

The Velocity of Light

by

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The Emission Theory of light

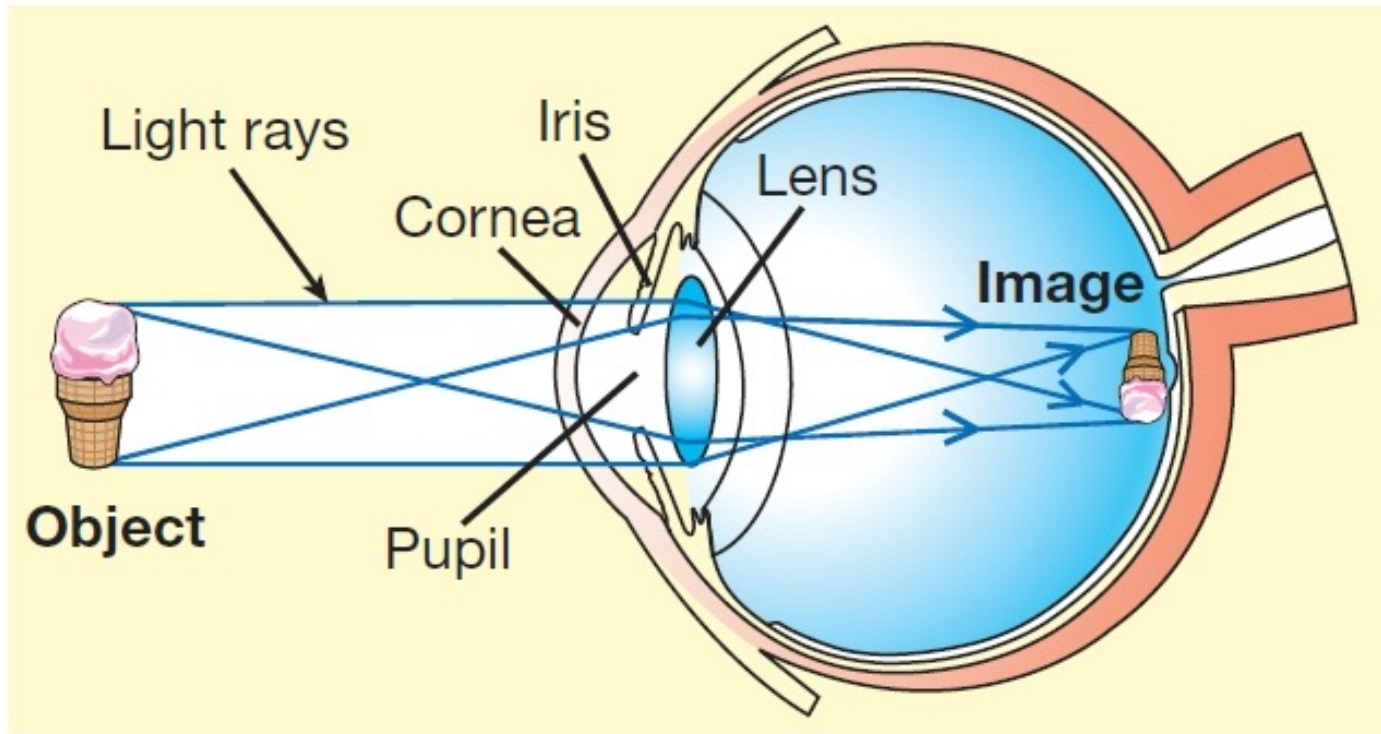
- Greek philosophers thought that the eyes see by emitting rays which probe the world and collect information
- In a 2002 study of US college students approximately 50% still held this view
- Modern ray diagrams show the light entering the eye.

Abū 'Alī al-Ḥasan ibn al-Ḥasan ibn al-Haythan
Alhazen (965 – 1040)



Modern Ray Diagram

Light Ray Eye Diagram



Prior to 17th Century the speed of light was considered to be infinite

Galileo thought light would have a finite speed

Experiments with lanterns?

Olaus Christensen Rømer (1644 – 1710)



Tuesday 14 March 2017 at 10pm GMT

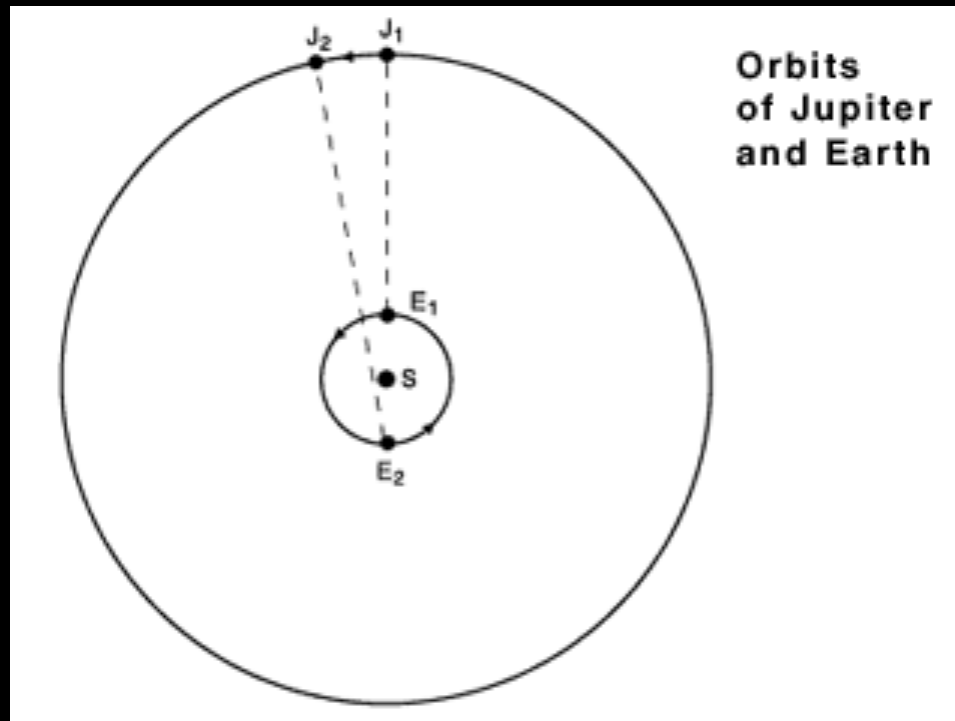


Galileo Galilei (1564 - 1642)

- Jupiter's moon Io
- Period of 42 hrs 27.5 minutes
- Galileo produced tables

Eclipses of Io, Jupiter's innermost moon

Io orbits Jupiter every 42 hrs 27.5 mins



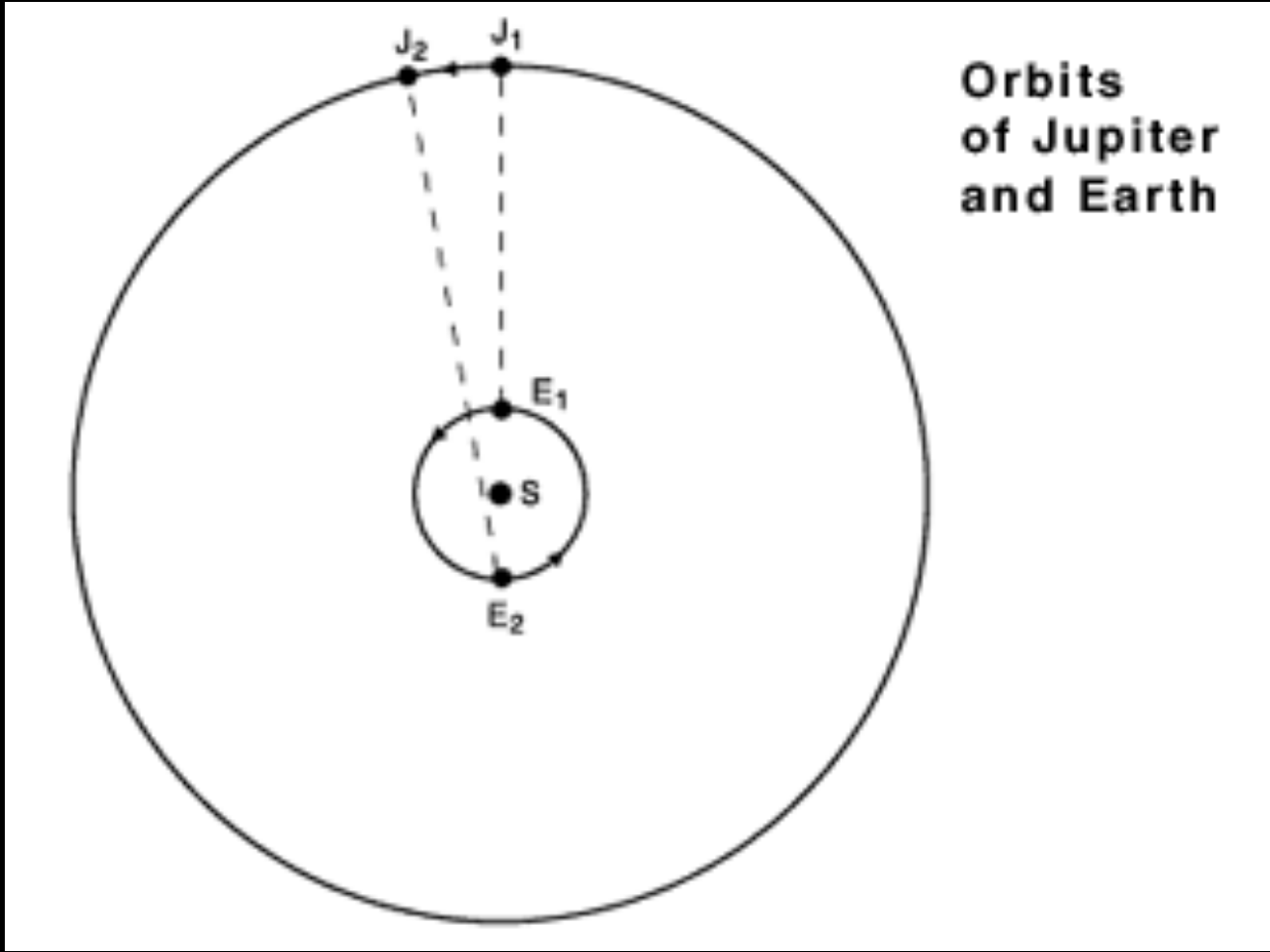
The distance between Jupiter and the Earth varies

Rømer (1676) noticed that the time between the eclipses of the moons of Jupiter got shorter and shorter as the distance between Jupiter and the Earth decreased, and got longer and longer as the distance increased.

Rømer took some 60 observations

Concluded that his times ONLY made sense if light took 22 minutes to cross the diameter of the earth's orbit. ie, $2 \times \text{AU}$

But Cassini had measured the value of AU in 1672 four years earlier



The Astronomical Unit (AU)

The distance between the Earth and the Sun

Giovanni Cassini (1625 – 1712) had measured the AU to be at 140 million kilometres (87 million miles)

The Astronomical Unit (AU)

The distance between the Earth and the Sun

149,597,892 kilometres

(92,955,820.5 miles)

Using Rømer's data:

Light takes 22 minutes to cross the diameter of the earth's orbit.

And Cassini's data for AU

Gives a speed for c of 220,000 km/sec

Some 36% low

James Bradley (1693 – 1762)



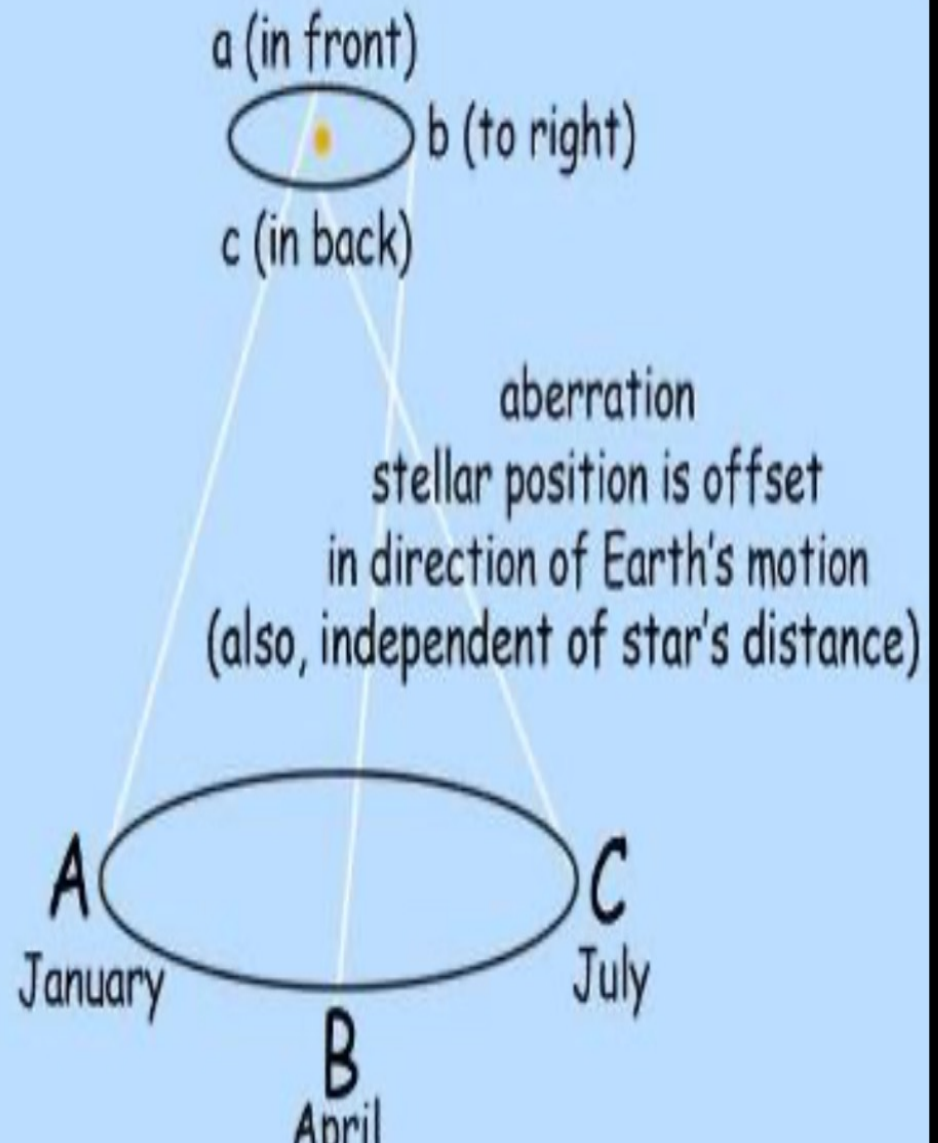
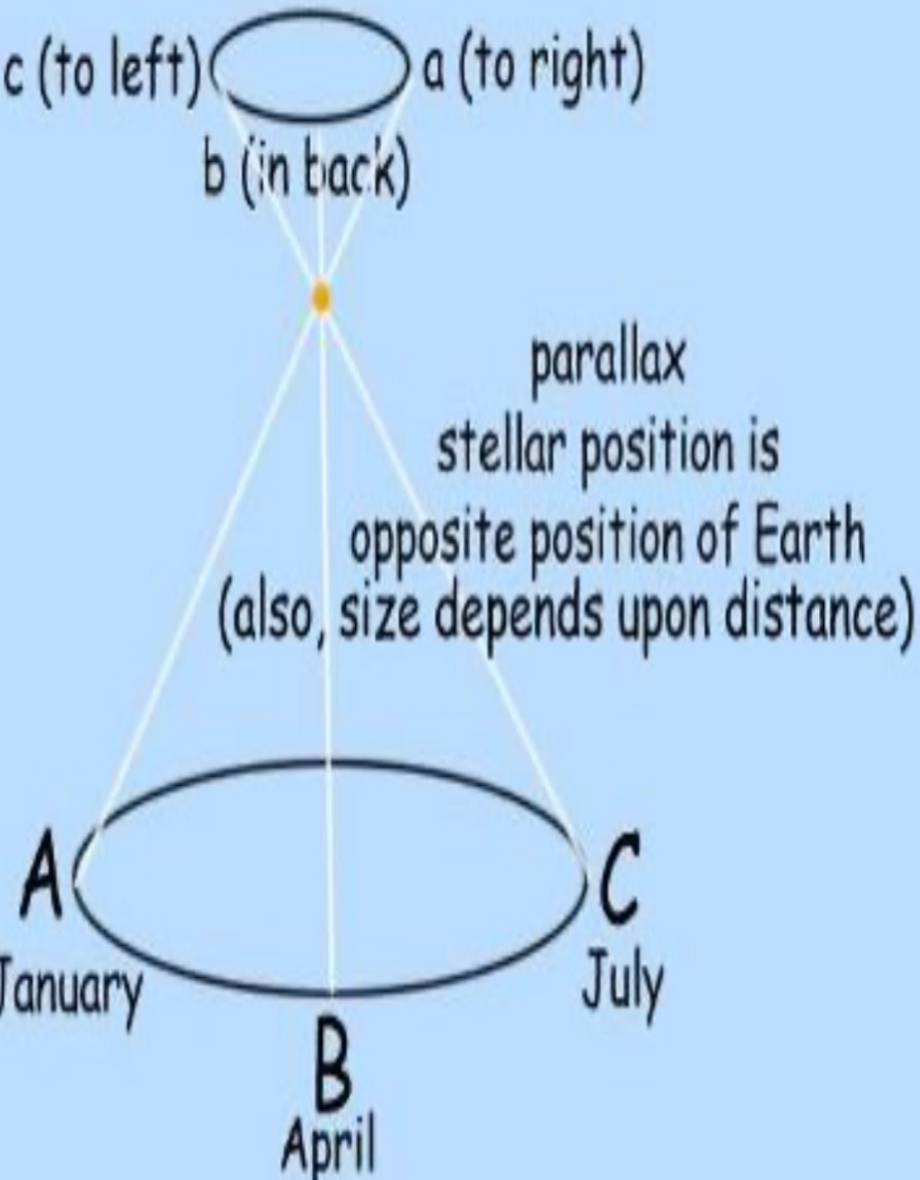
Stellar Aberration

While looking for stellar parallax he found stellar aberration (1729)

Stellar Parallax was not found until 1838 by Fredrick Bessel

So what is the difference?

Parallax v Aberration




Running in the rain!




The telescope angle

light from star



stationary Earth

motion of Earth makes light appear to come from direction ahead of actual direction



star appears up to 20 arc seconds "ahead" of true position

moving Earth

Stellar Aberration

20 arc seconds

Light travelled 10,210 times faster than the Earth in its orbit (the modern figure is 10,066 times faster)

Bessel (1838) found parallax:
0.314 arc seconds

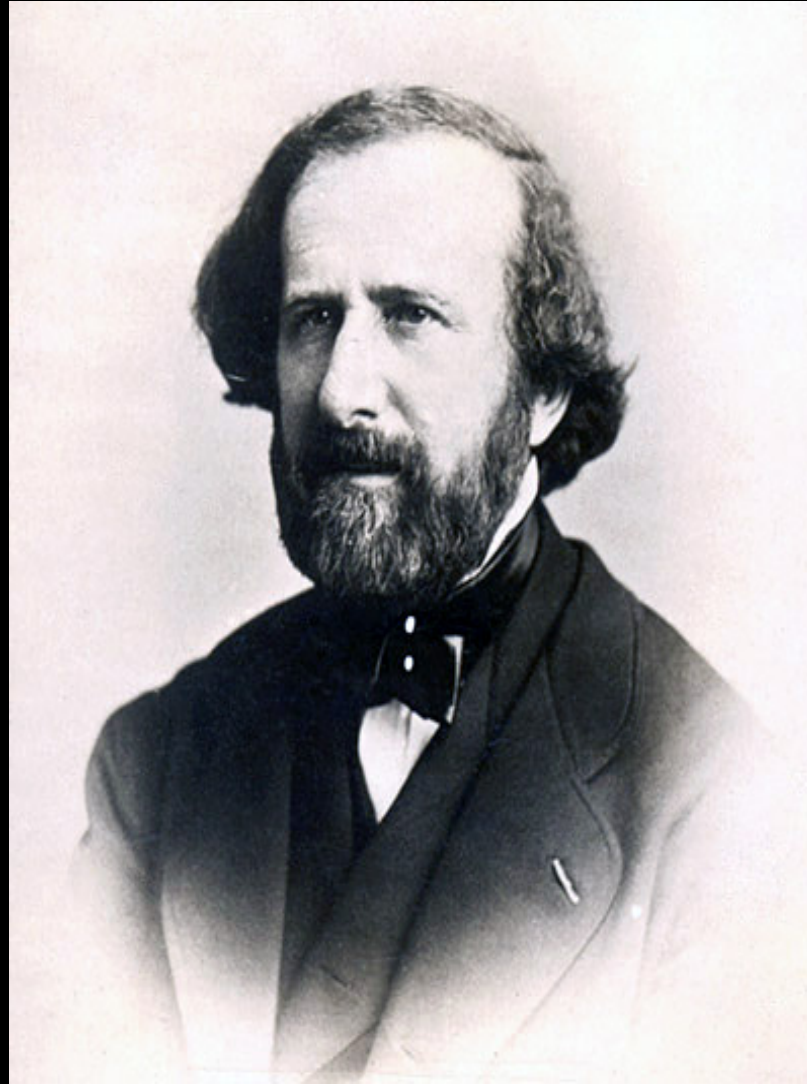
An old problem

How fast should one walk in the rain to minimise how wet one gets?

If you come from Manchester you need to know such things!

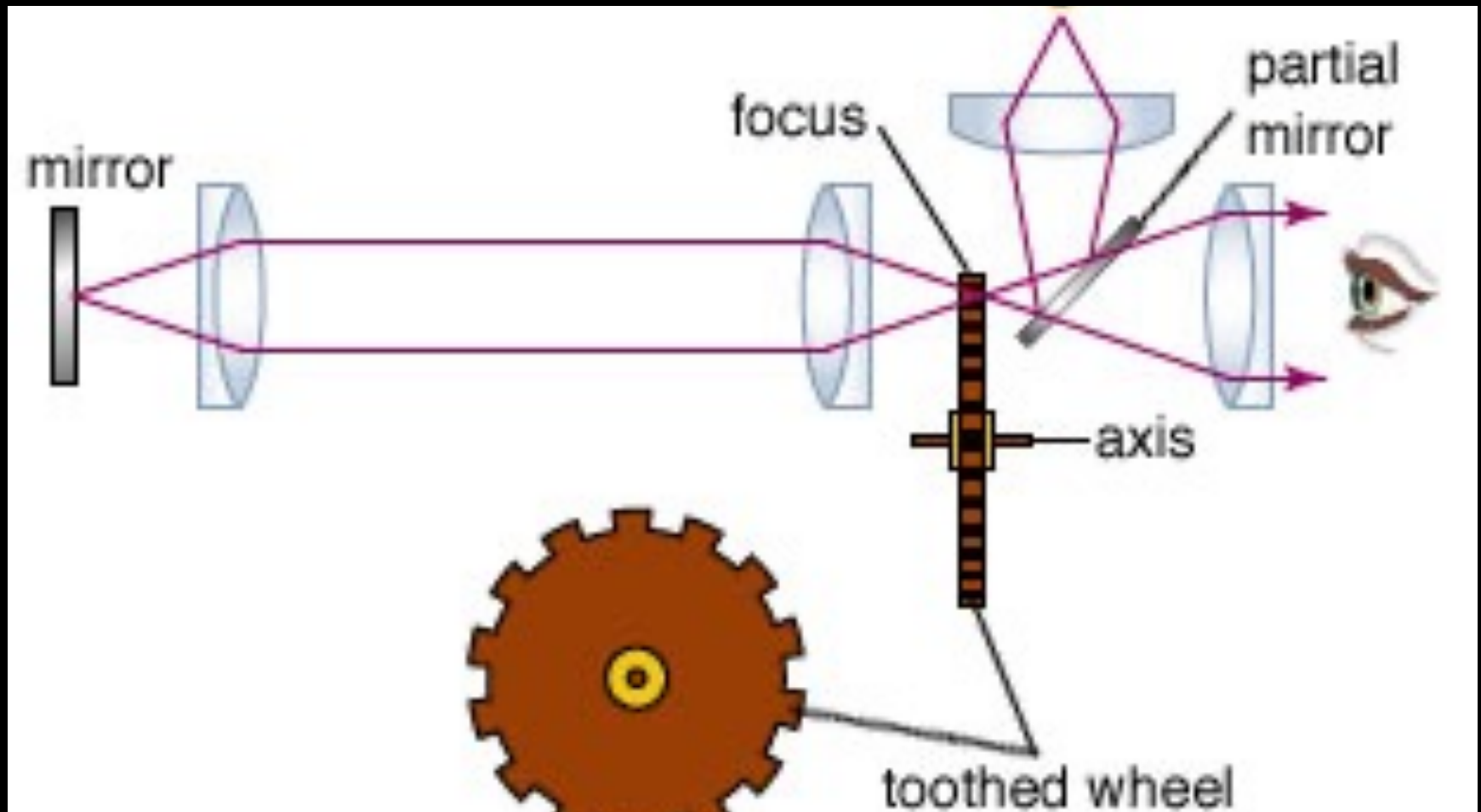


Armand Hippolyte Louis Fizeau (1819 – 1896)



Fizeau's Toothed Wheel 1848

($c = 315,000 \text{ km/s}$)

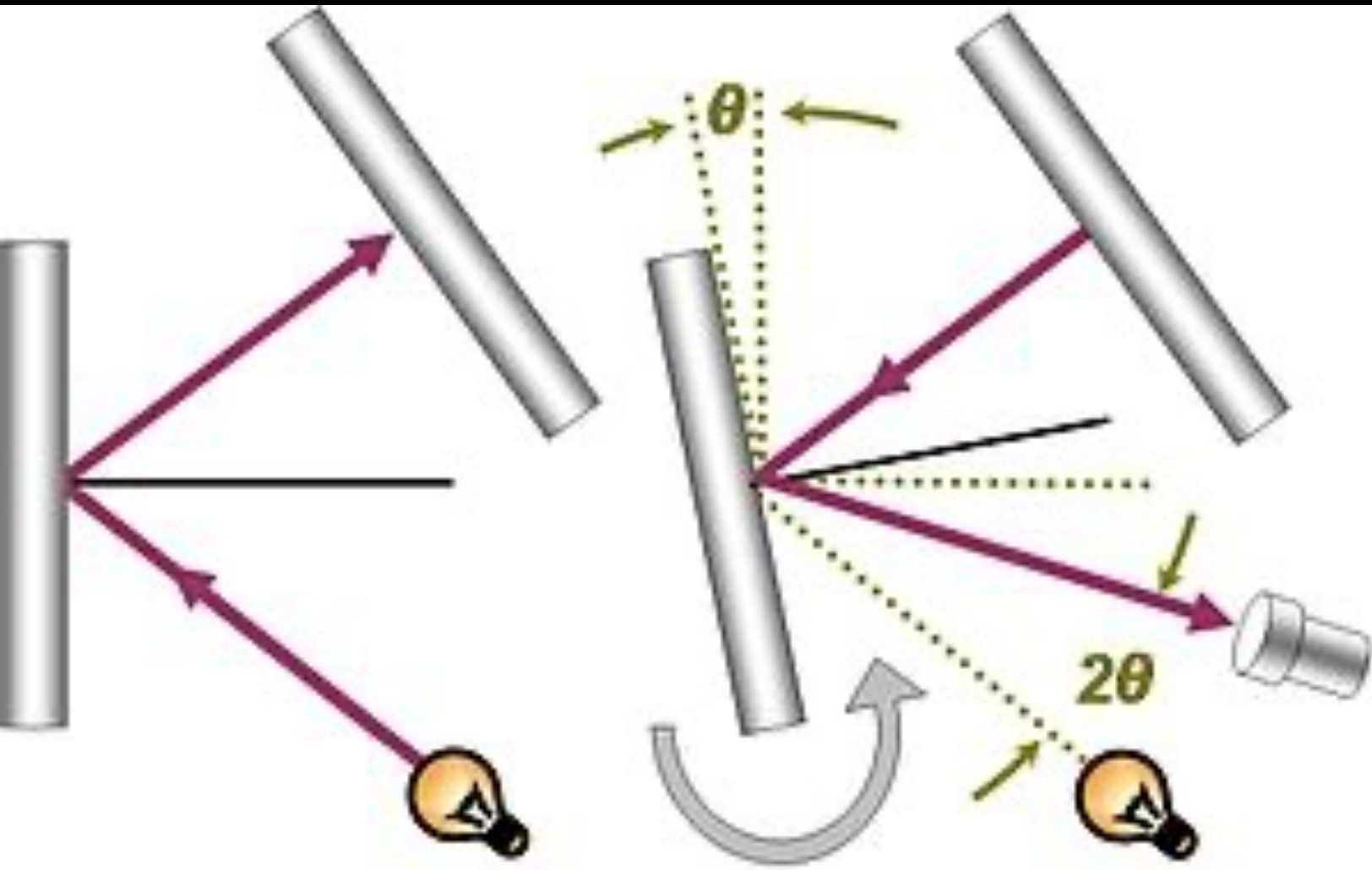


Jean Bernard Léon Foucault (1819 – 1869)

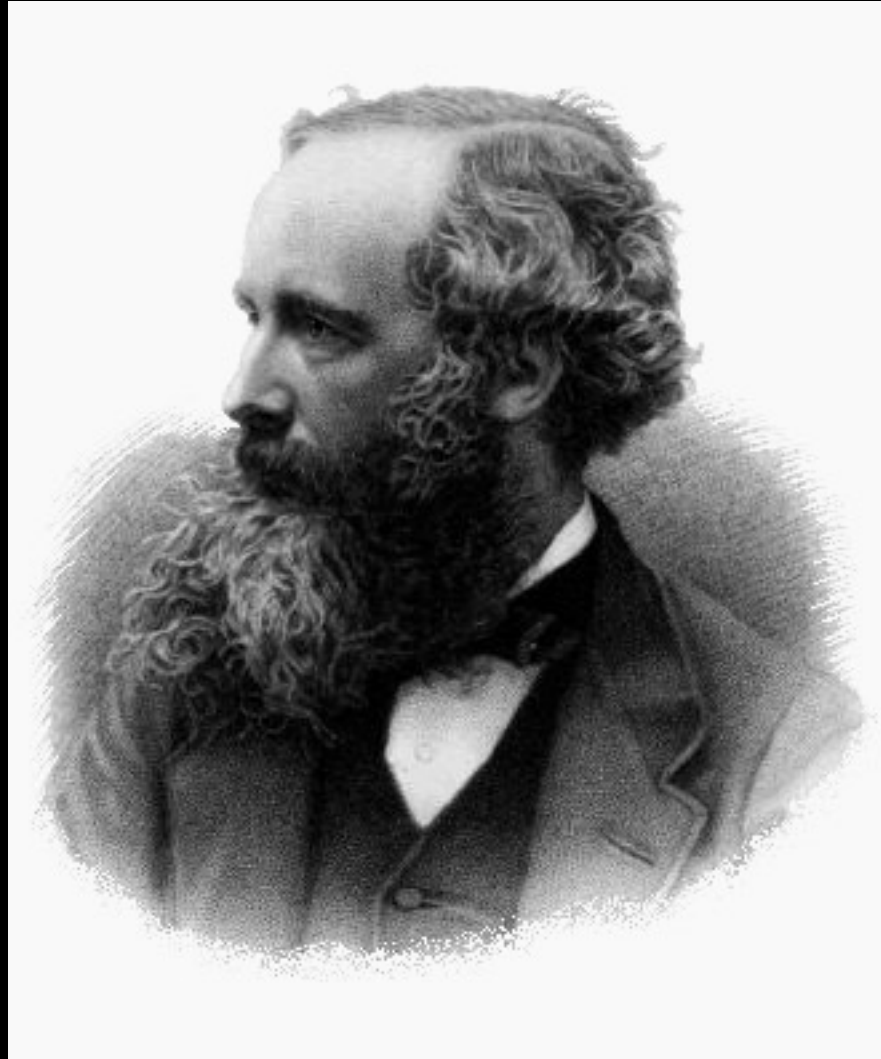


Rotating Mirrors

($c = 298,000 \text{ km/s}$)



James Clerk Maxwell (1831 – 1879)



Electro Magnetism

In 1857 Wilhelm Weber and Rudolf Kohlrausch were the first to show that the ratio of electrostatic to electromagnetic units produced a speed matching the then known value for the speed of light.

Maxwell's theory provided the theoretical model linking the two.

Heinrich Rudolf Hertz (1857 – 1894)



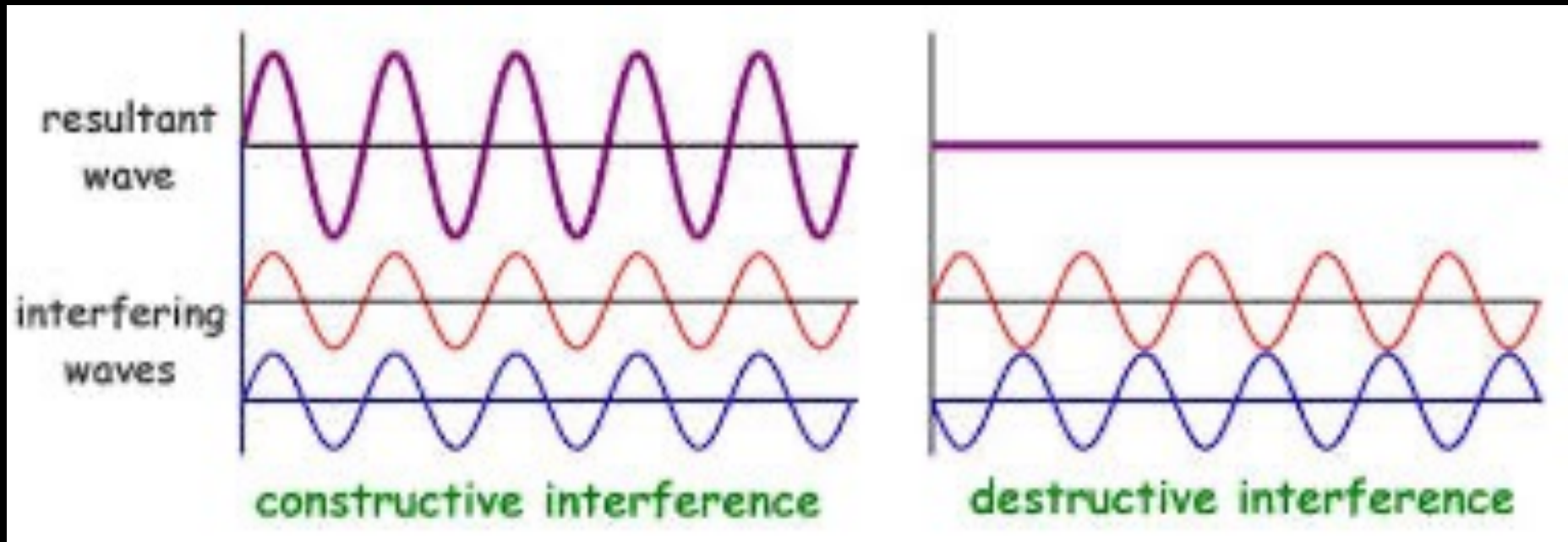
Electro Magnetism

Velocity = Wavelength X Frequency

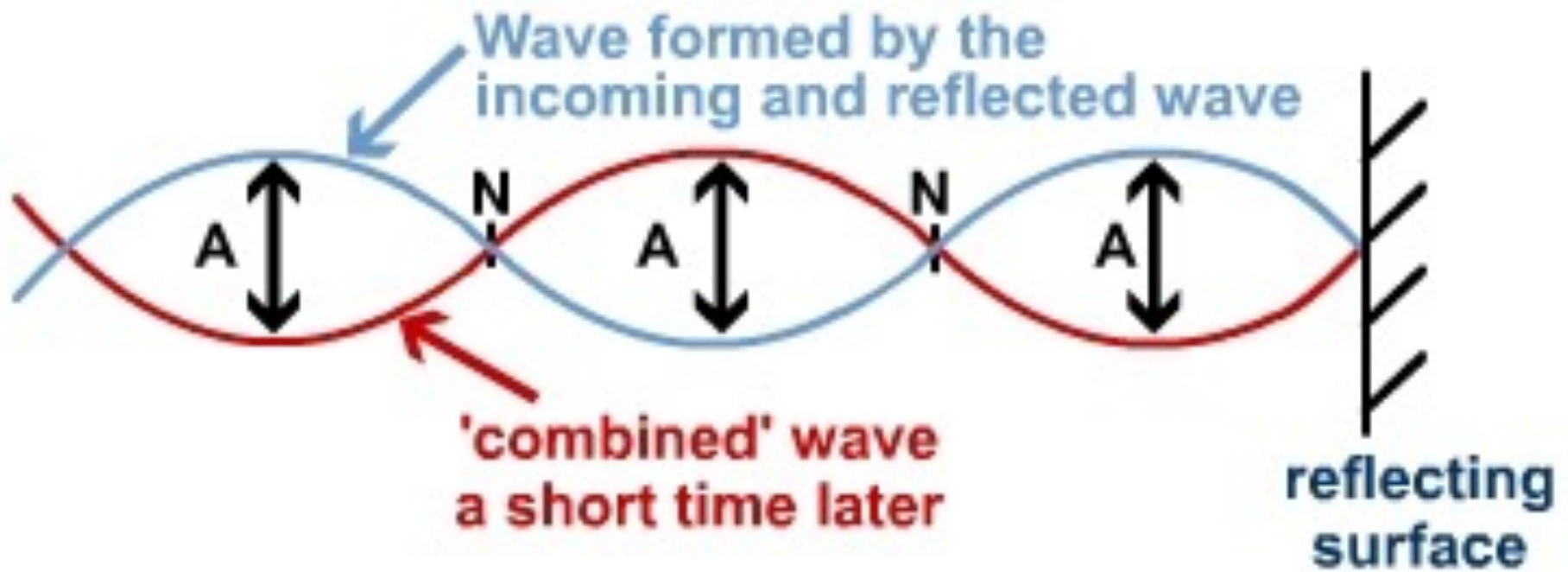
$$C = \lambda \times f$$

Hertz produced radio waves and made simultaneous measurements of the wavelength and frequency

Mixing Waves



Standing Waves



Post Maxwell

Thus after Maxwell linked Electricity, Magnetism and Light there were multiple ways of determining the speed of light which did not involve light beams, spinning mirrors or turning cogs

1638 Galileo: at least 10 times faster than sound

1675 Ole Roemer: 200,000 Km/sec

1728 James Bradley: 301,000 Km/s

1849 Hippolyte Louis Fizeau: 313,300 Km/s

1862 Leon Foucault 299,796 Km/s

Today: 299792.458 km/s

Kitchen Physics

You almost certainly have in your kitchen a means by which you can measure the speed of light.

A microwave oven.

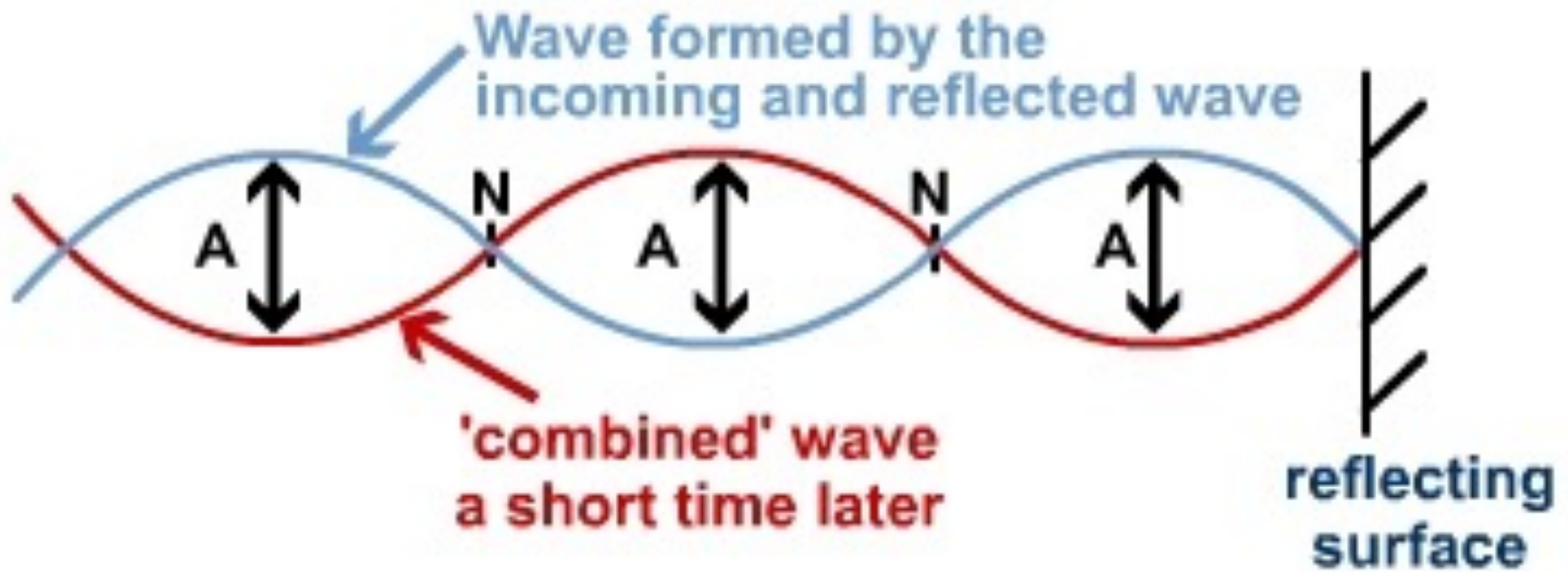
Kitchen Physics

Using a microwave oven with the turntable removed

Heat margarine

It will cook the fastest at the antinodes (the points at which the wave amplitude is the greatest), where it will begin to melt

Standing Waves



Kitchen Physics

The distance between two such spots is half the wavelength of the microwaves; by measuring this distance and multiplying the wavelength by the microwave frequency (usually displayed on the back of the oven, typically 2450 MHz), the value of c can be calculated

Butter (10 seconds)



Kitchen Physics

Measured Standing Wavelength = 6 cms.

Wavelength = $2 \times 6 = 0.12$ metres

Frequency = 2450 MHz

$$\begin{aligned}c &= 0.12 \times 2450 \times 10^6 \\ &= 2.94 \times 10^8 \text{ m/sec}\end{aligned}$$

Actual $c = 2.99 \times 10^8$ m/sec

Kitchen Physics

Less than 2% error!

Not bad for a one eyed
geriatric!

And now

Just in case you thought you
knew it all

This film from Derek Muller
will blow your mind

Muller claims that

No one has measured the
speed of light



And to end

Take a walk in the rain

Who remembers this chap?

