ether did not exist.

Answers provided later by



John Malkovich

No, really by



Albert Einstein