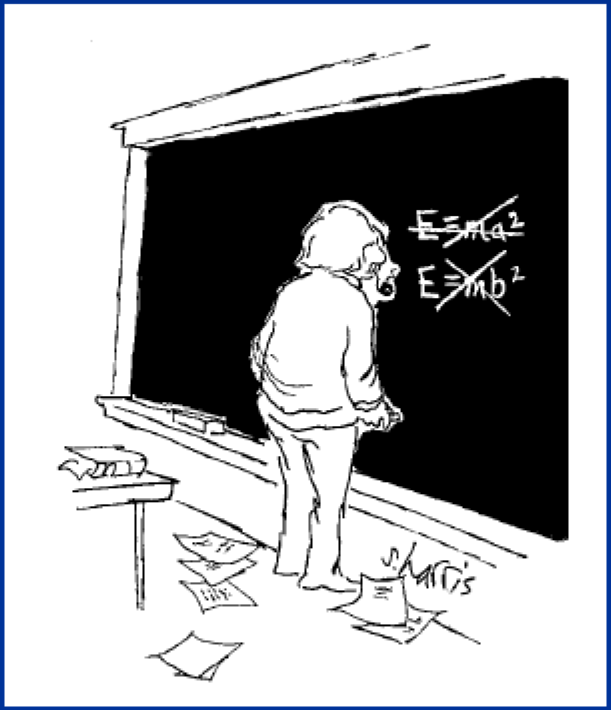
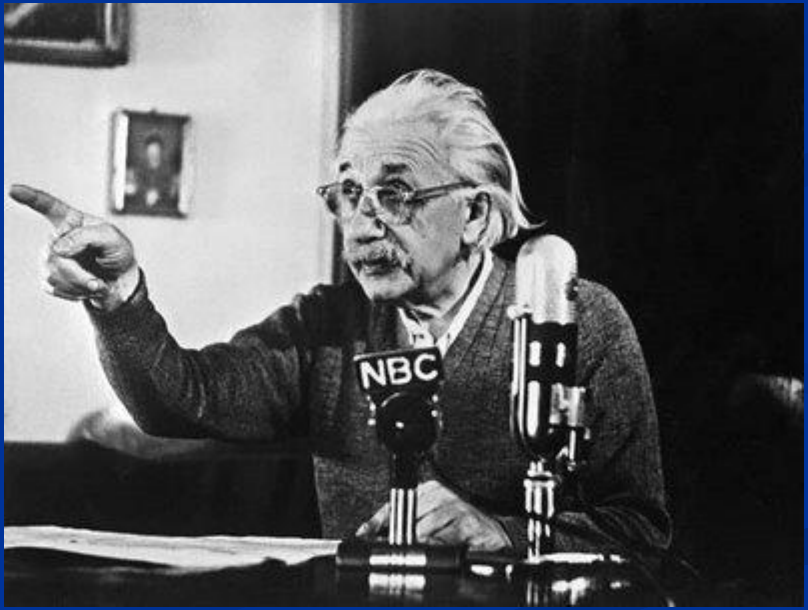
Special Theory of Relativity at 11:10 am





1st Lecture

Phy 207 1.0 – Special Theory of Relativity

Special Theory of Relativity

Min 10 hrs

Detailed

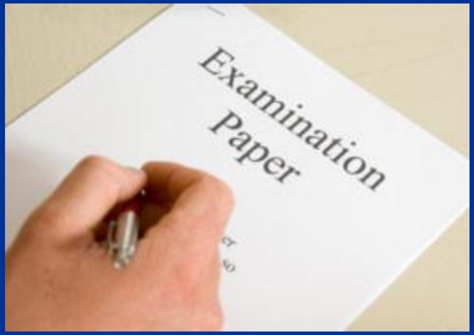
General Theory of Relativity

Min 2 hrs (Max 4 hrs)

Briefly

Phy 207 1.0 – Special Theory of Relativity

Examination Paper



Duration

01 hour

You should Answer

All the Questions

Special Theory of Relativity

Course Contents :

* Introduction to Philosophical Background of Science * Discovery of the speed of Sound * Discovery of the speed of Light * The Concept of the 'Ether' * Michelson – Morley Experiment

* Einstein's Postulates * Measurement of 'Time' and its experimental background * Proper Time * Measurement of 'Length' and its experimental background * Time Dilation and Length Contraction * Doppler's Effect in Relativity

* The Energy Equivalence * Relativistic 'Energy' * Relativistic 'Momentum' * Einstein's Relativistic Energy Equation * Relativistic 'Mass' * Experimental background of the Relativistic Mass * The Twin-Paradox

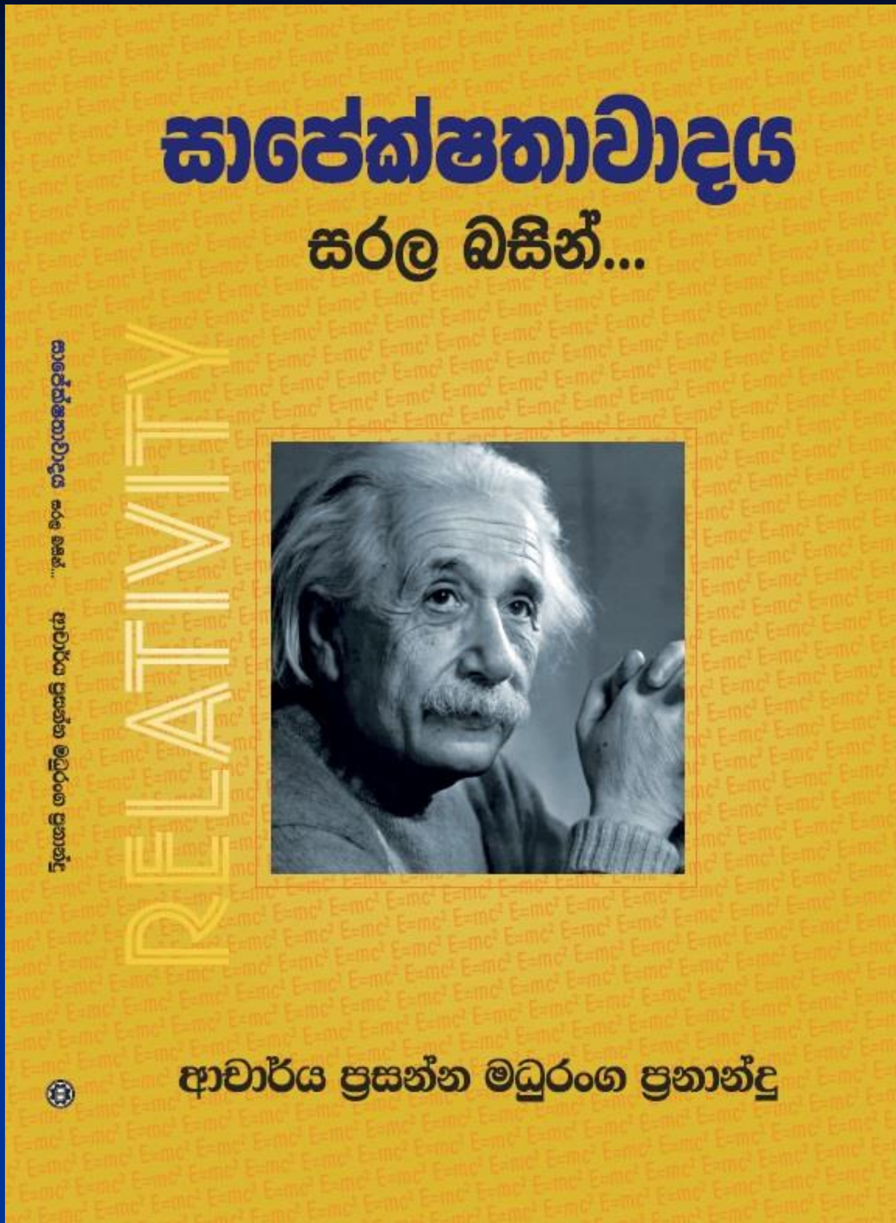
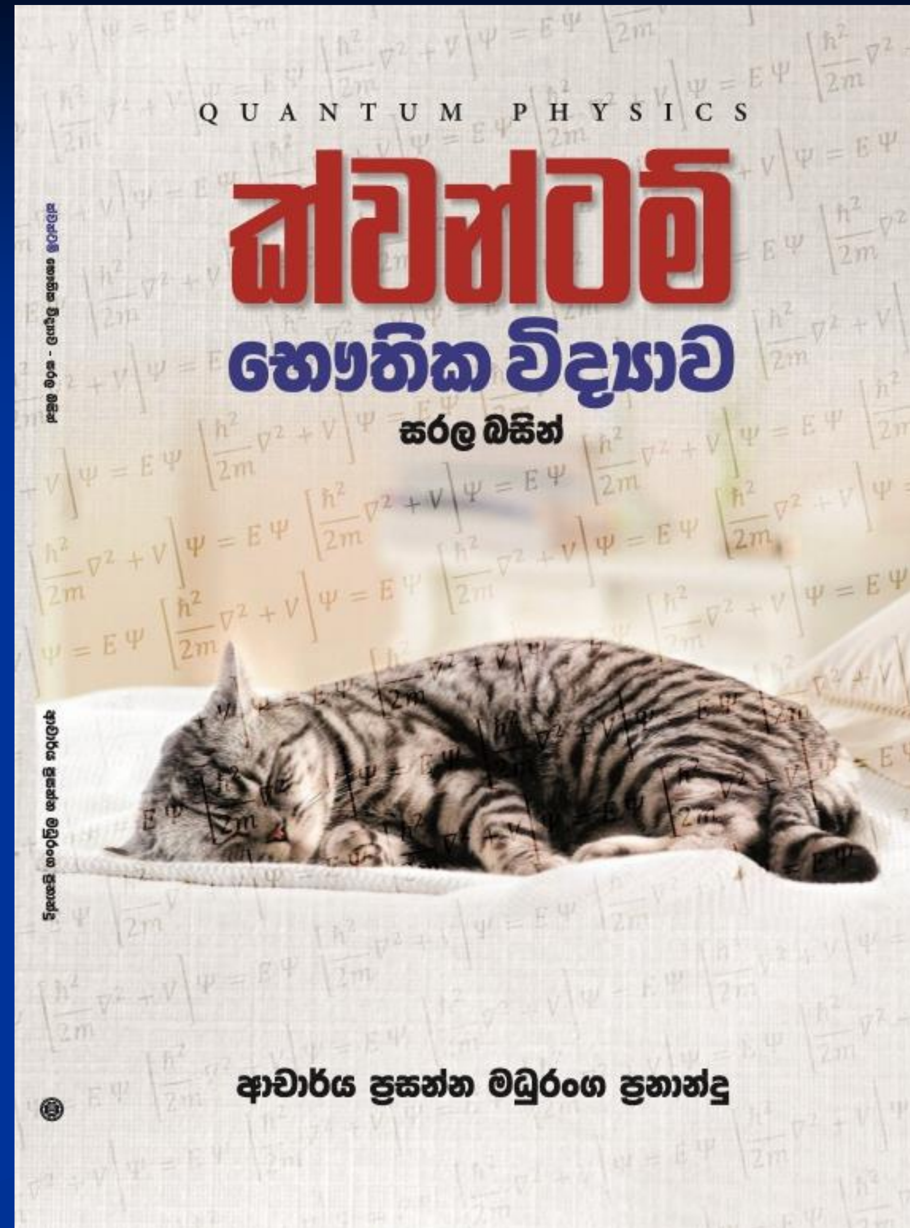
* Transformation Equations * Galilean Transformation Equations * Lorentz Transformation Equations (Time Dilation and Length Contraction) * Lorentz Inverse Transformations Equations * Lorentz Invariants

* Four Vector Spaces * Causality, Experimental evidence * Causality in Eastern and Western Philosophy

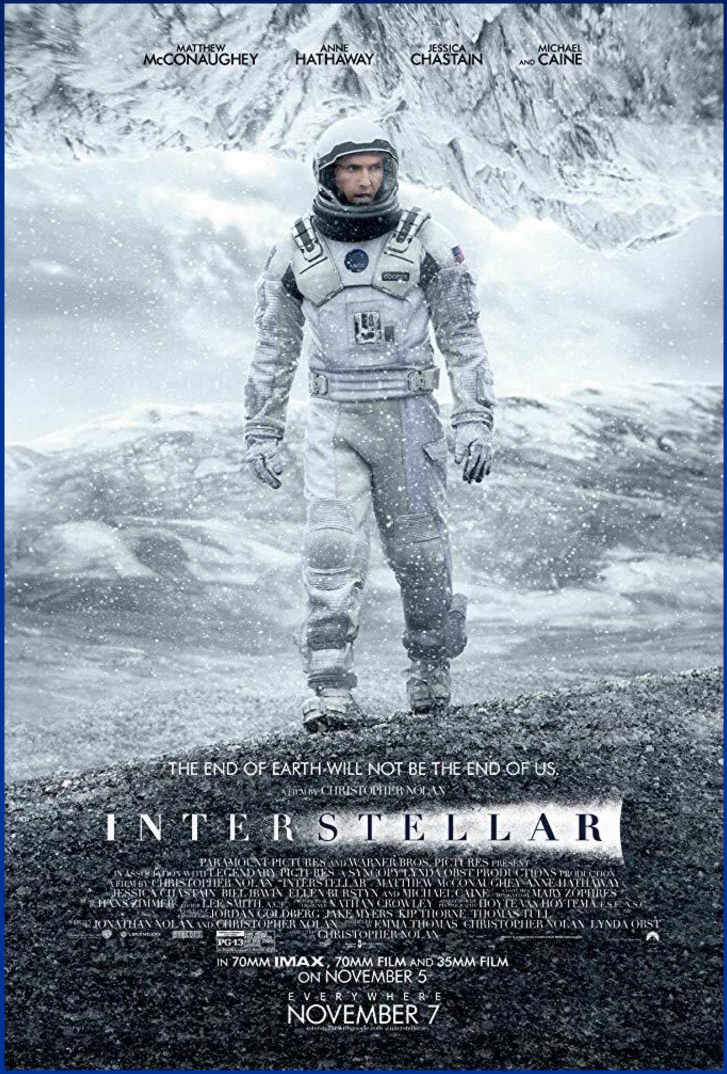
* Brief Introduction to General Relativity

References :

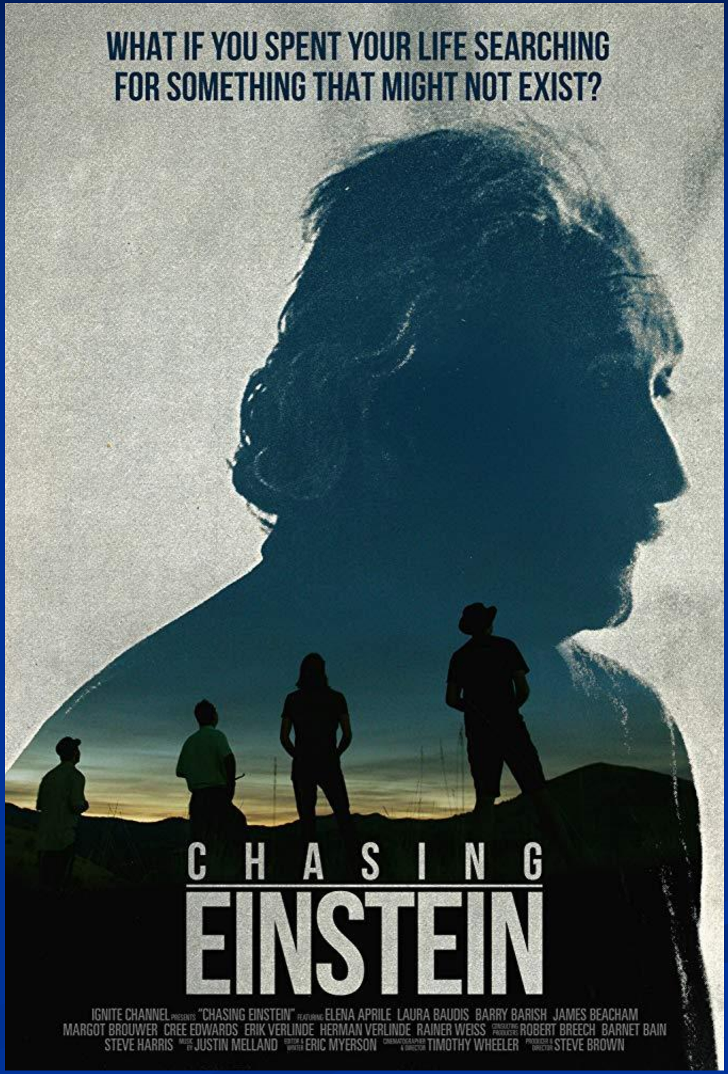
1. *Newton to Einstein – Ralph Baierlein.*
2. *On the shoulders of the Giants – Stephen Hawkins.*
3. *The Brief Introduction of Time – Stephen Hawkins.*
4. *Relativity for the Layman – James A. Coleman.*
5. *Understanding special theory of Relativity – Y. R. Waghmare.*
6. *Testing the Theory of Relativity – Brian Jones & Gerald Laban.*
7. *Elements of Special Relativity – S. P. Singh & M. R. Badge.*
8. *What the Buddha Thought – Rev. Walpola Rahula.*
9. *Special Relativity – A. P. Fench.*
10. *Special theory of Relativity – B. L. Warsnop.*
11. *Special theory of Relativity – David Bohm.*
12. *An Introduction to the special theory of Relativity – Robert Kats.*
13. *Introduction to the special theory of Relativity – James Smith.*
14. *අභිධර්ම මාර්ගය - මහාචාර්ය පූජ්‍ය රේරු කානේ චන්දවිමල.*
15. *අභිධර්මයේ මූලික කරු ණු - මහාචාර්ය පූජ්‍ය රේරු කානේ චන්දවිමල.*
16. *අභිධර්ම සමුච්චය - පූජ්‍ය හේන්පිටගෙදර ඥාණසීහ.*
17. *සූත්‍ර පිටකය (දීඝ නිකාය, මජ්ඣිම නිකාය, සංයුක්ත නිකාය, අංගුත්තර නිකාය හා ඛුද්දක නිකාය)*
18. *සාපේක්ෂතාවාදය, සරල බසින්... – ප්‍රසන්න මධුරංග ප්‍රනාන්දු [Sarasavi Publishing]*


සාපේක්ෂතාවාදය
සරල බසින්...
RELATIVITY
ආචාර්ය ප්‍රසන්න මධුරංග ප්‍රනාන්දු

QUANTUM PHYSICS
ක්වන්ටම්
භෞතික විද්‍යාව
සරල බසින්
ආචාර්ය ප්‍රසන්න මධුරංග ප්‍රනාන්දු

Films based on Relativity :

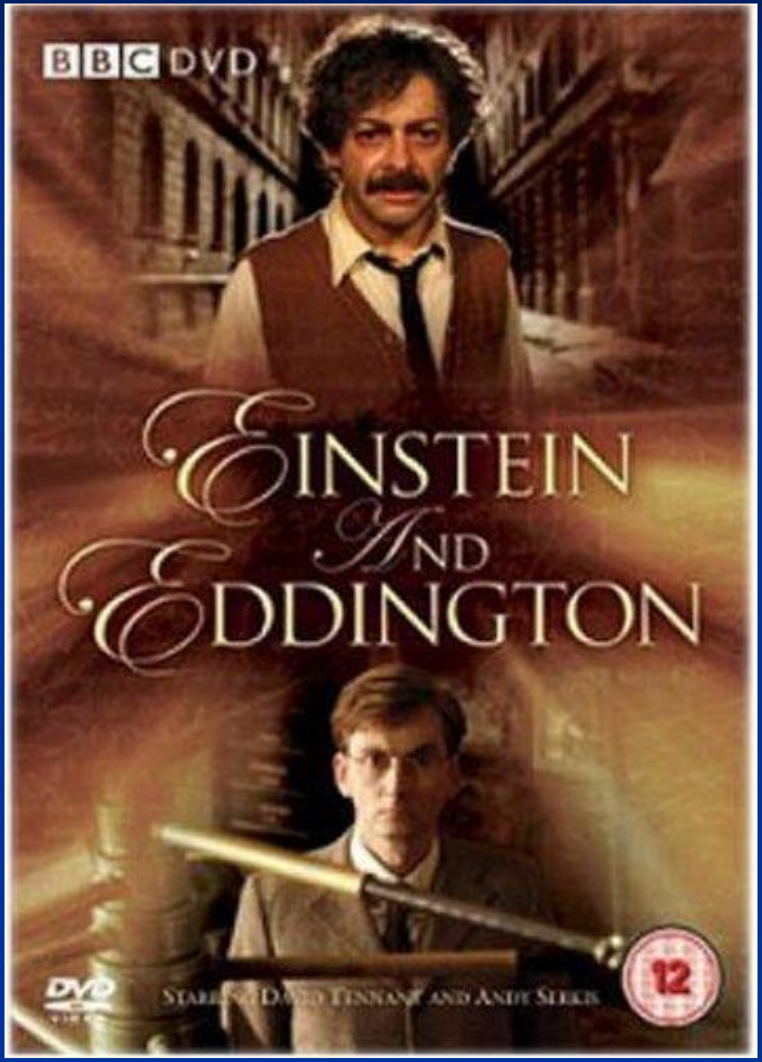


Interstellar (2014)



Chasing Einstein (2019)

Films based on Relativity :



Einstein and Eddington (2008)

Inception (2010)

Relativity :

The **theory of relativity**, or simply **relativity**, encompasses two theories of **Albert Einstein**: Special Theory of Relativity and General Theory of Relativity.

The basic overall concept is that **both time and space are relative**, not fixed.

Relative

Prettiest Woman ?

Relative

Is she tall ???

Relative

Tallest Woman ?

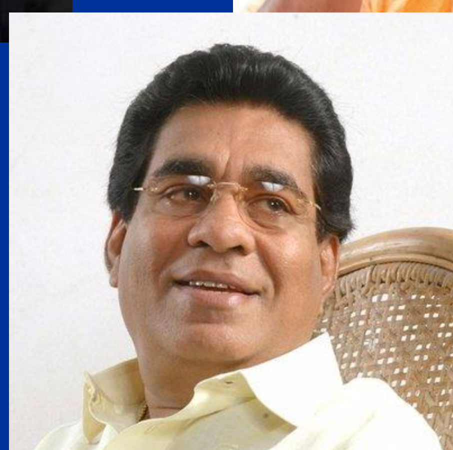
Relative

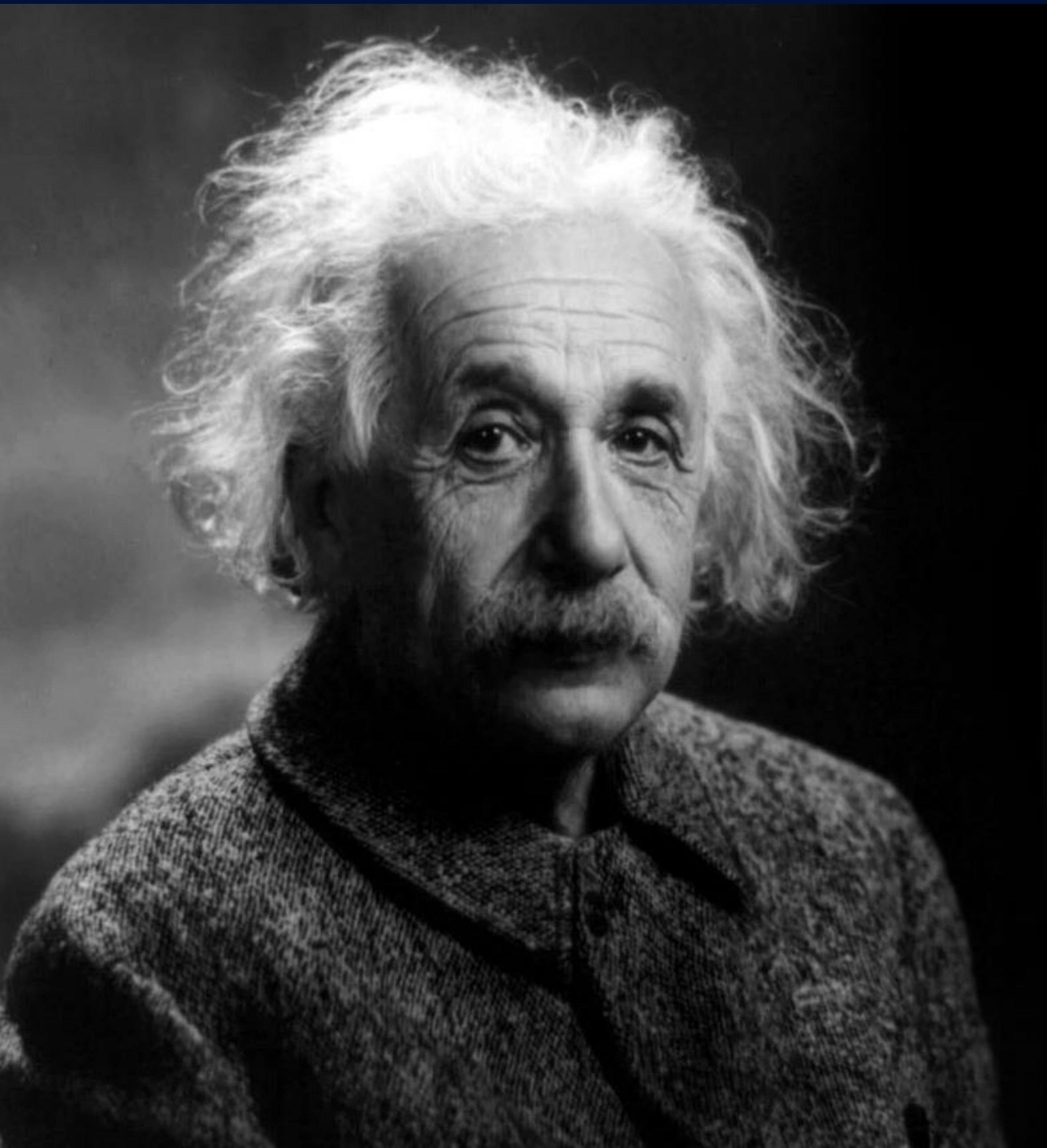
Who is the Greatest Leader ?









"Try not to become a man of success

but rather to become a man of value."

Introduction to Philosophical Background of Science

What is Philosophy ???

Philosophy is the study of general and fundamental problems concerning matters such as existence, knowledge, values, reason, mind and language.

The word " *Philosophy* " comes from the Greek Philosophy, which literally means " *love of wisdom* ".

What is Science ???

Science is just the attempt to understand, explain and predict the world we live in ? (This is certainly a reasonable answer!)

But is it the whole story ? After all, the various religions also attempt to understand and explain the world,

but religion is not usually regarded as a branch of science!!!

Similarly, astrology and fortune-telling are attempts to predict the future, but most people would not describe these activities as science!!!

Science ???

Experiment

Observation(s)

Conclusion(s)

Interpretations

Oil Exploration

Find Sedimentary Basins using the interpretation of (satellite) gravity anomalies!

Scientific reasoning

Scientists often tell us things about the world that we would not otherwise have believed.

For example,

biologist tell us that we are closely related to chimpanzees,

geologists tell us that Africa and South America used to be joined together and

cosmologists tell us that the Universe is expanding.

Explanation in Science

One of the most important aims of Science is to try and explain what happens in the world around us. Sometimes we seek explanations for practical ends.

For example,

we might want to know, why the Ozone Layer is being depleted so quickly, in order to try and do something about it.

In other case we seek scientific explanations simply to satisfy our intellectual curiosity – we want to understand more about " how the world works ".

Quite often, modern science is successful in its aim of supplying explanations.

For example,

Chemists can explain why sodium turns yellow when it burns.

Astronomers can explain why solar eclipses occur when they do.

Geneticists can explain why male baldness tends to run in families.

Neurophysiologists can explain why extreme oxygen deprivation leads to brain damage.

You can probably think of many other examples of successful scientific explanations!

Realism & Anti - realism

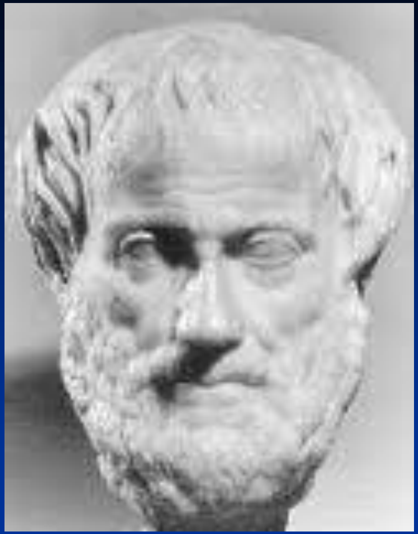
Realism :- Representing or viewing things as they are in reality.

Anti-realism :- opposite to realism

Realism holds that the physical world exists independently of human thoughts and perception.

The Greek philosopher Aristotle

(384BC – 322 BC)



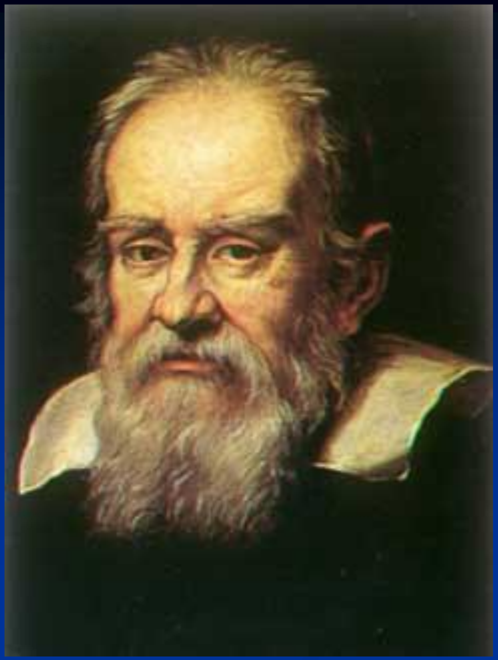
The dynamics of Aristotle :

He believed that objects only moved as long as they were pushed,

Thus objects on the Earth stopped moving once applied forces were removed,

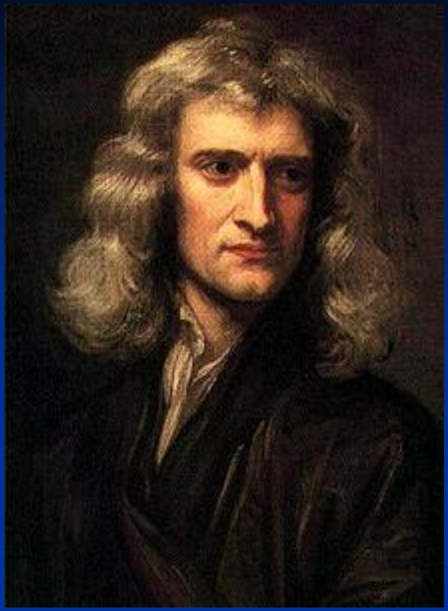
and the heavenly spheres only moved because of the action of the Prime Mover, *who continually applied the force to the outer spheres that turns the entire heavens*.

The Italian physicist **Galileo Galili** (1564 – 1643)



Galileo's concept of **inertia** was quite contrary to Aristotle's ideas of motion : in Galileo's dynamics the arrow (with very small friction forces) continued to fly through the air because of the law of inertia, while a block of wood on a table stopped sliding once the applied force was removed because of frictional forces that Aristotle had failed to analyze correctly.

The English physicist Isaac Newton (1643 – 1727)



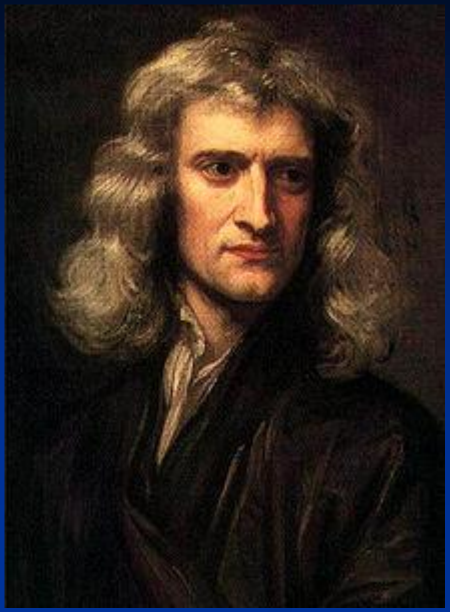
Newton had new ideas about motion, which he called his three laws of motion.

Newton's First Law of Motion :

An object at rest will remain at rest unless acted on by an *unbalanced force*. An object in motion continues in motion with the same speed and in the same direction unless acted upon by an unbalanced force.

The law is often called " *The Law of Inertia* "

Newton's Second Law of Motion :



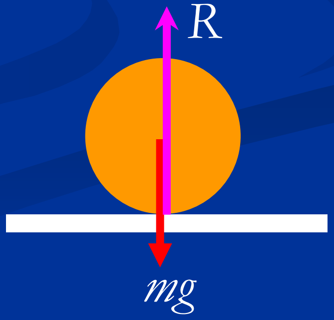
Acceleration is produced when a force acts on a mass.

However, the second law gives us an exact relationship between force (F), mass (m) and acceleration (a). It can be expressed as a mathematical equation;

$$\boxed{F = m\ a}$$

Newton's Third Law of Motion :

For every action there is an equal and opposite re-action.



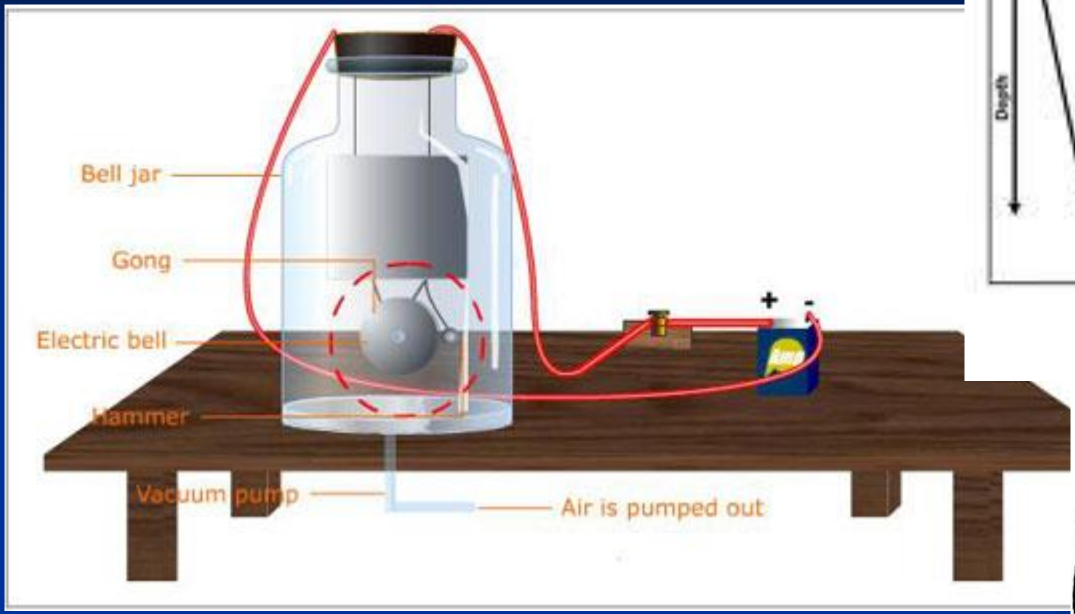
Discovery of Speed of Sound

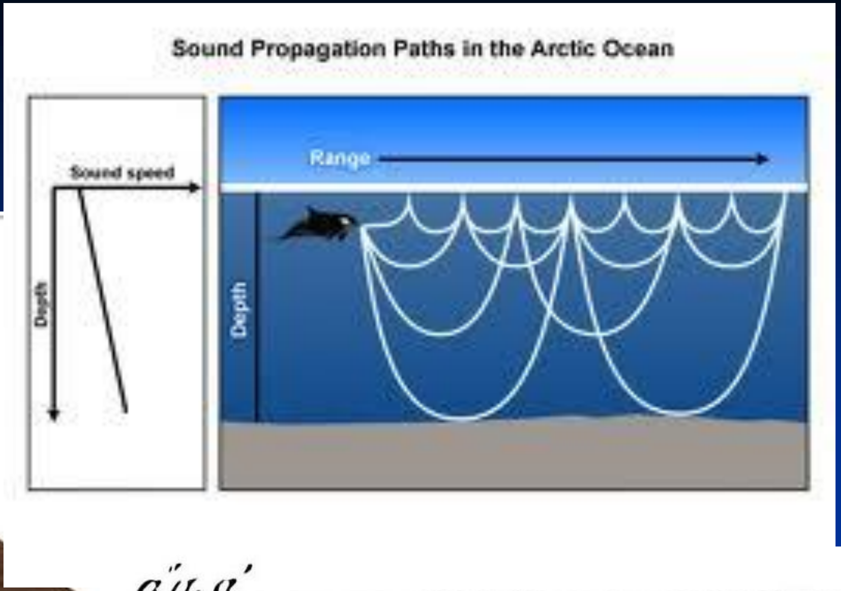
Mersenn's measurement of the speed of sound (1588-1648)

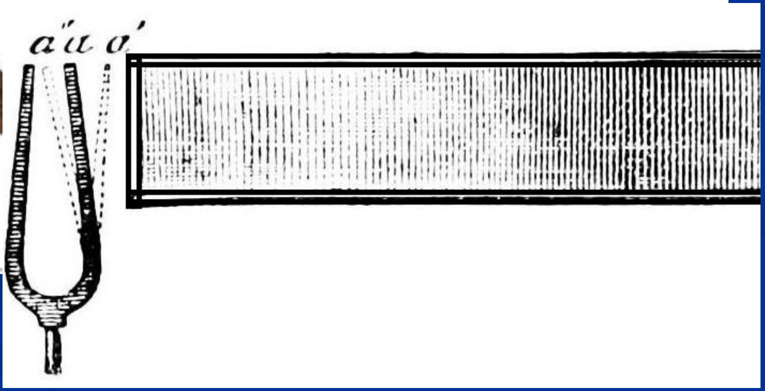
Mersenne set up a cannon (a big gun) several miles distant from him and has his assistant fire it. From his observation post he measured the length of time it took the noise of the blast to reach him after he saw the flash, by counting the swings of a pendulum during this time. [A swinging pendulum was used to measure the intervals since stop-watches were not yet is use.]

His result was approximately 700 miles an hour (311.11 m/s). [Exact value is ~ 750 miles an hour (333.33 m/s).]

Propagation Media of Sound







It was discovered by scientists in that period, media of propagating of sound is normal air (or liquid or solid).

Sound is a sequence of pressure which propagated through compressible media such as air (or liquid or solid).

Discovery of the Speed of Light

A scientist **Descartes** (1569-1650) clamming it to be infinite, ∞ !

Galileo (1564-1632) clamed the velocity of light to be finite !

Galileo's attempts to measure the speed of Light

He equipped himself and an assistant with lanterns that had shutters that would open, letting the light out. His assistant stood on a hill several miles away. Galileo opened the shutter, letting a beam of light travel towards his assistant. That person opened his lantern the instant he saw the light, sending a beam back to Galileo.

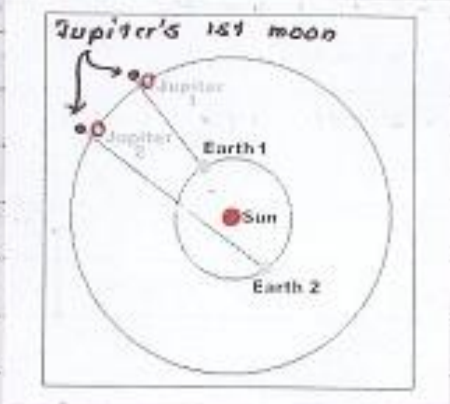
The time lag between Galileo's first opening the shutter, and eventually seeing the return beam, was supposed to enable him to calculate the speed of light.

Unfortunately, after repeating the experiment a number of times at different distances, he discovered that the time lag did not change!

Roemer's Astronomical Method

Failed

Later in the 1600's, another scientist, an astronomer by the name of Roemer was observing eclipses of Jupiter's moons. By watching the moons circling Jupiter through a telescope, he was able to observer the exact time that the moon moved behind Jupiter. After many years of observations, however, he noticed that the time intervals between eclipses were not always the same. He immediatedly figured out the reason. Here is what he relized



The light from the eclipsing moon sometimes took a relatively short time to reach earth (position 1).

Reference

Roemer's Astronomical Method

At another time during the year, however, (position 2) when earth was in a farther part of its orbit, the light from Jupiter's moon would take longer to reach earth.

This caused the interval between eclipses to lengthen.

Romer was able to use the time difference and the diameter of Earth's orbit to calculate the speed of light. He determined it to be about 185,000 miles per second, or 296,000 kilometers per second, very close to the actual value.

Reference

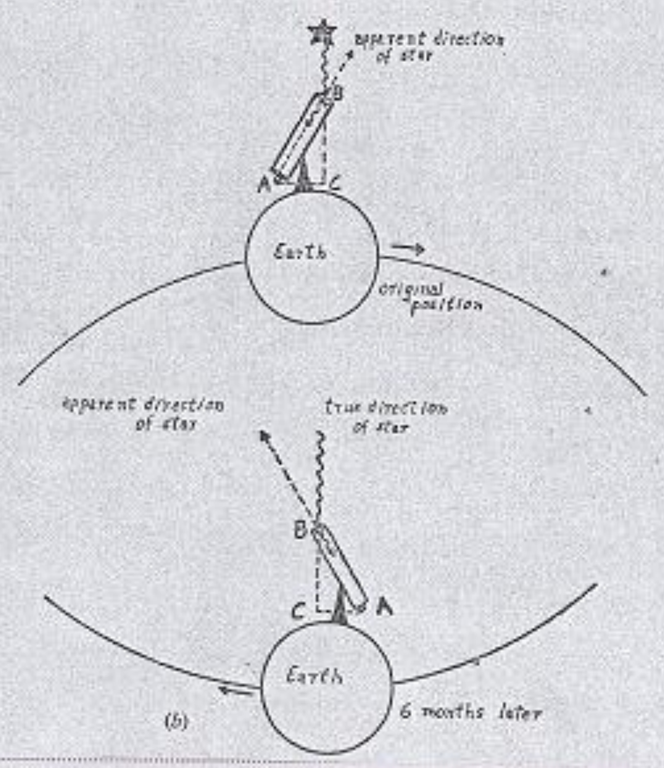
Bradley's Telescope Method

Failed

Approximately 50 years later, in 1728, the noted British astronomer James Bradley (1693–1762) made an entirely type of astronomical observation from which he was able to calculate the speed of light. This experiment involved the observation of a star using a telescope with its axis set perpendicular to the plane of the earth's rotation. It was found that in order to compensate for the speed of the incident light, the telescope's axis would have to be tilted through a small angle in the direction in which the earth is traveling. The amount of telescope tilt required allowed Bradley to calculate the speed of light, which he found to be 301,000 kms^{-1}

Reference

Bradley's Telescope Method



Bradley's method is illustrated in the above figure. We will assume we have a telescope and want to look at a distant star. If we want to see the star through the telescope, we must aim it so that the light coming from the star 'falls' down through the telescope barrel and hits our eye at the viewing end.

Reference

Bradley's Telescope Method

If the earth were stationary in space and did not move in an orbit, we would point the telescope straight up at the star and its light rays would 'fall' straight down through the centre of the telescope.

But we know that the earth does move in its orbit around the sun with a velocity of about nineteen miles a second. Hence, the actual situation is as shown and the telescope must be tilted so that when the light waves from the star enter the telescope at B, they will travel down the centre of the barrel and meet the eye at A. While the light waves are going from B to C, the observer (and telescope) will move from A to C, since he is on the moving earth.

We can not compute the velocity of the incoming light waves. And we do not know that the star is directly overhead. Since we see it in the aimed telescope, it looks as if the star is in the direction the telescope is pointing, i.e. along the line AB extended. This is the situation that existed up to Bradley's time. No one ever dreamed that a star could be in any other direction but that in which the telescope pointed.

Reference

Bradley's Telescope Method

But Bradley noticed that six months later the same star appeared to be in a different direction in the sky. He called the phenomenon aberration and explained it as we have done, asserting that the velocity of light must be finite as a consequence. He used the star Gamma Draconis and found that the variation in its direction over the appropriate six-month period was about forty seconds of arc, or about one ten-thousandth of a right angle. This told him that the angle of tilt was about twenty seconds of arc from the vertical. Then, knowing the angle of tilt, he constructed the right triangle ABC and computed the velocity of light. Here, similarly,

Reference

Bradley's Telescope Method

the velocity of light equals the product of the earth's orbital velocity and the ratio of the sides BC to AC.

Bradley's result wasn't too accurate, but his method was important because it lent greater credence to the fast-growing belief that the velocity of light certainly was finite even though it was as great as 186,000 miles a second.

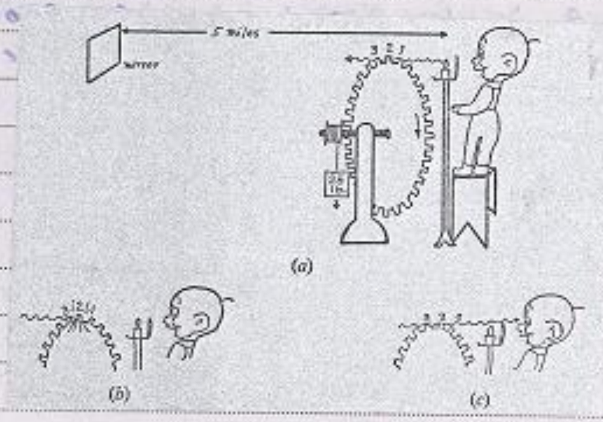
Reference

Fizeau's Terrestrial Method

Failed

Reference

The first determination of the velocity of light which didn't use astronomical methods was made by Fizeau in 1849. He supplied what was lacking in Galileo's attempt, i.e., the accurate measurement of the small interval of time it took a light beam to cover a relatively short distance on earth.



His method is illustrated schematically in the above figure, showing a cog-wheel being turned by a weight and pulley arrangement (there being no electric motors in Fizeau's day). The candle is the source of light waves whose velocity is to be measured while they run a course from the candle to a mirror five miles away and back again.

Fizeau's Terrestrial Method

If we first assume the wheel is not moving, then light from the candle will go between cogs 1 and 2, will travel the ten-mile round trip from the cog-wheel to the mirror and back, then go through the same opening between the cogs, and will be seen by the eye behind the candle. But now suppose the wheel is moving as shown in fig (a). Then the beam from the candle will be chopped up by the cogs as they pass before the candle, in the same way as a meet slicer slices bologna. The result will be a series of pieces of light or individual beams sent towards the mirror, their exact length depending on how fast the wheel is rotating; the faster it rotates, the shorter the beams. (Only the beam that originally starts out between cogs 1 and 2 is shown in the drawings for simplicity)

Fizeau's Terrestrial Method

Now consider what happens when this beam arrives back at the wheel after travelling the ten-mile round-trip to the mirror. If the wheel is rotating slowly, the light beam will arrive while cog 2 is in front of the candle, as in fig (b), and will not get through the space between the cogs to hit the eye beyond the candle. Hence, the observer will not see it. But if the wheel is rotating fast enough, cog 2 will be out of the way by the time the beam returns, as in fig. (c), and the beam will be able to pass between cogs 2 and 3 to be seen by the observer.

This is exactly what Fizeau did. Starting with his wheel at rest, he gradually increased its speed until he saw the reflected light coming through the spaces between the cogs. He then know that the light beam travelled ten miles in the time interval it took for one space between two cogs to be replaced by the next one. He computed this short time interval by

Reference

Fizeau’s Terrestrial Method

measuring the speed of rotation of his wheel
and knowing the number of cogs in the wheel.
Then he divided the total distance the beam had
travelled by the time interval and obtained
194, 600 miles a second for the speed of light –
a result about 5 per cent too high, but quite
accurate considering the limitations of his
equipment.

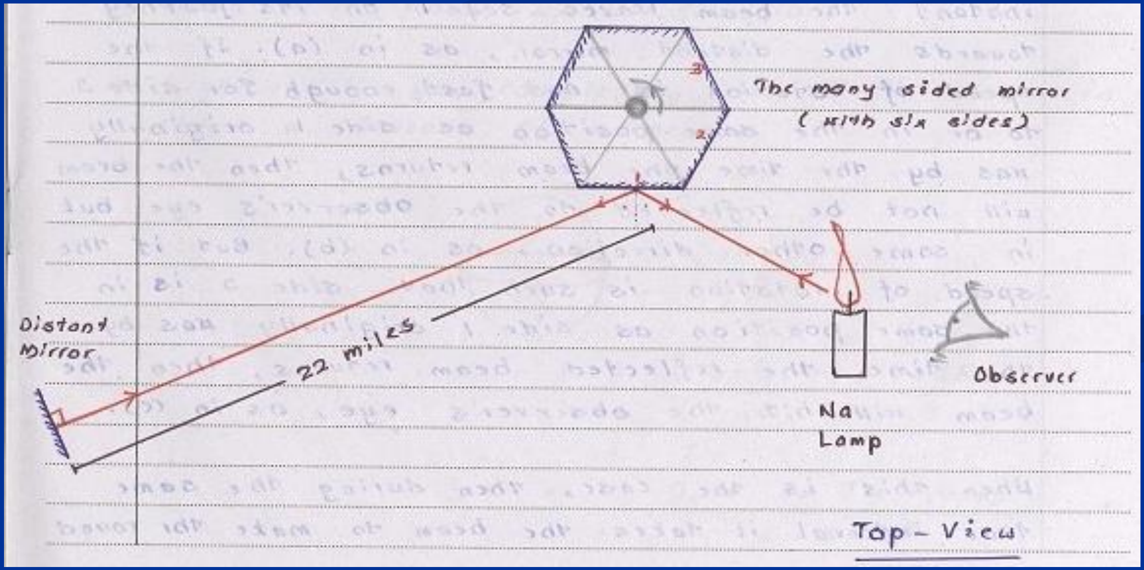
Reference

Michelson's Precise Method

The most widely known measurement of the velocity of light is that performed by Michelson (1852 - 1931) in 1879.

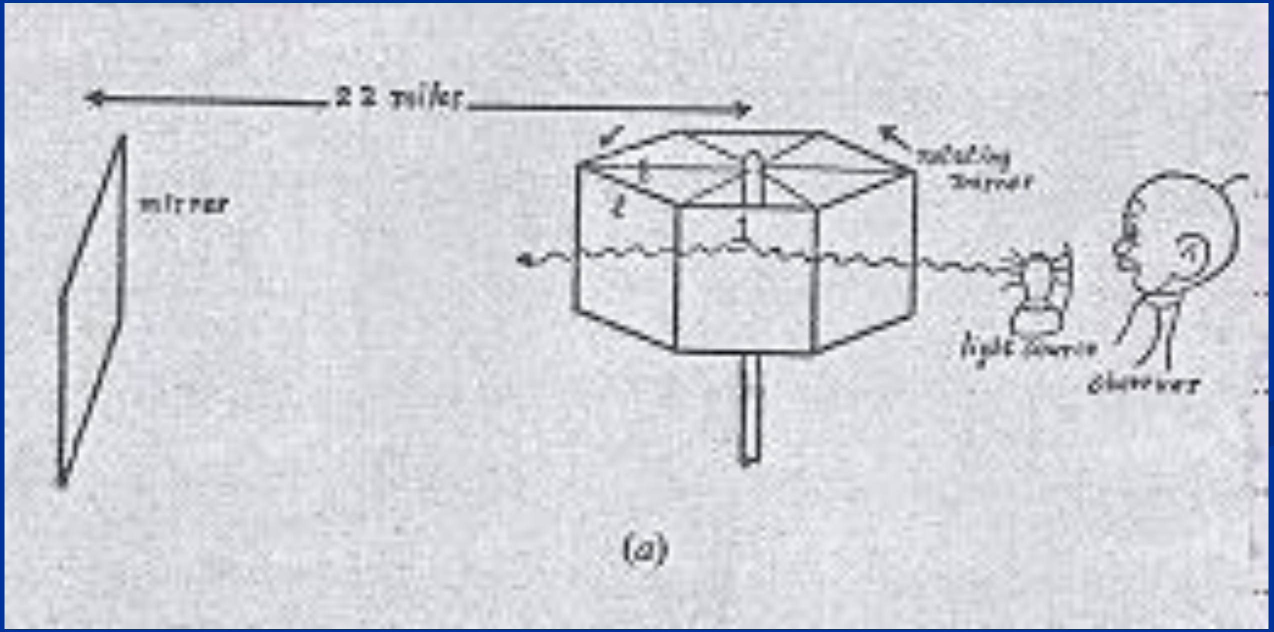
Michelson perfected the revolving mirror method. This is some what similar to Fizeau's cog-wheel but uses a rotating, many- sided mirror to chop up the original light wave into individual beams which, like Fizeau's are sent to a distant mirror (here 22 miles away!) and back again (see following figure).

The many-sided mirror is represented by one with six sides and can be rotated at any desired speed with an electric motor.

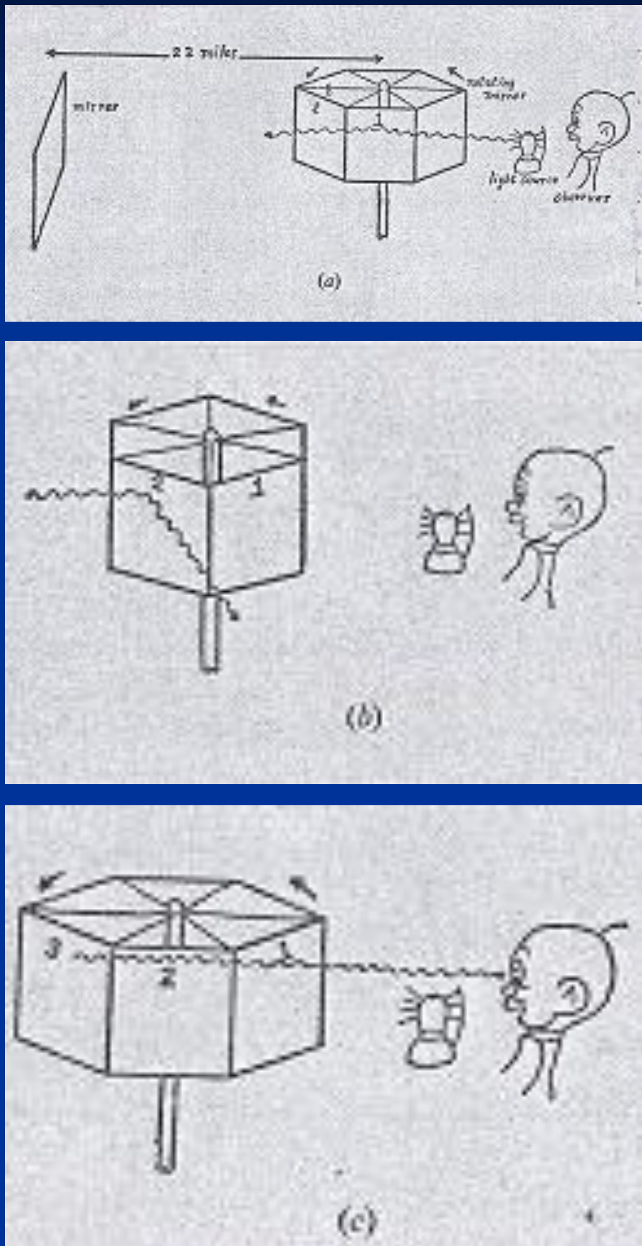


Michelson's Precise Method

We first consider that would happen if the mirror was not rotating and set at position (a). Light would leave the light source and hit side 1, from which it would be reflected to the distant mirror. Upon reflection there, it would return via the same general path, hit side 1 again, and would be seen by the eye near the lamp as it returned towards the general direction of the lamp.



Michelson's Precise Method



But now suppose, as happens in the actual experiment, that the mirror is rotated at the instant the beam leaves side 1 on its journey towards the distant mirror, as in (a). If the speed of rotation is not fast enough for side 2 to be in the same position as side 1 originally was by the time the beam returns, then the will not be reflected to the observer's eye but in the some other direction, as in (b). But if the speed of rotation is such that side 2 is in the same position as side 1 originally was by the time reflected beam returns, then the beam will hit the observer's eye as in (c).

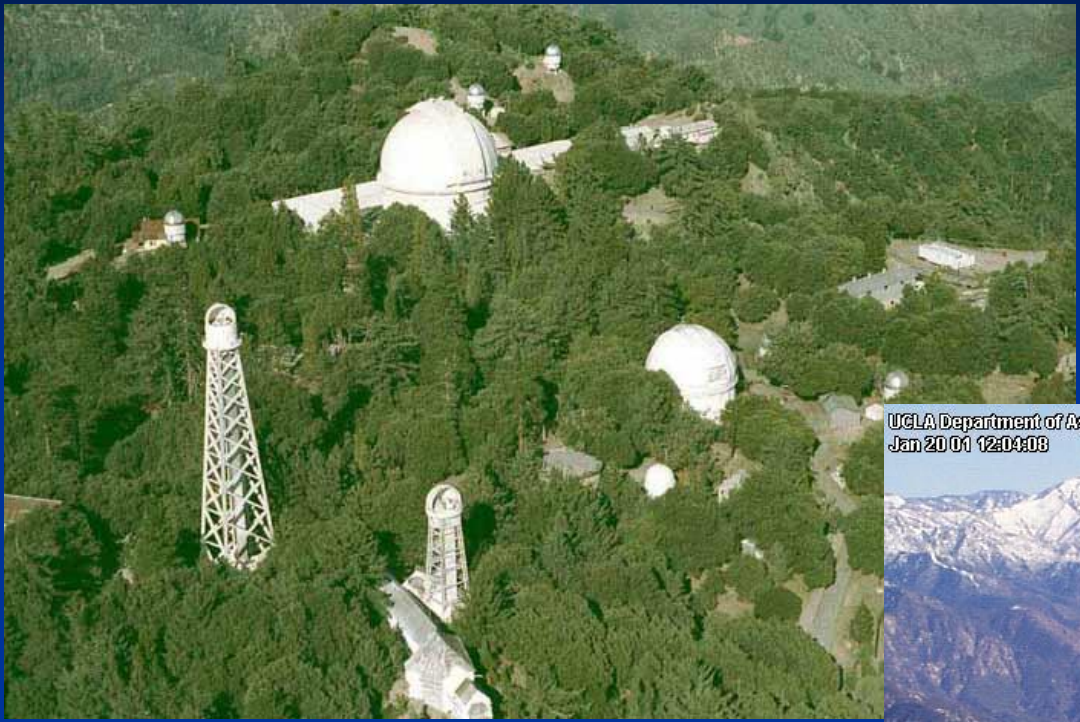
Michelson's Precise Method

When this is the case, then during the same time interval it takes the beam to make the round trip to the distant mirror and back, the rotating rotates by a sixth of a rotation. Further, since the speed of rotation of the mirror is known, the time for one revolution is known, and one sixth of this is the time it takes for the light beam to make its round-trip. Dividing the round trip distance by this time interval gives the velocity of light.

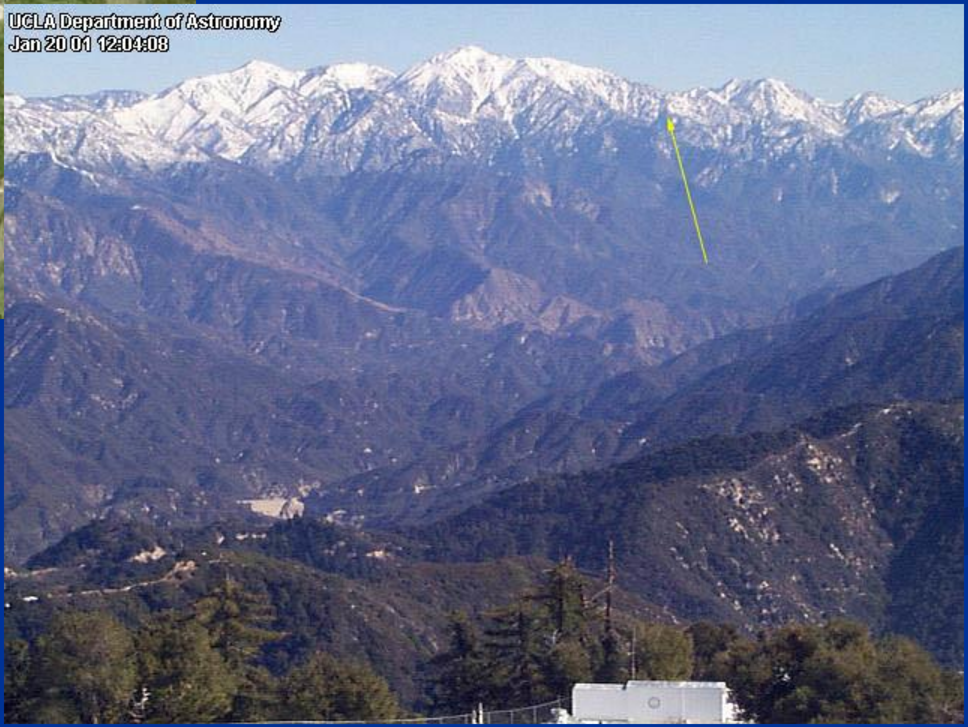
In Michelson's actual experiment various rotating mirrors of 8, 12 and 16 sides were used. This apparatus was set up on Mount Wilson in California. The mirror system comprising the distant mirror was set up on Mount San Antonio, approximately 22 miles away.

As a result of this and Michelson's subsequent experiments, the velocity of light is approximately **186,000 miles a second**.

Michelson's Precise Method



Mount Wilson in California



Mount San Antonio

Thank You!