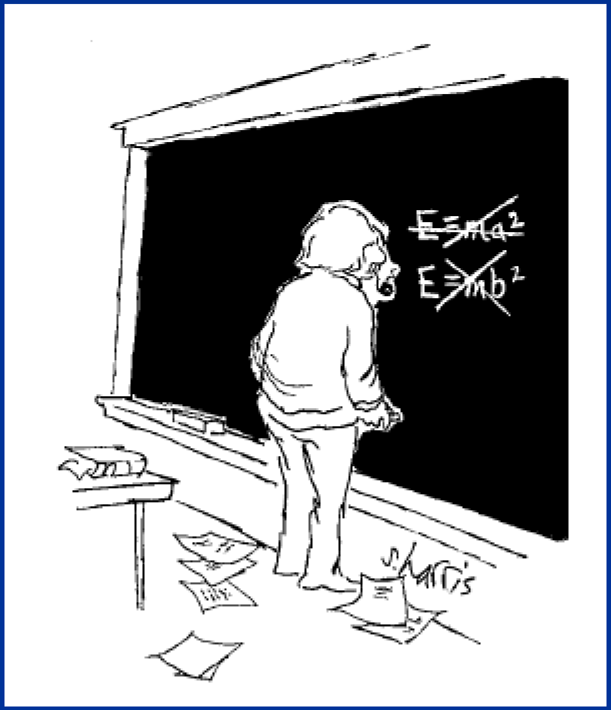
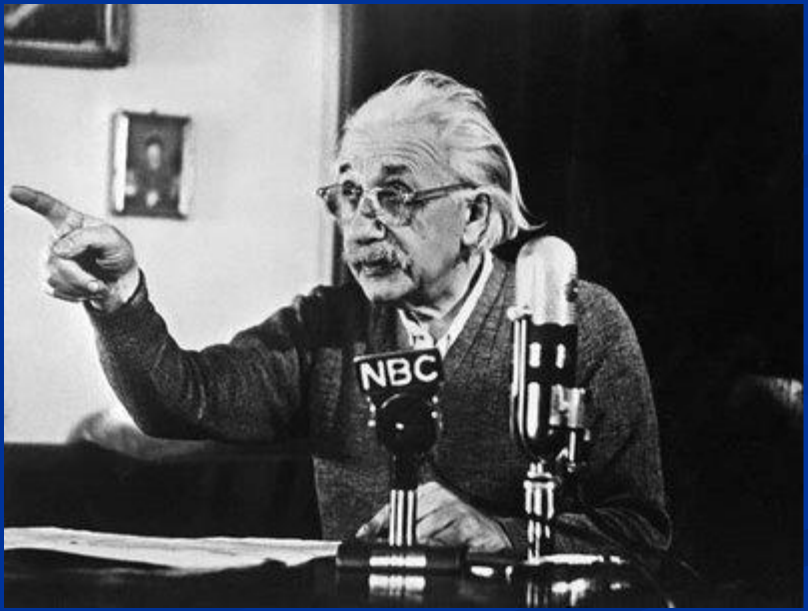
Special Theory of Relativity





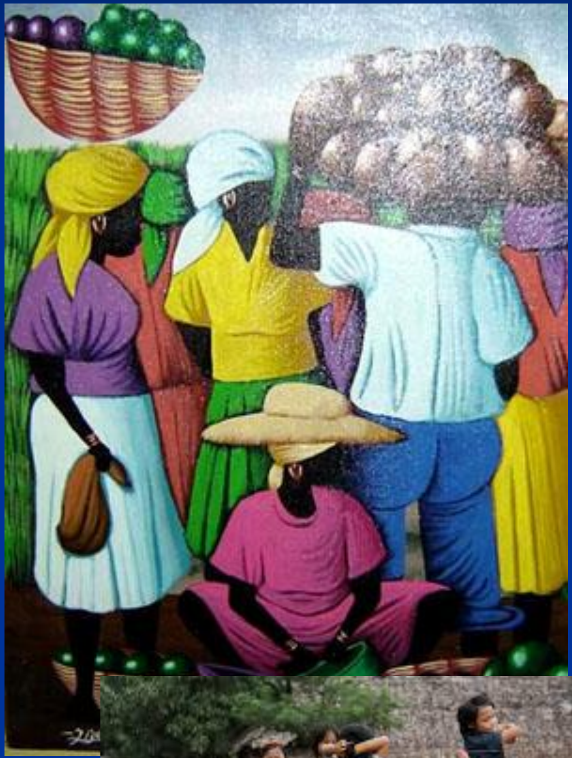
11th Lecture

Causality

Causality is the relationship between an event (the cause) and a second event (the effect), where the second is a consequence of the first.

Theories of causality in Indian Philosophy focus mainly on the relationship between cause and effect. The various philosophical schools (*darsanas*) provide different theories.

Special Theory of Relativity



For day to day life

General Theory of Relativity

Brief Introduction to General Theory of Relativity

Soon after the Special Theory was published in 1905, Einstein turned his attention to phenomena that occurred when observers were not restricted to movement with constant relative velocities (i.e. with zero acceleration) **but with varying velocities** (i.e. with accelerations not zero). **The results of his reasoning embody The General Theory of Relativity, which was presented in 1916.**

(PTO)

Brief Introduction to General Theory of Relativity

Everyone has ridden in an elevator at on time or another and has perhaps noticed that when the elevator is accelerating upwards, he is pushed towards the floor of the elevator. Also, if the passenger is carrying something, it too, is push towards the floor. He feels heavier and. Furthermore, the faster elevator starts up (the greater the acceleration), the heavier everything becomes.

Brief Introduction to General Theory of Relativity

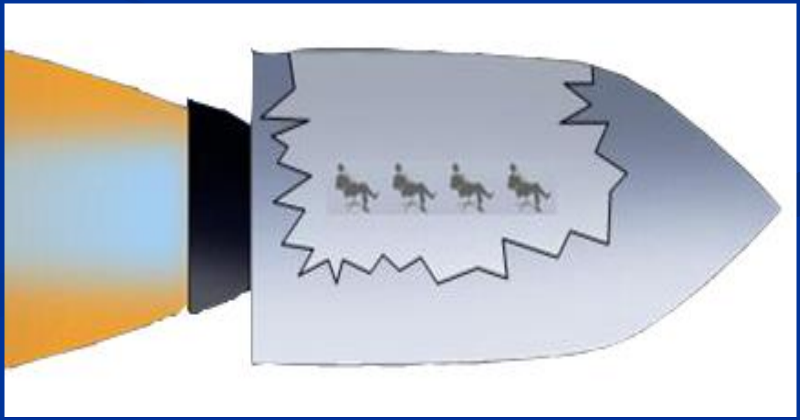
Conversely, when the elevator is accelerating downward, everything becomes lighter and the greater the acceleration downward, the lighter everything becomes. In particular, if the elevator should accelerate downward as fast as falling objects accelerate towards the Earth, then objects in the elevator would have no weight at all, and everybody and everything would tend to float around in the elevator like soap bubbles! And if the elevator plummeted earthward with an even higher acceleration, everybody and everything would be pressed to the ceiling of the elevator. When the elevator stops accelerating, and moves with a constant velocity up or down, these effects will not occur. (PTO)

Brief Introduction to General Theory of Relativity

Although the elevator passengers might be flustered momentarily by what is happening, they are not completely in the dark as to the cause of their discomfort. They know that the Earth's gravitational force on them has something to do with the peculiar effects they experience.

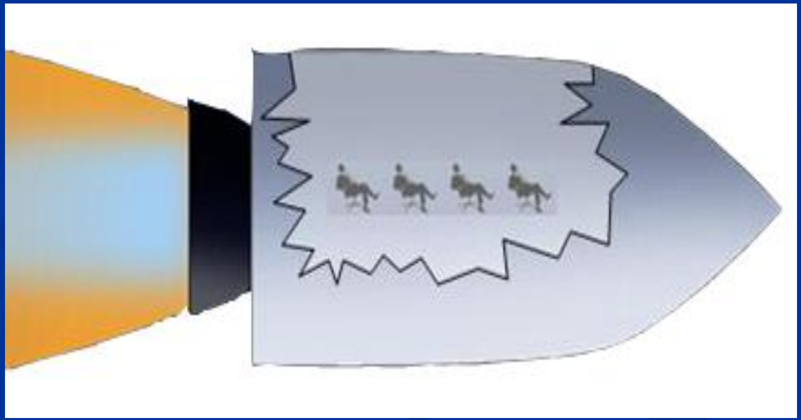
Brief Introduction to General Theory of Relativity

But now suppose these people are in a rocket travelling out in interstellar space, say on a star seeing trip. They have no weight, since weight is the force with which a large mass pulls on the object, and they are out beyond the pull, or gravitational field, of the earth. Hence, they must be tied down in some way to keep from floating around. (PTO)



Brief Introduction to General Theory of Relativity

Now; when the rocket accelerates in the forward direction relative to the distant stars, they are pushed back against their seats as the following figure, and when the rocket decelerates, they are thrust forward in the same way that people are in any conveyance which is speeding up slowing down on the Earth.



Brief Introduction to General Theory of Relativity

Thus, the people in the rocket would automatically associate a pressure backward with an acceleration of the rocket, and a thrust forward with a deceleration of the rocket. At other times, when the rocket is neither accelerating nor decelerating, they do not experience any effect. (PTO)

Brief Introduction to General Theory of Relativity

But now suppose that while they are journeying along in space with a constant velocity relative to the distant stars, a stray planet comes along. It is not seen by anyone in the rocket and narrowly misses hitting the rocket, passing by its tail, as in the following figure.

Brief Introduction to General Theory of Relativity

If we assume the rocket motors and controls are such as to keep the rocket moving with constant velocity relative to the distant stars, the question is what will the passengers feel? With the planet in their vicinity they are again given weight, and they feel this by being pulled towards the planet as it passes, i.e.; pushed to the back of their seats. But since they don't know of the presence of the planet and since the effect is the same as if the rocket accelerated, they will erroneously conclude that, that is what happened and not give it a second thought.

(PTO)

Brief Introduction to General Theory of Relativity

The larger question is whether there is any way they can tell (without looking outside) if the forces they feel are due to acceleration or the gravitational pull of a nearby mass. The answer is that there is no way of distinguishing the two. Einstein was stuck by this equivalence of acceleration and gravitational forces and stated this observation in what is known as 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**.

Brief Introduction to General Theory of Relativity

Going back to the accelerator, we wonder if the increased weight of the passengers, caused by the elevator being accelerated upward, could not also be caused by additional gravitational forces. If certainly could, suppose that the elevator and its passengers were suddenly ‘transplanted’ to Jupiter without their knowing it. They would all feel heavier because Jupiter has a mass over 300 times greater than that of the Earth and so exerts a greater gravitational pull on objects on its surface, causing objects to weigh 2.5 times more than they do on Earth. Hence a 50kg man would weigh 125kg on Jupiter, and would probably sag to the floor as a result. Furthermore, he would attribute his increased weight to an upward acceleration of the elevator, not knowing that an increased gravitational mass caused it. (PTO)

Brief Introduction to General Theory of Relativity

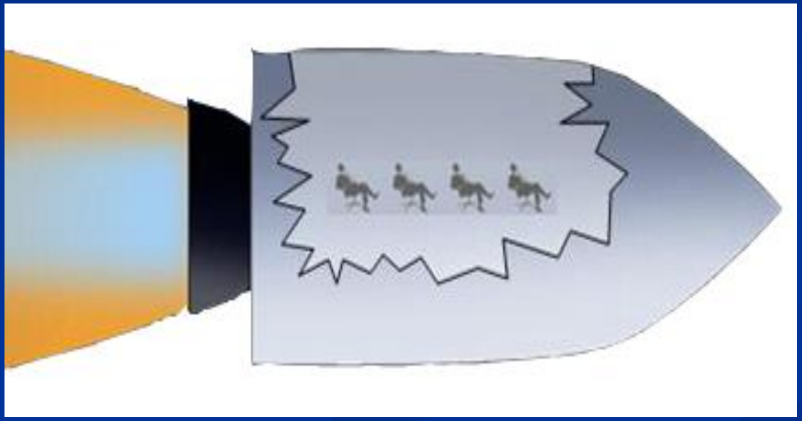
Or, if the elevator were transplanted to Mercury, which has a mass of 1/25 that of the Earth, everything would weigh only a third as, much and the 50kg man would weigh only 16.75kg. He and the other occupants would interpret their lighter weight as due to the elevator accelerating downward. Again we see that the effects of accelerated motion and gravitation are the same.

Brief Introduction to General Theory of Relativity

It would appear that the principle of equivalence is a simple, or even trivial, observation. It would seem so to one not versed in the history of scientific accomplishment, but Einstein was the first to draw attention to this conclusion. If it had no further ramifications, the principle would be considered interesting and then promptly forgotten. With this principle of equivalence as the basic postulate of the General Theory, **Einstein applied a branch of mathematics previously developed by Riemann and others, i.e.; tenser calculus, and obtained three important conclusions, each of which was tested experimentally.** These will now be discussed in detail.

Brief Introduction to General Theory of Relativity

The Concept of Gravity : Space & Time Curves



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.

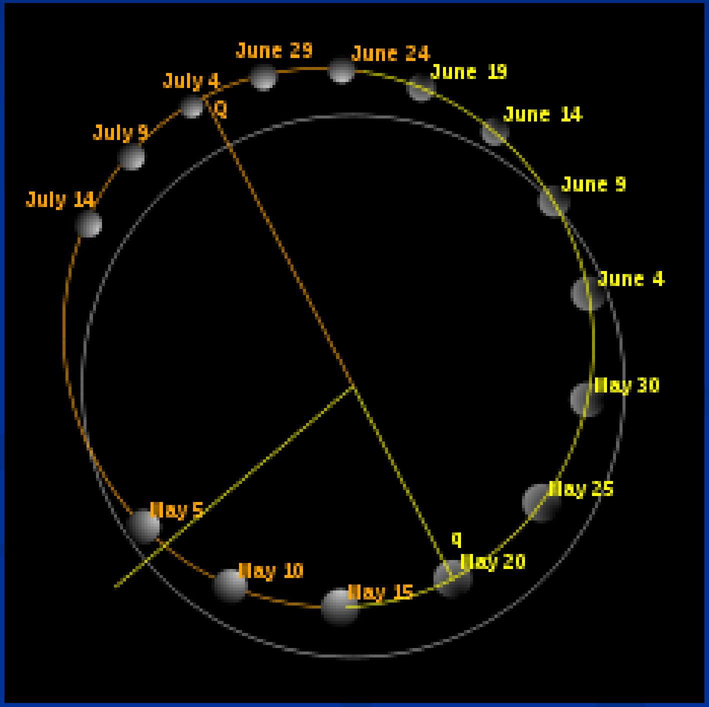
Newton's Law of Universal Gravitation and Einstein's Theory of Gravitation- Rotation of Mercury Orbit

Gravitation was a topic which had intrigued people for many years because of the mysterious way in which it acts. A freely falling object always falls towards the Earth. But how is it possible for the Earth to pull the object towards it without literally reaching up and grabbing the object? The air does not help, because objects are also pulled by the Earth even when they are in a vacuum. (PTO)

Newton's Law of Universal Gravitation and Einstein's Theory of Gravitation- Rotation of Mercury Orbit

Another mystery was the strange force which the sun seemed to exert on the planets to keep them continually revolving about the Sun.

Kepler had deduced, after considerable observation, that the paths travelled by the planets were ellipses, but he did not know why they were ellipses.



(PTO)

Newton's Law of Universal Gravitation and Einstein's Theory of Gravitation- Rotation of Mercury Orbit

A satisfactory answer to both of these unknowns was given by Newton in 1687 when he published what is now known as Newton's Law of Universal Gravitation. This says that every object in the universe attracts every other object with a gravitational force given by the following Equation:

$$F = \frac{G m_1 m_2}{d^2}$$

Where,

m1 - the mass of one object,

m2 - that of the other,

d - the distance between them, and

G - a universal constant (Newton's Gravitational constant)

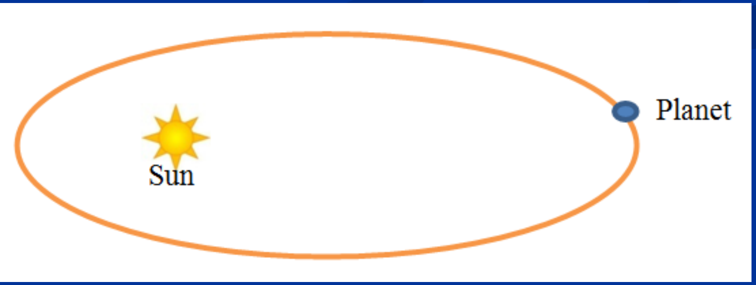
Newton's Law of Universal Gravitation and Einstein's Theory of Gravitation- Rotation of Mercury Orbit

When an object is falling freely, the force of attraction of the Earth on the object is obtained from the above equation by inserting the mass of the object for *m1* and the mass of the Earth for *m2*.

It should be noted that Newton's equation was entirely the result of observation. (PTO)

Newton's Law of Universal Gravitation and Einstein's Theory of Gravitation- Rotation of Mercury Orbit

He observed falling objects and the movements of the planets about the Sun and evolved his formula as the one which best fitted the facts- thus obtaining what is called an empirical equation. With this equation for the force of attraction between two masses, be then arrived the equations for the paths the planet make around the Sun. He found that these paths were ellipses, which were stationary with respect to the Sun as in the following figure.



Under Newton's Law a planet's orbit is a stationary ellipse

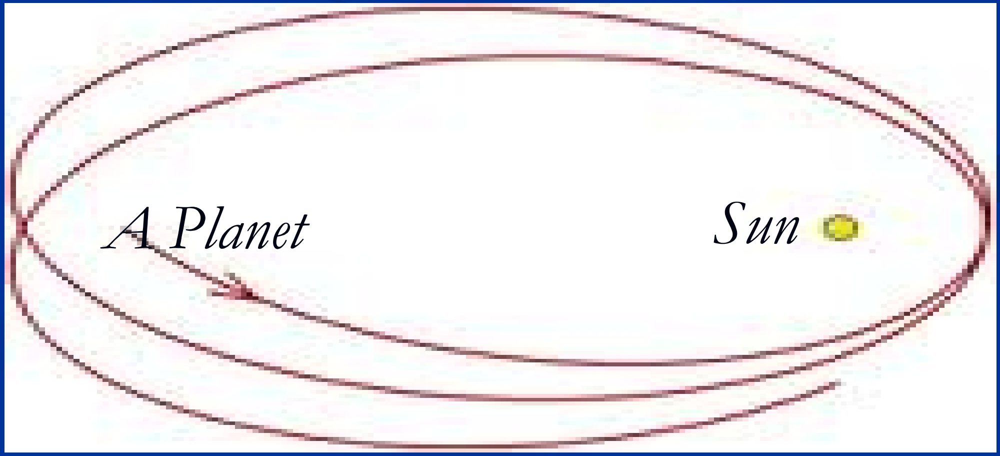
Newton's Law of Universal Gravitation and Einstein's Theory of Gravitation- Rotation of Mercury Orbit

The planets travel over and over again in the same elliptical paths in space. Since observations through years verified this, Newton's Law of gravitation was hailed as a great accomplishment, as indeed it was.

In his development of General Theory, Einstein concerned himself with the development of a theory of gravitation. (PTO)

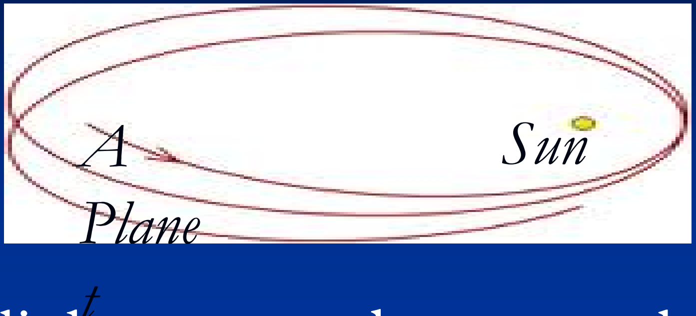
Newton's Law of Universal Gravitation and Einstein's Theory of Gravitation- Rotation of Mercury Orbit

For this reason the General Theory of Relativity is also called the Einstein theory of gravitation. As a result of this theory; Einstein also determined the Equation of the paths the planets make in their journey about the Sun. The end result was approximately the same as Newton's but there was a slight difference. **Although Einstein also found that these ellipses were not stationary but were slowly rotating in space, as in the following figure.**



Under Einstein's Theory a planet's orbit is a rotating ellipse.

Newton's Law of Universal Gravitation and Einstein's Theory of Gravitation- Rotation of Mercury Orbit



But this predicted rotation is so light as to be scarcely detectable for most of the planets. The orbit of the Earth, for example, rotates at a rate of only 3.8 seconds of are every century. When we remember that there are 324,000 seconds of are in a right angle, it can be realized how small a value 3.8 seconds of are really is about one one-hundred thousandth of a right angle. And, further, it takes 100 years for the Earth's orbit to rotate by this amount. At this rate, it would take about 34 million years for the Earth's orbit to rotate one revolution!

Newton's Law of Universal Gravitation and Einstein's Theory of Gravitation- Rotation of Mercury Orbit

Strictly speaking, since the elliptical orbits of the planets are rotating, the orbits **rosette patterns** similar to the paths of the electrons about the nucleus in the Sommerfeld theory. But since this rotation rate is so small, it would take too long for a rosette to be complicated. Hence, we think of the planetary orbit as rotating ellipses, and not as rosette patterns.

Obviously, since the Einstein theory of gravitation produces different results from the Newton low of gravitation, one of these is incorrect, however slightly.

(PTO)

Newton's Law of Universal Gravitation and Einstein's Theory of Gravitation- Rotation of Mercury Orbit

As we shall see, the Einstein theory is correct one, but we first would like to see how these two theories differ mathematically. If the Newton law of gravitation is modified so that the results agree with Einstein's, i.e., so that the orbits of the planets turn out to be slightly rotating eclipses instead of stationary ones, then the corrected formula should be in the following equation;

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

Newton's Law of Universal Gravitation and Einstein's Theory of Gravitation- Rotation of Mercury Orbit

Which is only slightly different from Newton's law is correct to a high degree of approximation. It is for this reason that Newton's law of gravitation has given such good results for so many years.

One proof of the General Theory of Relativity consisted in looking for a planet whose orbit rotated the most over a given period of time. The theory showed that the amount of rotation would be greatest for the planet with the highest orbital velocity.

(PTO)

Newton's Law of Universal Gravitation and Einstein's Theory of Gravitation- Rotation of Mercury Orbit

But it was also necessary to use a planet whose orbit was as elliptical as possible, since some of the planetary orbits, like the Earth's, are so nearly circular that is difficult to tell whether or not they have rotated. With an orbit that is very flat, or higher elliptical, it is easy to see in which direction it points, and hence its rotation can be detected.

Newton's Law of Universal Gravitation and Einstein's Theory of Gravitation- Rotation of Mercury Orbit

It so happens that the **planet Mercury** has one of the flattest orbits and the greatest orbital velocity. There had been a peculiar and puzzling behavior of this planet's orbit for many years: it had a rotation of about 43 seconds of arc per century which could not be accounted for. (Although the total rotation of Mercury's orbit is about 574 seconds of arc per century, it was known that 531 seconds of this was due to the gravitational effect of the other planets)

(PTO)

Newton's Law of Universal Gravitation and Einstein's Theory of Gravitation- Rotation of Mercury Orbit

In 1845 the French mathematician Laverrier showed that this excess amount of rotation would be produced if Mercury were being influenced by another planet between it and the Sun. The anticipated planet was eagerly looked for by astronomers but has never been found. (The planet Neptune was also predicted by Laverrier as a result of variations in Uranus' orbit, and was thus subsequently discovered in 1930 as a result of still-remaining variations in Uranus' orbit) (PTO)

Newton's Law of Universal Gravitation and Einstein's Theory of Gravitation- Rotation of Mercury Orbit

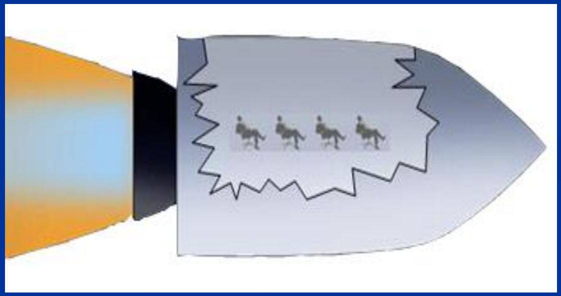
The cause of the excess rotation of Mercury's orbit remained a mystery until the introduction of the General Theory of Relativity. When the General Theory was used to compute the amount of the excess rotation of Mercury's orbit for the period of a century, the result was 43 seconds of arc-the exact amount of rotation which previously could not be complained. This constituted the first proof of the General Theory. It should be noted that this particular proof is the most convincing of the three so far known, since the effect is a relatively large one compared to the other two be discussed.

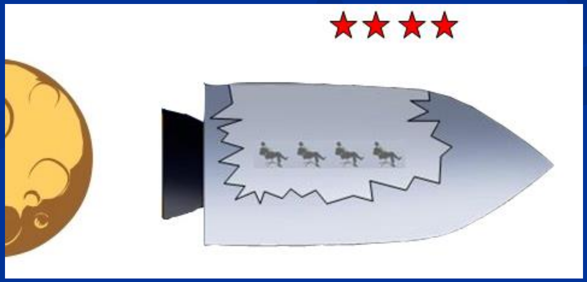
Newton's Law of Universal Gravitation and Einstein's Theory of Gravitation- Rotation of Mercury Orbit

We found in the discussion of the Sommerfield theory of atomic orbits that the rotation of the orbits there was caused by the variation in mass of the electron as predicted by the special Theory. You may wonder if the excess rotation of Mercury's orbit could be due to the same effect. Since Mercury travels in an elliptical orbit, its orbital velocity varies and, hence, its mass would vary, with its orbit being caused to rotate as a result. However, it can be shown mathematically that the amount of this rotation predicted by the Special Theory will be only one-sixth that predicted by the general theory. In this case it would account for only about 7 of the excess 43 seconds of arc per century that Mercury's orbit is known to rotate. The General Theory, then, satisfactorily accounts for the excess rotation.

Effect of a Gravitational Mass on a light beam - weighing a Beam of light

In connection with the General Theory, Einstein also investigated the behavior of a beam of light under the influence of gravitational field due to a large mass. His results are best presented by again referring to the following figures, where now we will assume that the rocket passes a row of stars in its flight. Since there is only a single skylight in the ceiling of the rocket, a single beam of light from each star will enter the rocket via the skylight as the rocket passes each star.

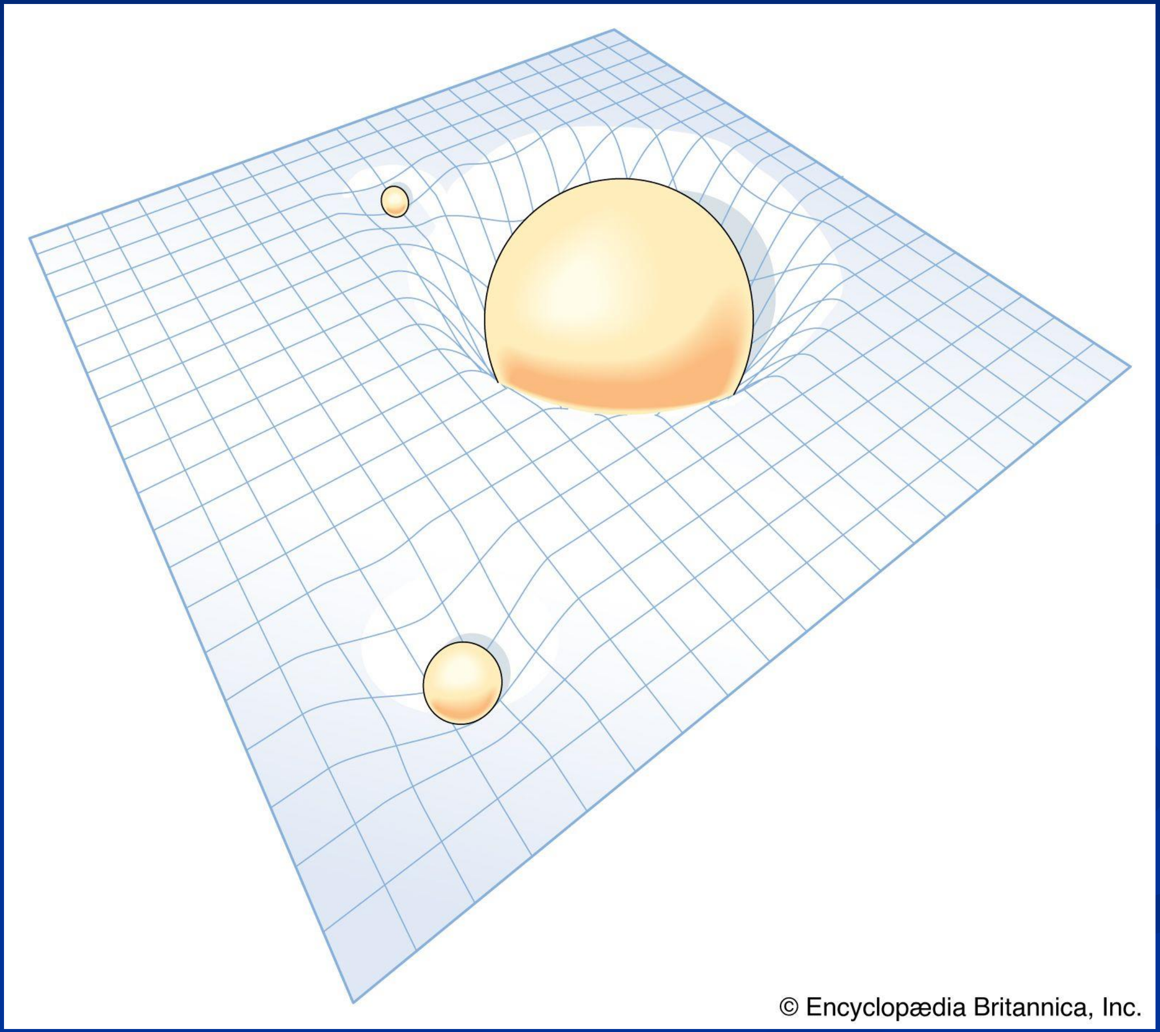




Effect of a Gravitational Mass on a light beam - weighing a Beam of light

In the above diagram, it is seen that while the rocket is passing the row of stars, the stray planet is passing by the rear of the rocket. What effect does this have on the resultant light beam in the rocket? The general Theory states that the gravitational field due to the planet's mass will attract the light beam towards it in the same way that the Earth will pull a flying bullet or arrow towards it. This causes the light beam inside the rocket to be curved.

What is curve space-time?



What is curve space-time?

Newton's Gravity Concept

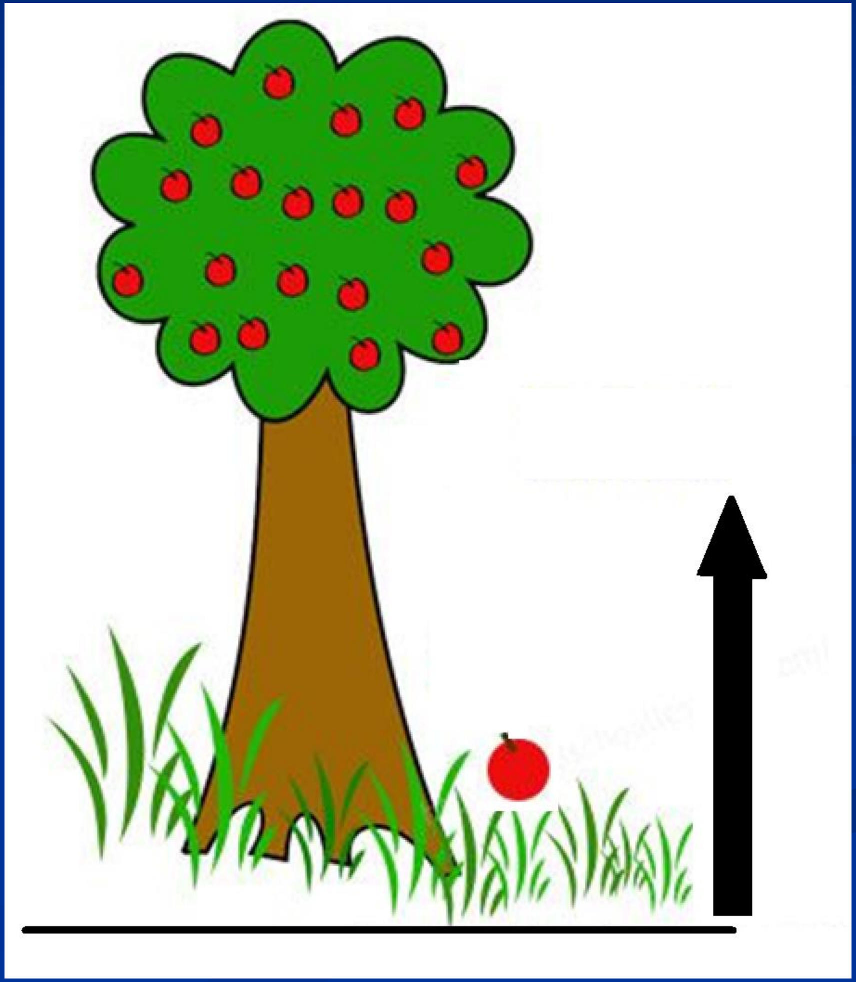
Newton's law of universal gravitation is usually stated as that every particle attracts every other particle in the universe

What is curve space-time?

Einstein's Gravity Concept

The key difference between Einstein and Newton gravity is that **Einstein gravity describes that gravity is a curvature in a 4-dimensional space-time fabric proportional to object masses**, whereas …..

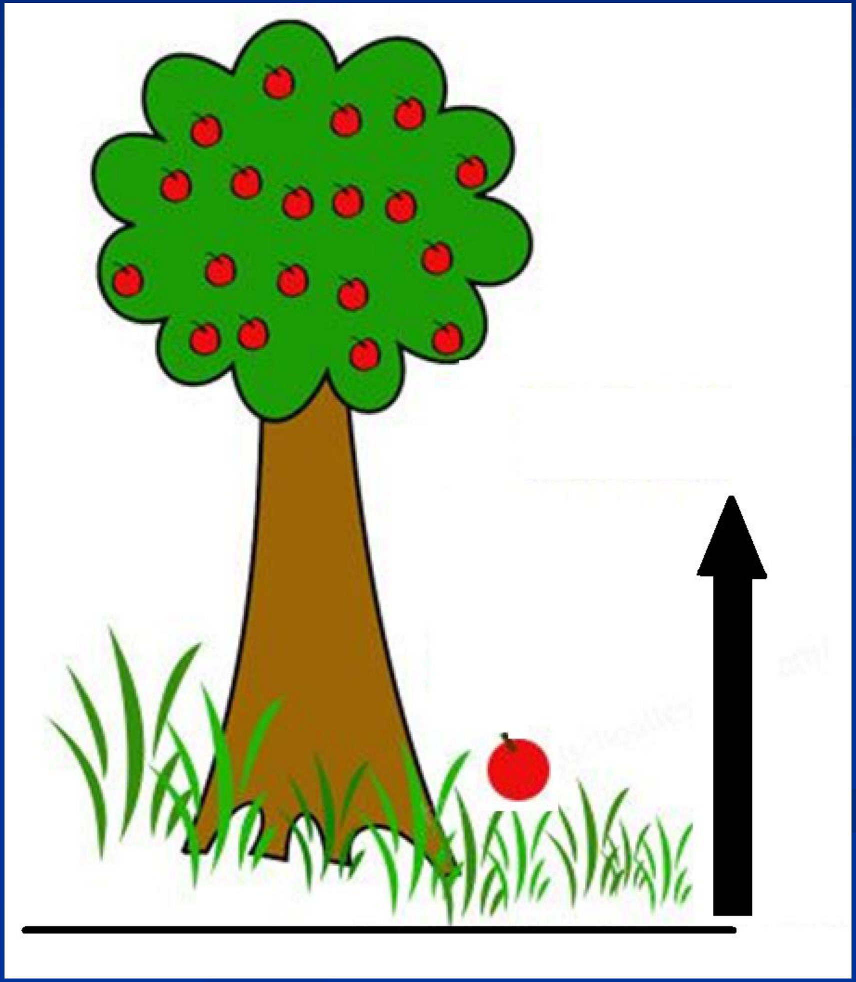
(PTO)



What is curve space-time?

Einstein's Gravity Concept

…. whereas Newton gravity describes gravity as a force expressed mutually between two objects in relation to their masses. Moreover, Einstein considered gravity as a push while Newton considered gravity as a pull.

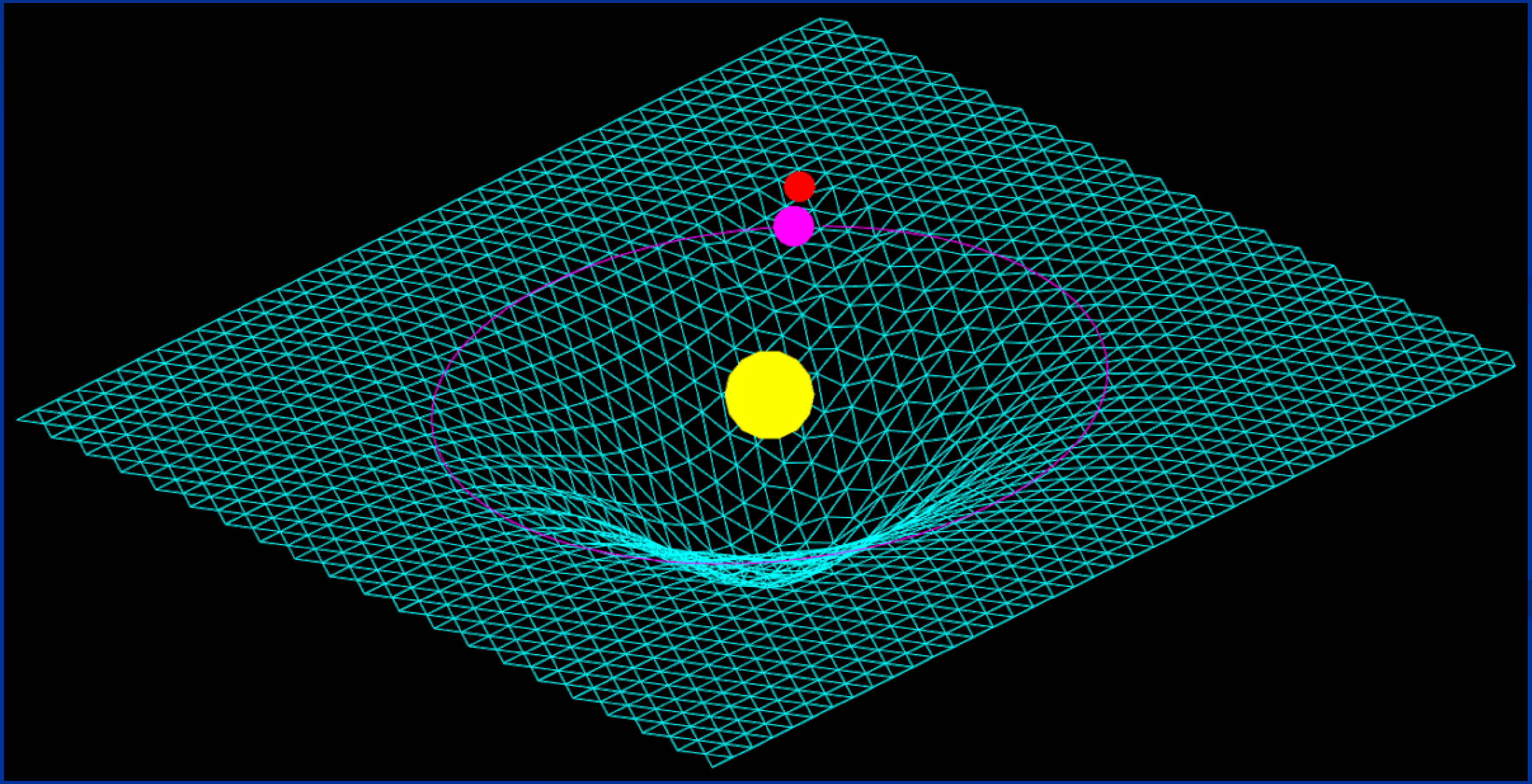


Einstein vs Newton Gravity

More Information Online WWW.DIFFERENCEBETWEEN.COM

	Einstein Gravity	Newton Gravity
DEFINITION	Einstein gravity is described by the general relativity or general theory of relativity, which is a geometric theory of gravitation published by Albert Einstein in 1915	Newton gravity states that every particle tends to attract every other particle in the universe with force
NATURE	Considered gravity as a push	Considered gravity as a pull
DESCRIPTION OF GRAVITY	Describes that gravity is a curvature in a 4-dimensional space-time fabric proportional to object masses	Describes gravity as a force expressed mutually between two objects in relation to their masses

The motion of Earth & Moon around the Sun
according to the Einstein's GTR



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. …..**

Thank You !