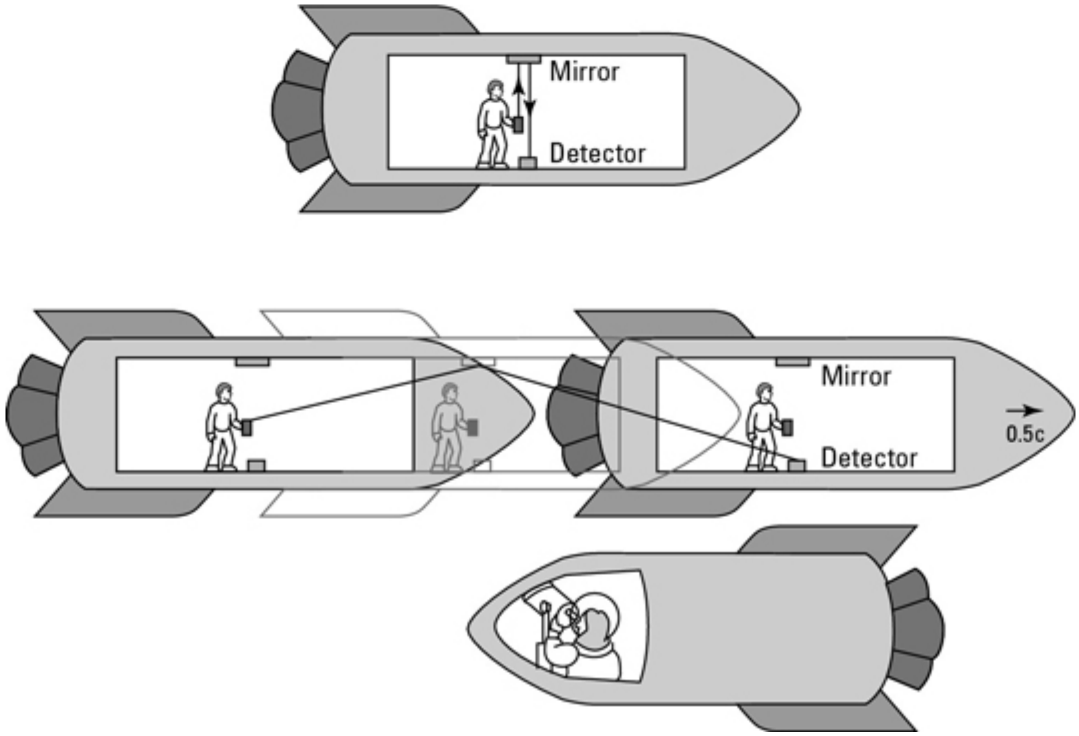
AU Science Club--1/15/13

Gravity and Relativity

Special Relativity—The definition of Special Relativity (SR) is based upon the fact that it involves motions of Bodies and Coordinate Systems which are at rest, or moving at constant speed with respect to one another. It does not address motions of Bodies which are accelerating –thus it is considered 'Special' or perhaps less 'General'. One of the most basic and important conditions with regards to SR, is that the laws of physics do not change for objects moving at constant speed. Secondly, the speed of light is the same for observers, regardless to their motion relative to the light source. The speed of light is extremely fast (186,000 miles per second), and so great that we simply can not relate it to our experience. Einstein's genius was to establish thought experiments to illustrate his revolutionary theories. A Space Traveler fires a Beam of Laser Light at a mirror mounted on the ceiling, and it is reflected straight down to a detector mounted on the floor. But, if you are observing this Space Ship (from the side) which is traveling at constant speed at half the speed of light, the Laser Beam is seen to move along a different path, which is longer, because the Space Ship is moving relative to your position. Since the Speed of Light is Constant, but the Path length is greater, the time for the Beam to travel from the Laser to the ceiling and floor becomes greater (TIME = DISTANCE/SPEED). Again, to maintain the Ratio of the Distance to Time fixed (which is SPEED), Time as Measured on a Clock become slower — this is known as Time DILATION. This effect must be accounted for in the use of information from GPS Satellites which travel at 87,000 miles/hour. This Special Relativity effect causes the Clock to lose 7 microseconds per day (approximately a 1 mile error.) (Note that since the GPS Satellites orbit 12,400 miles where the Earth's Gravity is less, the Clocks run faster by 45 microseconds per day, the net change in time is 38 microseconds per day or a 6 mile error). To summarize, SR demonstrated that Space and Time are closely linked –simply by

moving through space, the flow of time is influenced, as seen by an outside observer. General Relativity (GR), discussed below, ties the two together in the 'mesh' of Space/Time.



(Top) You see a beam of light go up, bounce off the mirror, and come straight down. (Bottom) Amber sees the beam travel along a diagonal path.

Gravity--Newton's Law of Universal Gravitation--
Force of Gravity (between 2 Objects) =
G (Gravitational Constant) X(Mass A) X (Mass B)/Distance (between Masses) Squared.
If the Distance between the 2 Objects becomes small, the Force becomes Large (approaching Infinity as the Separation goes to Zero).
For a person standing on the Earth, the Gravitational Force is:
F=m X g, where 'm' ('Weight of the Man'), and 'g' is the Acceleration due to Gravity. 'g' is a Constant that combines 'G—mass of the Earth' and 1/d Squared, and is equal to 32 ft/sec squared. Newton's Gravity Law involved 'force or action at a distance', although it was never fully explained.
Gravity causes Bodies to Orbit around on another. Einstein determined that as the Bodies Rotate, the Gravitational force varies in the form of Gravity Waves. He also determined that nothing can exceed the Speed of Light. Light from the sun arrives at the Earth in approximately 8

Minutes. If the Sun suddenly disappears, the loss of the Gravitational Force would instantly cause the Earth to Spin out of its Orbit, even though, the sun's disappearance is not observed for some 8 minutes. This issue, along with the in Gravitation Force approaching Infinity, as the distance between the Bodies became small, caused Einstein to realize that Newton's Law had to be essentially 'thrown out'.

Space-time. We all understand the concept of motion of a body in the 3 Dimensions in Space, but Einstein realized that by simply moving through space, it is possible to influence the flow of time as witnessed by an outside observer. Thus, it was impossible to think purely about an effect in space without considering the impact of time. In addition to the 3 spatial dimensions, to totally define the 'location' of a body, it is necessary to include time as a fourth dimension. If a body is fixed in space (not moving), time is still going forward, or the body is 'moving' in Space-time. Herman Minkowski developed the concept of Space-time a few years after Einstein published his paper on Special Relativity. His concept can be illustrated on a 2 dimensional plot where Space is the Horizontal axis, and Time the Vertical. If a Space Ship is not moving, the 'x' Component is zero, but the 'y' (Time) axis shows a straight vertical line. If the Space Ship is moving at the speed of light, the path will be a straight line at 45 Degrees. (Note that Time is Measured in years, and Distance in Light years—5.8 Billion Miles.) If the Space Ship is moving at 25% of the speed of light, the path is the straight line in the Figure. If the paper is twisted, the straight line path of the Beam of light shooting at a 45 degree angle, will now appear to also be warped or twisted—this is an indication of the curvature of Space. While the Minkowski plot appears like a traditional two-dimensional diagram of Space it is Not. It is a Space and Time diagram, where time only Flows in a positive (forward) direction (it can not go backwards). Also, where we might think our that the 'distance' along Space-time path could be calculated using the Pythagorean Theorem (Hypotenuse Squared equals the Sum of the 2 Sides of the Right Triangle Squared), this not true (Space-time 'distance' is the Difference between the Length of the 2 sides). Additionally, note that while the Plot illustrates the Space Ship simply moving along the 'x' axis, whereas there are 3 spatial dimensions --Length, Width and Height--, the coordinate System can be modified to satisfy any path for the Space Ship.

We would expect that Einstein's concept that the presence of matter would warp Space-time should be noticed in everyday life. It is experienced on Earth where the Shortest Distance between 2 Points on the Earth is not Straight Line, but an actual Circle. We do not notice

this effect in everyday conditions because the distance for which the curvature is noticeable is outside our field of view. This idea that Gravity (as caused by the existence of mass) is a tendency of bodies to move along warps in Space-time eliminates the whole problem of Newton's Gravity of 'force at distance'. Thus, the issues of the force becoming exceeding large as the distance approaches zero, and the Earth spinning out of its orbit before the light from the Sun arrives are resolved. Einstein turned Gravity into a kind of geometry.

Gravity/Acceleration-- Equivalency

General Relativity was born at the Swiss Patent Office in 1907 when Einstein realized that 'If a person falls freely, he will not feel his own weight'. He said this was 'The happiest thought on my life'. This thought, now known as the 'Principal of Equivalency', says that the effects of Gravity and Acceleration are the same. If you are standing on the floor in a Space Ship (no light or sound from the outside, with no vibrations), you will not be able to determine if the Space Ship is stationary on the ground and experiencing the pull of Gravity, or you are accelerating at the speed of 32 ft/sec/sec, where the acceleration is pushing you to the floor. It is interesting to note that Galileo had come up with his concept of relativity in the 1500s, where if you were inside an enclosed boat, you could not tell whether you were moving or standing still (this was known as Classical Relativity). Einstein goes beyond Classical Relativity, and includes the effect of Acceleration, with his revolutionary ideas about Gravity as the warping of Space-time.

References:

Book and PBS NOVA DVD, 'The Elegant Universe' by Brian Green

Book, 'Gravity' by Brian Clegg.