GENERAL RELATIVITY

Whereas Special Relativity is the study of *constant velocity* motion, General Relativity is associated with situations in which *accelerations* exist. As gravitation produces acceleration, gravity it dealt with in General Relativity.

The presence of matter affects 4-space.

In areas where there is no matter, space is the same everywhere (i.e., clocks all move at the same rate). This is called flat space.

In areas where there *is* matter, space is not the same everywhere (i.e., clocks do not all move at the same rate with those closest to the massive object moving slowest). This is called curved space, or warped space.

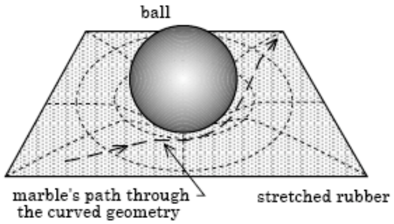
An interesting consequence of this is that in Einstein's world, GRAVITATIONAL FORCES DON'T REALLY EXIST. Indeed, gravitational *effects* do exist, but gravitational forces? No!

Example: Why does the moon orbit the earth?

Newton would say it is due to a gravitational force exerted on the moon by the earth.

Einstein would say that in reality, the moon moves as a force-free object, moving in a straight line. What's wild is that it does this in a *curved geometry* . . . so the path is circular in shape. (You can do a similar thing. Start walking west and sooner or later you will come up over the horizon from the east. You are walking, but you are doing it in a curved geometry.

A graphic example:



The marble doesn't change directions because there's a gravitational force on it, it changes direction because it is moving through a curved geometry. Einstein's theory suggests the same thing happens when light changes direction as it passes by a massive object like the sun. It isn't gravity that alters its motion, it's the fact that it is moving through a curved geometry.

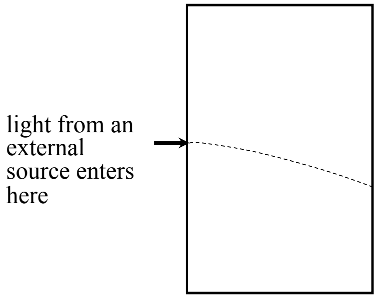
Proofs for both Special and General Relativity?

The eclipse of 1919 (General Relativity)

An abundance of mu-mesons in our lower atmosphere (Special Relativity)

Other stuff:

One of the things Einstein noticed is that there is no difference between a frame of reference that is under the influence of what Newton would have called gravity (i.e., one that resides in *curved space*) and a frame of reference that is accelerated (Einstein called this observation *the Principle of Equivalence*). In both cases, the light will curve downward.



As bizarre as this may seem, this slowing of time as one gets closer to the surface of the earth (or any massive body) has been experimentally observed. The Pound-Rebka experiment at Harvard University used a gamma ray source, a Mossbauer detector and the Doppler effect to indirectly show that time on one floor of a Harvard building ran more slowly than time on an upper floor of that same building. In 1969, another experiment determined that time measured at the Bureau of Standards at Boulder, Colorado (altitude 5400 feet above sea level) gains 5 microseconds per year relative to a similar clock at the Royal Greenwich Observatory in England (altitude only 80 feet above sea level). Nowadays, all clocks used to track international time (i.e., in Paris, in Tokyo, etc.) must be adjusted to correct for the fact that time runs more slowly at sea level than it does in the mountains.

Black holes: If you have a star whose core is greater than 1.8 solar masses, it's death (a supernova) will find its core imploding. As was the case with neutron stars, the implosion will force electrons into nuclei whereupon the joined protons and electrons will combine to make neutrons. What's different is that with the enormous mass involved, not even the jamming of neutrons against neutrons will stop the implosion so the collapse continues FOREVER. When this happens, we end up with a structure that is so gravitationally massive that not even light can escape when emitted inside the structure's event horizon. This is a BLACK HOLE.

The radius of the event horizon for a non-rotating black hole is called the Schwarzchild radius.

At the center of a black hole is a singularity. A singularity is a zero-volume, infinitely dense "region" in which exists infinitely curved space-time.

Even though black holes are not visible, they are detectable in the sense that when gas is pulled into one the gas's temperature increases enormously and it ends up emitting high energy X-ray radiation.

It is believed that there is an approximately 4,000,000 solar-mass black hole at the center of our galaxy.

The largest known supermassive black hole is found at the center of OJ 287 and weighs in at 18,000,000,000 solar-masses (that's 18 billion solar masses).

What would it be like to jump into a black hole?

This would depend upon your perspective. Suppose you were on earth using a powerful telescope to watch a friend jump into a black. What would you see?

You'd see your friend approach the black hole and SLOW DOWN as he got close. In fact, at some point it would appear to you that he would actually stopped altogether and simply hanging out there in space. You could leave your telescope, go off and live life, then return fifty years later just before you died, and your friend would not appear to have moved hardly at all.

What would it be like to jump into a black hole?

What would it be like for your friend?

For him, everything would happen very fast--within seconds as measured by his clock. But during those few seconds before the tidal forces at his feet more or less noodled him out into an aggregate of atoms, if he looked out into the heavens he would see galaxies being born, living then dying.

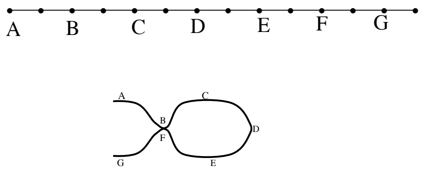
That is, enormous periods of time would elapse “out there” during his few seconds.

Why? Because the black hole would so warp the geometry of space around it, time would nearly slow to a stop (relative to time “out there”).

Pretty cool, eh?

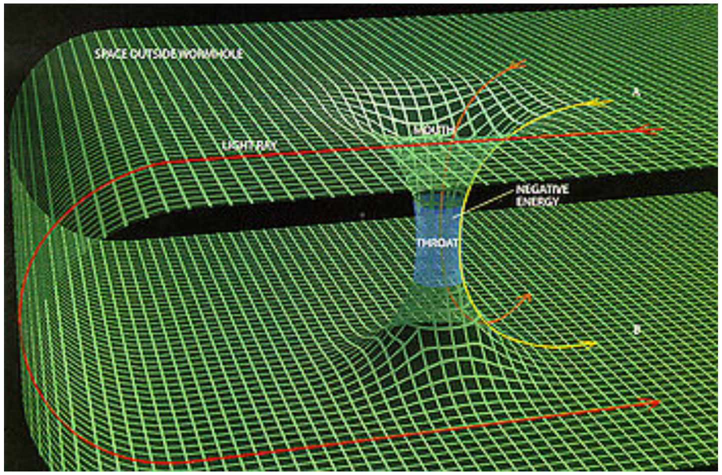
Other stuff to know about:

Gravity waves: Under the right conditions, when a massive object moves in space it can disturb the curvature of the space-time geometry in which it resides. This disturbance moves out away from the event in what is called a *gravitational wave*.



Wormholes: Space is not a nice, linear structure. It is possible that space-time might curve back on itself in such a way that a point that is a considerable distance from another in point in space is actually quite close due to the curvature. Example: Take a long string. Identify coordinates on it. Curve it back on itself. Note that Point B is right next to Point F. If they were to touch, you would have a wormhole.

A three-dimensional example of a wormhole is shown below (I yanked the photo from Wikepedia.



Also to be discussed:

Time travel using wormholes.

What would happen if you jumped into a black hole?