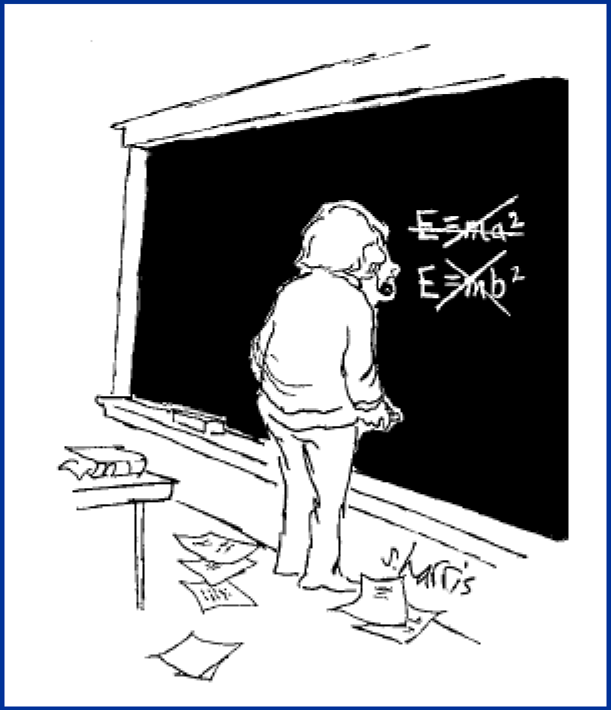
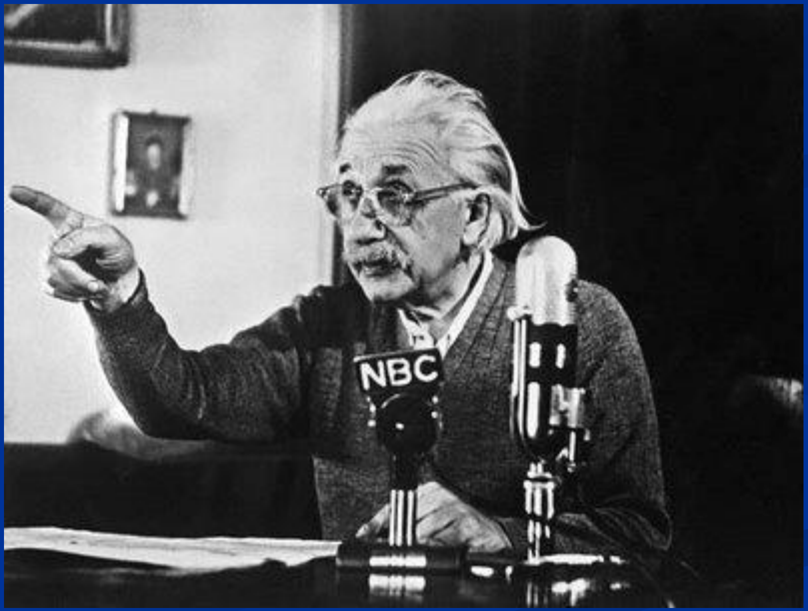
Special Theory of Relativity





11th Lecture

General Theory of Relativity

Brief Introduction to General Theory of Relativity

The principle of equivalence at a single point in space effects of **gravitation and accelerated motion are equivalent** and **cannot be distinguished** from each other.

Newton's Law of Universal Gravitation :
Corrected formula by Einstein, should be in the following equation;

$$F = G.\frac{m_1 m_2}{d^{2.00000016}}$$

Radiation pressure :
Radiation pressure is the **pressure** associated with the interaction of electromagnetic **radiation** on any given surface. In other words **Radiation pressure** is defined as **force per unit area exerted by electromagnetic waves**.

Brief Introduction to General Theory of Relativity

Radiation pressure : $P_r = \frac{\text{Force}}{\text{Area}}$ ➡ $\frac{\frac{\partial p}{\partial t}}{A}$

Where momentum : $p = \frac{\mathcal{E}}{c}$

And Plank Law : $\mathcal{E} = h f$

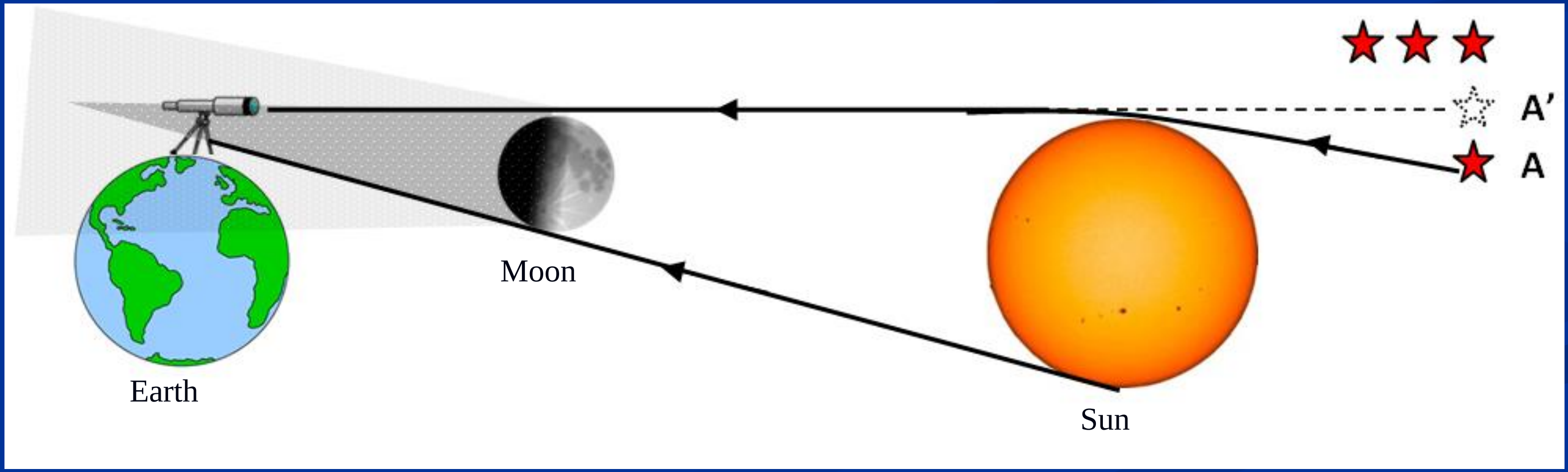
or

$\mathcal{E} = \hbar \omega$

Radiation pressure : $\frac{1}{Ac}\frac{\partial \mathcal{E}}{\partial t}$

Effect of a Gravitational Mass on a light beam - <u>weighing a Beam of light</u>

There are no intervening gravitational masses, so the star's light travels in a straight line from the star to the observer on the Earth. Later on, the earth has travelled sufficiently far in its orbit so that the sun comes between the earth and the star in such a position that the light from the star just grazes the sun's surface on its way to the observer on the earth as in the following figure.



Incoming light beam is bend sun's mass

Effect of a Gravitational Mass on Time (Slowing Down of atomic clocks on the Sun and stars

Another result of the General Theory is the **effect of a gravitational mass on time**. The prediction is that all time processes will be slower on a large mass than on a small mass, or that

time will move more slowly on a relatively larger planet, such as Jupiter, than on Earth.

Although a clock which runs at a certain rate on the Earth will run slower on Jupiter, it will run even slower on the Sun.

Indeed, Einstein found that a second of time on the Sun should correspond to 1.000002 Earth seconds.

Effect of a Gravitational Mass on Time (Slowing Down of atomic clocks on the Sun and stars

To measure this slight difference, literally speaking, we would have to **put a clock on the Sun, synchronize it with one just like it on the Earth, and then periodically compare the two.** With the difference in time rates indicated, **the Sun clock would be one second behind the Earth clock after 500,000 seconds**, or **after just under six days**. Of course, we have no way of putting a clock on the Sun; but we do not have to, since we have many 'atomic clocks' there already.

Atomic clock

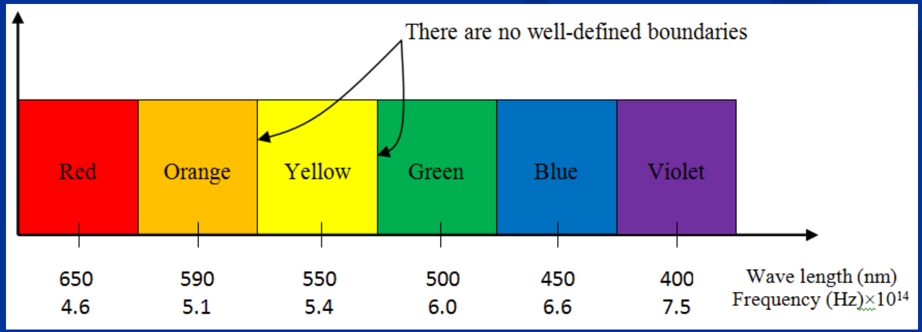
An atomic clock is a clock device that uses an electronic transition frequency in the microwave, optical, or ultraviolet region of the electromagnetic spectrum of atoms as a frequency standard for its timekeeping element.

Atomic clocks are the most accurate time and frequency standards known, and are used as **primary standards for international time distribution services**, to control the wave frequency of television broadcasts, and in global navigation satellite systems such as GPS.

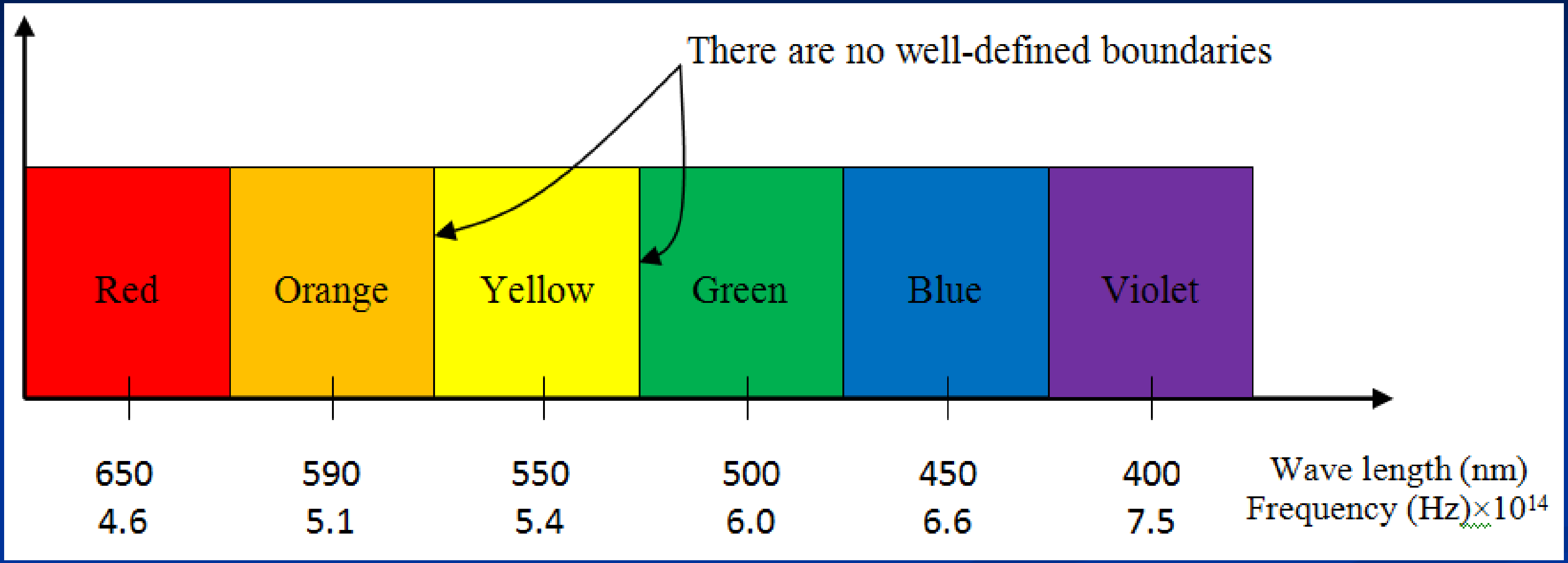
Effect of a Gravitational Mass on Time (Slowing Down of atomic clocks on the Sun and stars)

The light from the sun is caused by many different types of vibrating atoms, the frequencies of these vibrations can be determined experimentally, from which the times per vibration can be computed. The frequencies and corresponding times per vibration also can be measured for the same atoms vibrating on Earth. These can then be compared the former. As we saw previously, if the frequencies of vibration of the atoms in the Sun are less than those for the same atoms on Earth, it means that the times per vibrations have increased, or that time itself is slowed down on the Sun.

Since the prediction was that the frequencies of the Sun's light would be decreased, the frequencies were expected to be shifted towards the red end of the visible spectrum, because the frequency of the colour red is lower than that of the other colours in the spectrum.



Effect of a Gravitational Mass on Time (Slowing Down of atomic clocks on the Sun and stars



To differentiate this particular red shift from others effects which also produce a red shift, it is referred to as the relativistic or Einstein shift.

The Einstein shift was first looked for in the Sun. Unfortunately, the expected shift was so small that it was barely within the limits of measurement, so that these early attempts did not confirm the effect conclusively.

Effect of a Gravitational Mass on Time (Slowing Down of atomic clocks on the Sun and stars

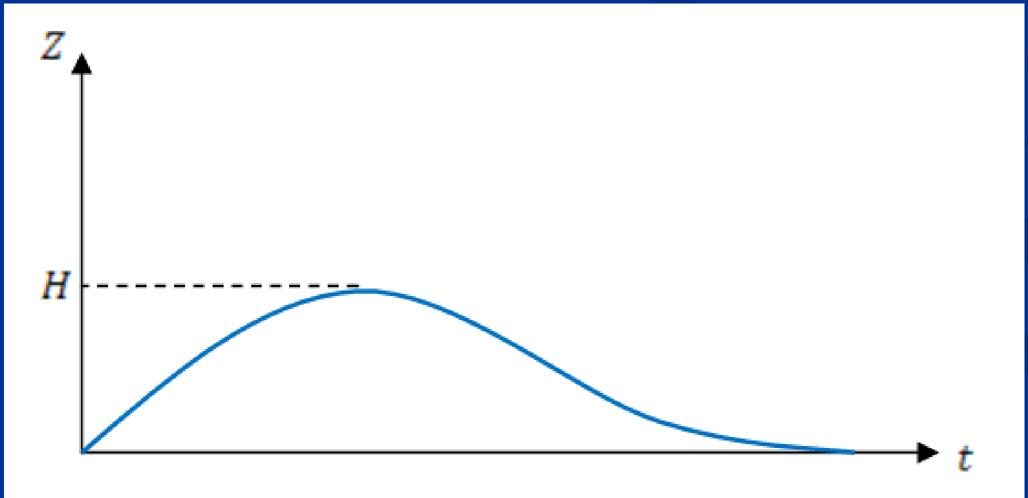
Since then, a class of stars called the white dwarfs has been used to detect the shift. These white dwarfs are small in comparison with most stars, but extremely dense. In particular, β Sirius (The companion of Sirius, the Dog Star, which is really a double star) has a diameter about 3% that of the Sun's, but its density is more than 25,000 times greater. On such a star a pint of the nuclear fluid making up the star would weigh about 18 tons! You can expect that life would be slower on such a star, where a person would be so crushed by his own weight that he couldn't even more!

Since the predicted frequency shift for the star β Sirius is over thirty times that expected for the Sun, this star was used by Adams in 1925 in his attempt to find the predicted effect. He found a frequency shift towards the red end of the spectrum of the expected amount. This constituted proof that a strong gravitational field does slow down time processes, as the General Theory predicted.

Minkowski's four Dimensional Space – Time

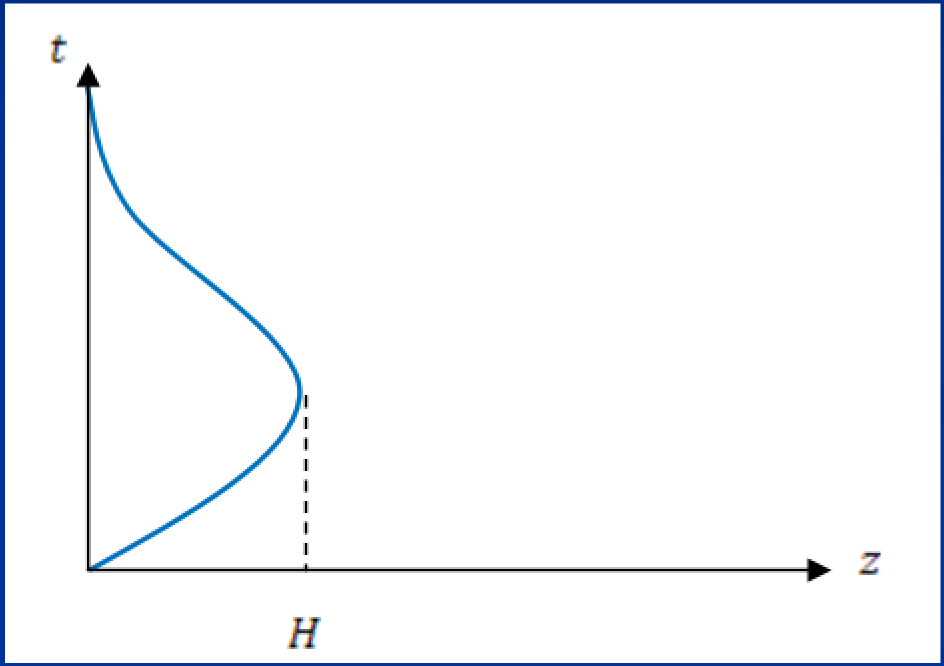
The idea of representing any physical event as a point in terms of the four dimensional space (x, y, z, t) was first conceived by Poincare in 1904. However, it is developed in its full glory by Minkowski in 1908.

Consider the motion of a particle thrown vertically upwards with an initial velocity v. It will reach a height of $H=v^2/(2g)$, where its velocity will become zero and it will start descending. If we consider (x, y, z, t) as our four dimensional space, then the motion of the projectile is a two dimensional motion with coordinates (z, t), where z is the vertical axis. The graph of z *vs.* t will have the form as shown in the following figure.



Minkowski's four Dimensional Space – Time

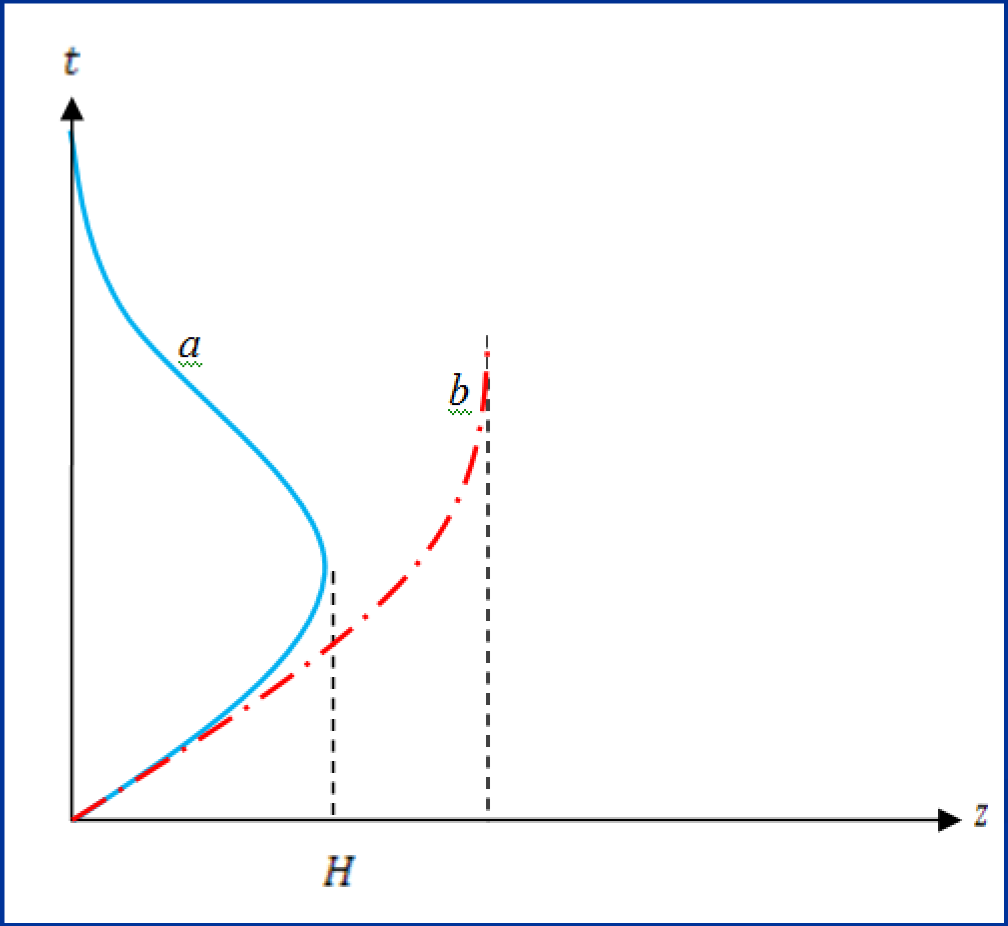
The some results plotted with ordinate and abscissa interchanged will look as in the following figure.



Now consider the motion of a two stage rocket. In a two stage rocket the lift- off is attained by the firing of the first stage which sustains it to attain a desired elevation. At that elevation all the fuel in the first stage is burnt out and the stage physically separates and falls back to the ground.

Minkowski's four Dimensional Space – Time

At the instant the first stage separates, the second stage is ignited and the rocket takes-off with increased speed. The motion of such a rocket is illustrated by the *(z, t)* diagram in the following figure.



However, in plotting this diagram the rocket is treated as a point particle.

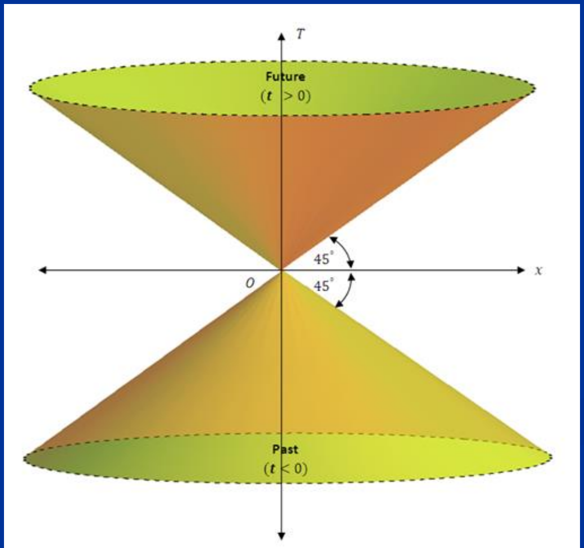
This lines *a* and *b* in the above figure are known as world lines.

Minkowski's four Dimensional Space – Time

Consider the case of a photon (corpuscle of light) travelling in a *(x, t)* plane. Its motion will be given by,

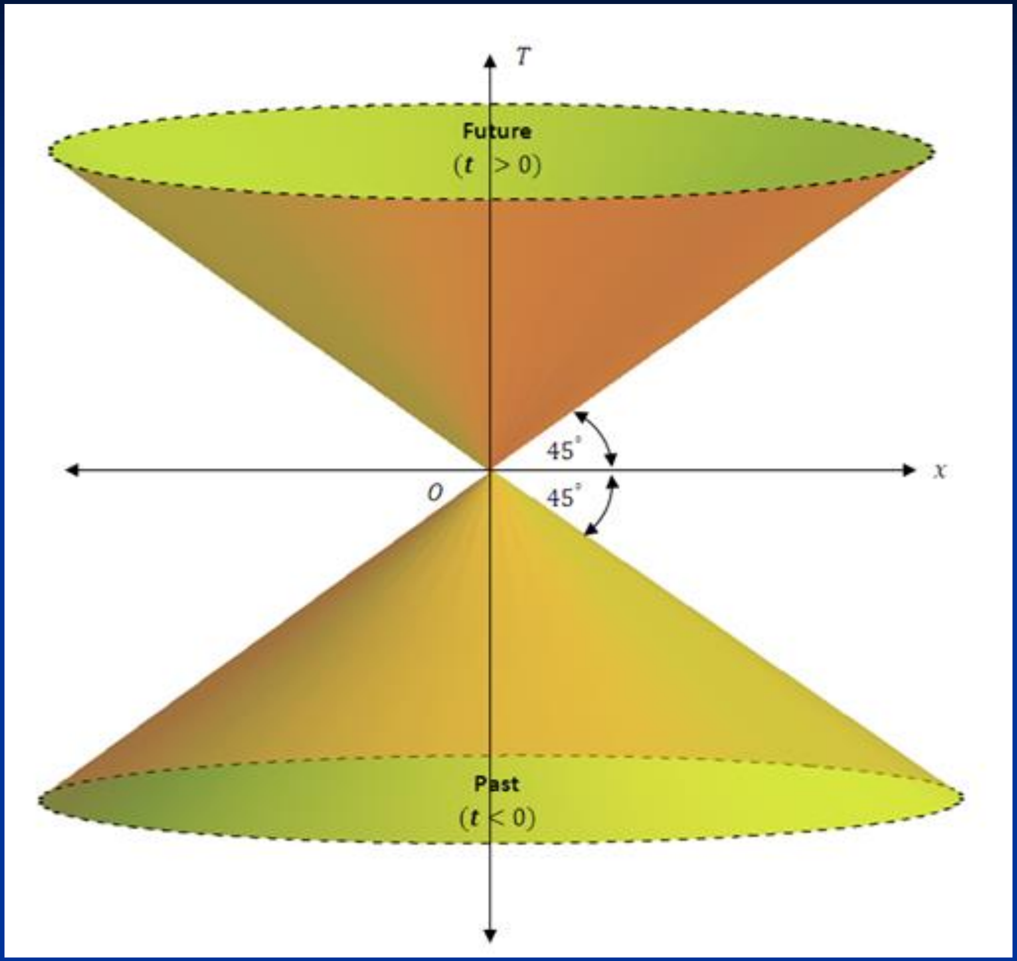
$$x = \pm ct = \pm T$$

depending upon whether it is travelling in the $+x$ or $-x$ direction. Both these paths are incorporated in a single equation on $x^2 = T^2$. Both these lines divide the space-time plot into four zones as in the following figure. Equations $x = \pm T$ can be interpreted in terms of $\pm x$ as well as $\pm T$, thus giving the four zones.



Light cones for past, present and future events…

Minkowski's four Dimensional Space – Time



Light cones for past, present and future events…

The four- dimensional plot of the same situation would provide light cones in the $+T$ and $-T$ directions, and the remaining two zones have the same property, and can be grouped into one (continuous) zone, which we call the third zone.

Minkowski's four Dimensional Space – Time

Let us now consider the events taking place in two inertial frames in 'future' and 'past' zones separately.

I. Future zone :

Consider two inertial frames S and S' moving relative to each other with a uniform velocity v. Then space-time event in S' given by has the value,

$$x'^2 - T'^2 = \gamma^2\left(x - \frac{v}{c}T\right)^2 - \gamma^2\left(T - \frac{v}{c}x\right)^2$$

$$= \gamma^2\left(1 - \frac{v^2}{c^2}\right)(x^2 - T^2)$$

$$= (x^2 - T^2)$$

Similarly, starting for the events in , we obtain $x^2 - T^2 = x^{1^2} - T^{1^2}$

Thus, $(x^2 - T^2)$ is an invariant quantity; it has the same value in two inertial frames, under Lorentz Transformation. Another important point to note is that in 'future' zones. $T > 0$ and $x < T$, i.e. $(x^2 - T^2)$ is always negative (and so is $x'^2 - T'^2$).

Minkowski's four Dimensional Space – Time

II. Past zone :

In this case also the situation is same in the 'future' zone case, except that, here, $T < 0$.

III. Third zone :

Here there is no restriction on T, and $(x^2 - T^2)$ is positive.

Thus,

i. For future zone : $(x^2 - T^2) < 0$; $T > 0$

ii. For past zone : $(x^2 - T^2) < 0$; $T < 0$

iii. For third zone : $(x^2 - T^2) > 0$

In four dimensional case the results are,

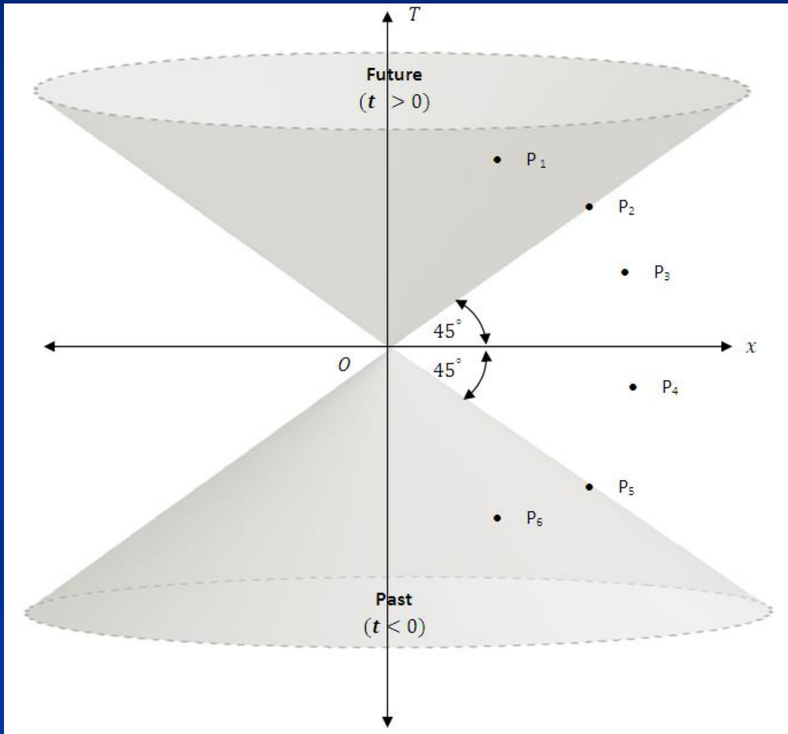
i. For future cone : $(x^2 + y^2 + z^2 - T^2) < 0$; $T > 0$

ii. For past cone : $(x^2 + y^2 + z^2 - T^2) < 0$; $T < 0$

iii. For remaining (third) space : $(x^2 + y^2 + z^2 - T^2) > 0$

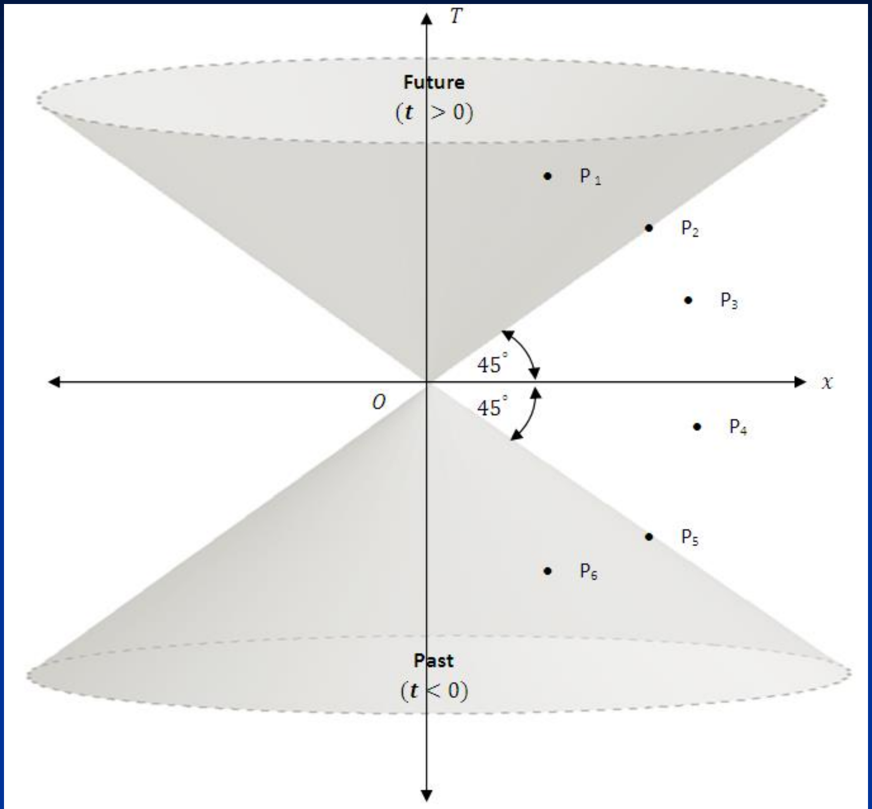
Minkowski's four Dimensional Space – Time

We now physically interpret the above figure as follows. Consider events represented by points p1, p2, p3, p4 and p5 (in the following diagram) in the two dimensional *(x, t)* space. From *O* it is possible to make contact with future ($T > 0$) event p1 with speed less than *c* (the velocity of light), or with p2 with speed equal to *c* but never with p3 or p4. Similarly, from past ($T < 0$) point p6 it is possible to make contact with *O* (and not with p1 or p2 directly) with speed less than *c*, or from point p5 with speed equal to *c*, but, again, never with points p3 or p4. In other words, the events represented by points p3 and p4 have no communication possible with past or future, and have no causal relationship with *O*.



Connection between events occurring in light cones

Minkowski's four Dimensional Space – Time



Connection between events occurring in light cones

Similar interpretation exists for event-points in four – dimensional space. Because of these properties, the **future** cone is also called the time-like cone, while the **past** cone is called the light-like cone, and the remainder four dimensional space is called space-like. It is usual to say that the **past cone** is the light-cone for the event O.

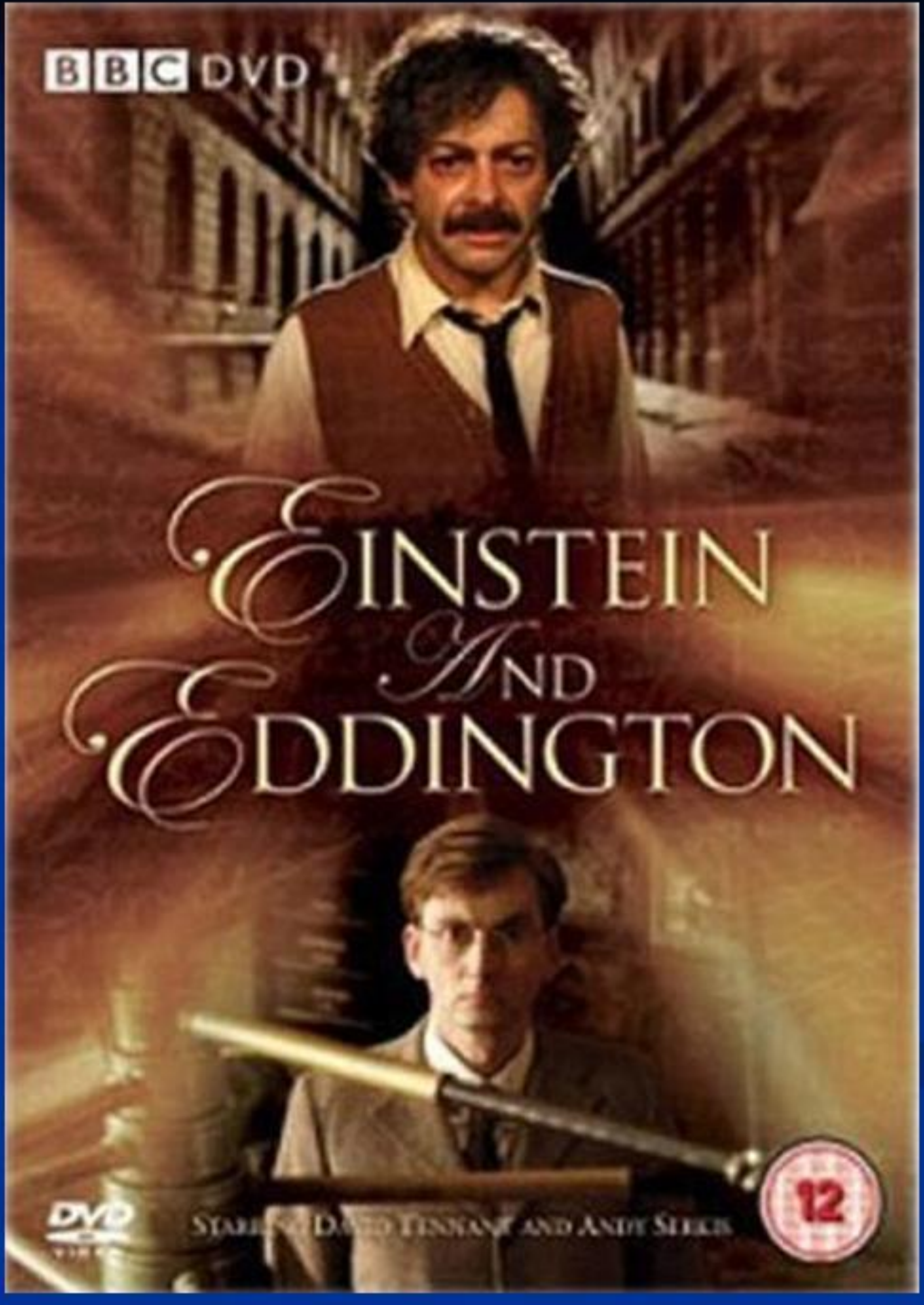
Einstein

&

Eddington

film

01 hrs & 30 min



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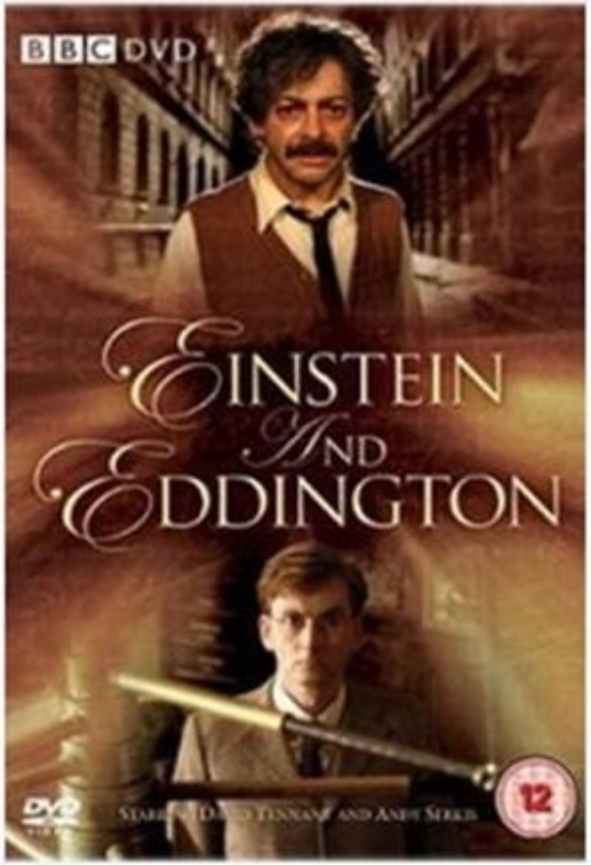

Einstein and Eddington (2008)

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TV Movie - 90 min - Drama | History

7.3

Your rating: ★★★★★★★★★★ 10/10

Ratings: **7.3**/10 from 1,797 users

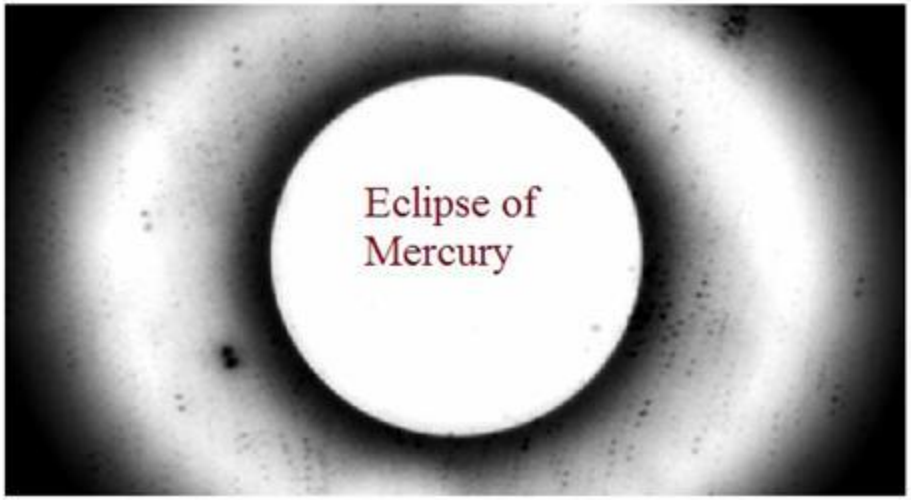
Reviews: 11 user | 1 critic

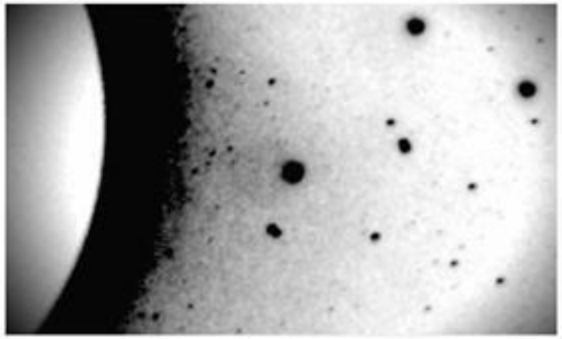
A look at the evolution of Albert Einstein's theory of relativity, and Einstein's relationship with British scientist Sir Arthur Eddington, the first physicist to understand his ideas.

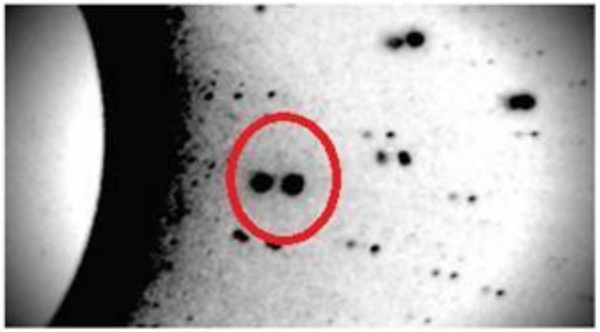
Director: Philip Martin

Writer: Peter Moffat

Stars: David Tennant, Richard McCabe and Patrick Kennedy







Storyline

Sir Arthur Eddington is a renowned physicist at Cambridge University and an expert in the measurement of the physical world. He along with all of his colleagues are also avowed Newtonians. Sir Oliver Lodge suggests that he read a new thesis put forward by a German-Swiss scientist named Albert Einstein who is suggesting that Sir Isaac Newton may have got it wrong. The expectation is that Einstein's theories will be disproven but Eddington admits that his General Theory of Relativity has merit. These are turbulent times as England and Germany are at war and Eddington's own loyalty is called into question when, as a Quaker, he refuses to fight. In the end, Eddington develops a series of tests to either prove or disprove Einstein's theories. For his part, Einstein has his own struggles during this period: the breakdown of his marriage, his integration into the university in Berlin and his own strident pacifism that led him to oppose German militarism and the First World War... *Written by garykmcd*

Thank You !