EINSTEIN'S GENERAL THEORY OF RELATIVITY
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Einstein's Special Theory of Relativity, published in 1905, describes how the world looks to observers moving in straight lines at steady velocities. Einstein's General Theory of Relativity, published in 1915, describes how the world looks to observers moving in a non-uniform manner, accelerating and decelerating, and, in particular, the theory developed an entirely new understanding of gravity. This new approach was based on the Principle of Equivalence. Einstein's Special and General Theories of Relativity are cornerstones of modern physics and have passed all tests of their validity.

Einstein's insight into the nature of gravity was greatly assisted by his visualisation of standing in a freely-falling lift. The lift accelerates towards earth under gravity at 32 feet per second per second, but the man in the lift is weightless, able to push himself from floor to ceiling with ease. Einstein concluded that, since the downwards acceleration exactly cancels out gravity, acceleration and gravity are equivalent to each other - the Principle of Equivalence.

By the same token, a man in a rocket accelerating uniformly through space at 32 feet per second per second will feel a force holding him to the floor of the rocket exactly equivalent to the force of gravity. If the man is unable to look out of the rocket, there is no experiment he can perform which will tell him whether the rocket is moving through space or standing stationery on the earth.

In another thought-experiment on the accelerating rocket, Einstein imagined shining a beam of light through a small hole in one wall, aimed across the rocket towards the other wall. If the rocket were moving at constant speed the light would hit the opposite wall at the same height from the floor as the hole on the other wall. But because the rocket is accelerating, the second wall moves up slightly as the light crosses the rocket, and the light hits the second wall at a point slightly lower than the height of the hole on the first wall. In other words, the beam of light seems to bend as it crosses the rocket. According to the Principle of Equivalence, if a beam of light is bent in an accelerated frame of reference, then it will also be bent by the same amount by gravity.

But how can gravity bend a beam of light, since there is no matter in the beam? This is where the concept of the space-time continuum comes in, which I described in my article on special relativity. Classical physics viewed space as a continuous phase with three dimensions, and time as a separate two dimensional line that moves inexorably from the past, to the present, and the into the future. But the Special Theory of Relativity showed that space and time are not separate entities. They are bound together into a four dimensional space-time continuum (three space dimensions and one time dimension). All movement takes place in this continuum. The shape of the space-time continuum is bent and distorted by the presence of matter, and, according to Einstein, it is these deformations that account for the ‘force’ of gravity, bend beams of light, and cause moving objects to veer off from straight line trajectories. A rule of thumb says - ‘Matter tells space how to curve, space tells matter how to move’.

A helpful analogy is to imagine the empty space-time continuum as a flat stretched rubbery surface. Now place a heavy cannon ball onto this surface. It will produce a marked local depression where it lies. This is how Einstein visualised that a large lump of matter would distort the space-time continuum.

Now imagine a ball-bearing rolling along the elastic surface. It will roll smoothly along in a straight line making only a small indentation. However, if it comes near the cannon ball, the ball-bearing will follow a curved path along the distortion in the elastic surface. This is the modern model for the force of gravity. Objects follow a path of least resistance through space-time, and the path is curved when space-time is distorted. When a ball-bearing, a planet, or a beam of light moves near a large mass, it follows a curved path.

The classical concept of gravity describes it as a force of mutual attraction possessed by all bodies of matter. The Law of Gravitation, formulated by Isaac Newton in 1684, states that the gravitational attraction (F) between two bodies is proportional to the product of the masses (M1, M2) of the two bodies, and inversely proportional to the square of the distance (D) between them ($F=GM1M2/D^2$, where G is the gravitational constant).

According to Einstein, Newton's Law of Gravitation is unnecessary. Einstein attributes the 'force' of gravity to acceleration. A stationery object on the earth is attracted to the centre of the earth - gravity. How is this attributable to acceleration? Well, whereas in three dimensional space, the object is stationery, in four dimensional space-time the object is in motion along the curvature of the space-time continuum in the neighbourhood of the earth. Newton's hypothesis is replaced by the hypothesis that the continuum is curved in the neighbourhood of massive objects.

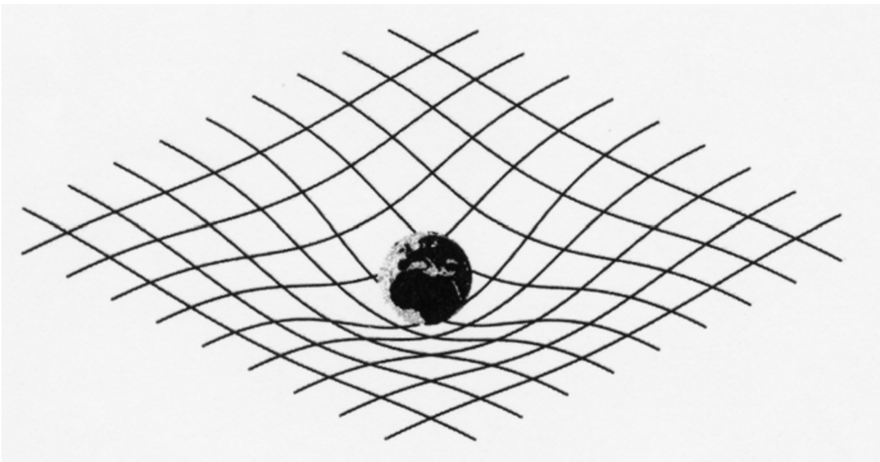
The Theory of General Relativity has passed every test that has been applied to it. For example, it explained the curious way that Mercury orbits the Sun. Mercury is the closest planet to our massive Sun and therefore occupies a space-time that is strongly distorted. Mercury’s orbit cannot be completely explained by Newton's theory of gravity. The curious orbit however was explained exactly by general relativity. When gravity is weak, the Theory of General Relativity and Newton's inverse square law give the same results. However, in a very strong gravitational field the inverse square law does not apply precisely, whereas general relativity does.

General relativity has satisfactorily explained the strange properties of newly discovered exotic objects such as black holes, pulsars and quasars. Everyone has heard of black holes - bodies that are so intensely dense that not even light can escape their gravitational power. In terms of the concepts of general relativity, a black hole would so distort space-time as to wrap it around itself completely, pinching itself off from the rest of the universe and disappearing from all outside view.

At the end of its life, when its core nuclear fuel is used up, a star eventually collapses under its own gravity. Some collapse to the extent of becoming neutron stars. These can contain as much matter as our Sun, but squeezed into a volume no bigger than a mountain on earth. They have a density approximately the same as the nucleus of an atom, which is close to the density at which a black hole forms. If a neutron star could gain enough extra mass, for example by attracting gas from a neighbouring star, it could succeed in becoming a black hole. A black hole rotating around another star in a binary system would emit X-rays as super-heated gas, stripped from the star, plunges towards the black hole. X-ray sources have been discovered in binary systems with properties matching those predicted for black holes by the general relativity equations.

The Theory of General Relativity also predicts the phenomenon of gravitational radiation. This depends on the concept of space-time as a physical phenomenon which can be distorted by matter. Using the analogy of the elastic sheet for space-time, one can visualise gravity waves arising from the vibrations sent out through the sheet when a lump of matter vibrates. Gravitational radiation is very weak - 10^{-40} times the strength of electromagnetic radiation. Elaborate experiments are in progress in order to detect gravitational radiation.

The Theory of Evolution and The Theories of Relativity (Special and General) were the two greatest turning points in the history of modern science. Both theories, particularly evolution, often attract attempts to prove their invalidity. Attacks on evolution are frequently motivated by religious beliefs. Attacks on relativity are usually argued from a scientific viewpoint. Relativity theory has withstood all tests applied to it, and remains a masterpiece and a corner stone of modern physics.



The rubber-membrane model to illustrate gravity: the presence of mass distorts the flat Euclidean space-time continuum.

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