Ch 12, 13: Relativity and universe

Special relativity

1. Time Dilation
   a) Experiments in which one atomic clock is placed on a moving airplane, and another remains at rest on Earth will show different times on the two clocks. Less time will have passed according to the clock on the moving airplane. Both clocks are right: One gives the time according to the reference frame of the moving airplane (v = 675 mph); the other gives the time according to the "laboratory" reference frame (v = 0 mph)

   b) Radioactive decay of particles moving at high speeds has been measured to occur less frequently than radioactive decays for particles moving at lower speeds.

   c) Clocks on GPS satellites have to be adjusted for both the time dilation of special relativity (since the satellite orbits the earth at a reasonably high speed) and also for the general relativistic effect of gravity (or altitude) on the satellite.

   d) A particle moving at the speed of light experiences no time. It cannot experience radioactive decay.

2. Length Contraction
   a) The length of an object moving with velocity v, as measured in the laboratory reference frame, will be less than the length of the object according to the reference frame of the moving object (i.e. the frame with velocity v).

   b) Length contraction of particles moving at high speeds has been experimentally verified.

3. Mass Increase
   a) The mass of an object moving with velocity v, as measured in the laboratory reference frame, will be more than the mass of the object according to the reference frame of the moving object (i.e. the frame with velocity v).

4. Order of Events.
   a) The time in between two events depends on the reference frame in which the time is measured. In fact, if one event occurs a very short time after another event, and the two events occur at a distance from each other, then the order of the two events can be different in the laboratory reference frame and the reference frame of a tachyon!

   b) If two events occur in the same location, then the order of the two events is unambiguous. It is the same in all reference frames.

5. Relative Velocity.

a) If the velocities of two particles are both less than c (the speed of light in a vacuum), then the relative velocity of the two objects must be less than c.

b) If the velocity of a particle is c, then the relative velocity between it and anything else is also c.

6. E = mc^2.

a) The mass m is the relativistic mass, which is the rest mass divided by the Einstein factor.

b) At relatively low velocities, this is approximately equal to the rest mass times c squared ("rest energy"), plus the kinetic energy (one half times the rest mass times the square of the velocity). Unless the velocity is huge, as long as the rest mass is nonzero, the rest energy is much greater than the kinetic energy.

c) A mathematical consequence of this is that a particle moving at velocity c must have zero rest mass. So a photon has no rest mass. If a particle has nonzero rest mass, then it moves at a velocity other than c. Hypothetically, it could move at a speed faster than c (tachyons), but it could not move at the velocity c.

d) Rest mass can be converted into kinetic energy. In radioactive decay, the sum of the rest masses of the fission fragments is less than the rest mass of the nucleus that decayed. This rest mass is converted into kinetic energy. A further example is that if matter/ antimatter pairs collide, then two photons are produced. The energy of these photons is purely kinetic, since they have no rest mass. Therefore, by conservation of energy, the rest energy of the matter/antimatter pair was converted into the kinetic energy of the photons.

General Relativity

1. The geometry of space is determined by gravity. The gravitational attraction between masses "curves" space in a precise mathematical sense usually studied in graduate courses.

2. Time depends on gravity, and therefore altitude: time passes more quickly at high altitudes than lower ones. This effect has to be combined with time dilation from special relativity in order to correctly set GPS clocks.

The Big Bang

1. The Big Bang is believed to have occurred 14 billion years ago.

2. The first few minutes of the early universe were extremely hot, and would have been filled with visible light. Light from distant regions of the universe emitted during that

time would only be reaching us now. But since those regions are moving away from us, taking into account the Doppler effect, that light would be detected as microwaves. Indeed, the predicted microwaves have been detected,, providing the most compelling evidence for the Big Bang.

3. In the first few seconds of the Big Bang it is believed that there were only a few elementary particles, electrons, protons, and hydrogen. Due to the intense heat, helium was created for the first 3 or 4 minutes in a fusion process. As the universe expanded, it cooled, and the fusion of helium stopped after this 3 or minute period. It was calculated that 25% of the mass of stars should be helium. Measurement verifies this providing additional evidence for the Big Bang theory.

4. The cooling matter began to clump together due to gravitational attraction. Thus stars, planets, comets, etc were formed. The interior of stars is hot and dense enough that further fusion processes take place within them, creating lighter elements such as carbon and nitrogen. But elements heavier than iron would not be formed in this manner.

5. Occasionally stars explode in supernova events. Heavier elements than Iron are formed through fusion due to the intense heat of the explosion. Later the remains of the exploded star clump together due to gravity forming secondary stars such as the sun and planets such as Earth. Our solar system is about 4.5 billion years old.

6. It is believed that in the first fraction of a second of the Universe's existence, all particles were massless, but had a "Higgs charge" that measured their interaction with one another. Within the first millionth of a second after the Big Bang, the "false vacuum" was filled with the Higgs field, causing particles with a strong Higgs charge (such as electrons and protons, but not photons) to become massive. The Higgs particle is a massive particle that many physicists believe will be soon detected at Cern.

7. The universe is expanding in a uniform way in accordance with Hubble's law, $v = HR$. However, the known matter and also dark matter should cause the expansion of the universe to slow down. But measurements show that the expansion of the universe is accelerating! Some energy must be driving the acceleration. This mysterious energy is given the name dark energy. The uniform character of Hubble's law implies that the universe has no center. In combination with General Relativity, the acceleration of the expansion of the universe also implies that the universe is infinite.

More on the universe

1.The sun is 8 light minutes away from the Earth. The next nearest star, Proxima-Centuri, is 4.3 light years away. The Andromeda galaxy is 3 million light years away.

2. There is a black hole at the center of the Milky Way galaxy. There are about 10 billion stars in the Milky Way, and also Andromeda. The sun and earth spin around the black hole in the center of the Milky Way at a speed of about 1 million miles per hour. It takes

250 million years for the Earth to revolve around this galactic center. There are more galaxies in the universe than there are stars in the Milky Way.

3. The mass of all the known matter in the Milky Way is not enough to keep the Sun in orbit around the galactic center. There must be some additional mass keeping the sun in orbit. This mass is given the name dark matter. Dark matter may be WIMPS or MACHO's.

4. Drake's equation attempts to calculate the number of planets in our galaxy with intelligent life that our trying to communicate with us. The equation is a product of 8 terms. There is so much uncertainty regarding the correct values to plug in to these terms that the value of the equation is unclear.