TIME LINES WE ARE INTERESTED IN

1.) The creation of protons and neutrons.

2.) The creation of nuclei.

3.) The creation of atoms.

4.) The production of forces.

5.) The progression of the size of the universe, both of the event horizon at various times and the event horizon of the stuff that is now inside our current event horizon at those times.

6.) The progression that led to the universe being lumpy.

The Production of Protons and Neutrons

--Before 10^{-43} seconds after the Big Bang (this is called *the Planck era*), enormous energy fluctuations created enormous, random, gravitational field variations and all sorts of bizarre, random matter interactions. As we don't have a theory that links gravity and the physics of the very small (i.e., quantum mechanics), we have no idea what was going on during the Planck era. (Note that if we ever do get such a theory, it will be dubbed "The Theory of Everything," or TOE.)

--By 10^{-10} seconds, the universe's expansion had dropped the temperature to approximately 10^{15} degrees Kelvin.

Theory predicts that at that temperature, *W bosons* should come into existence through mass/energy conversion ($E = mc^2$). Sure enough, the particle accelerator at CERN in Switzerland was able to generate this kind of energy in 1983 and, lo and behold, when it did, out came *W bosons*. (Isn't this fun!)

--It is believed that just above the 1TeV point (i.e., just before the 10^{-12} seconds mark and just above what our best particle accelerators can achieve) in the universe's expansion an asymmetry in quarks occurred. (In fact, there has been one observed situation in which an energy interaction has produced a similar asymmetry, though that situation is not believed to be the actual mechanism involved in the early quark happening.) As a consequence, from that point on there were more quarks in the universe than anti-quarks.

before 10^{-10} seconds after the Big Bang:

--During this period, the temperatures and pressures in the universe were so high that energy-turning-into-matter and matter-turning-into-energy happened so frenetically that no “permanent” particles “frozing out.”

between 10^{-10} seconds and 10^{-3} seconds (called "the particle era"):

--During this period, particles and antiparticle were going through the process of annihilation to create energy, and energy was creating matter via pair production. As a consequence, the number of particles (both matter AND anti-matter) and photons throughout this period were approximately the same.

around 10^{-6} seconds after the Big Bang:

--At around 10^{-6} seconds, there was a kind-of phase shift in the quark population that made it more energetically favorable for quarks to group together into packets (can you spell P R O T O N S, A N T I - P R O T O N S, N E U T R O N S, etc.). During this time, anti-matter was common.

During this time, the particle energy of the universe was around 1 GeV. This means the rest mass of protons and neutrons is around 1 GeV. In fact, the rest mass of a neutrons is only 1 MeV higher than that of a proton.

by 10^{-3} seconds:

By this time, the temperature and pressure in the universe dropped to the point where photons no longer had enough energy to create particles via pair production, so this process stops.

Note: As there was approximate parity between photons and particles (i.e., protons, anti-protons, etc.) when particle production ended, and there is now a billion to one ratio between photons and particles, it can be deduced that for every billion proton/anti-proton annihilations during this period, one proton survived as matter. That matter survives to this day, quite possibly in your own body!

After this point, quarks are no longer being created (expansion has rendered the universe's energy too low) and all anti-particles have annihilated with their particle counterparts. This eliminated all of the anti-protons and anti-neutrons in the universe. Due, though, to the quark/anti-quark asymmetry, some protons and neutrons were left over. Those protons and neutrons are the entities that now populate our known physical universe.

The Production of Atomic Nuclei

between 10^{-3} seconds and 3 minutes (era of nucleosynthesis):

Before 1 second after the Big Bang, the universe was so energetic that protons and neutrons would collide but would not stay bound.

The binding energy of a proton and neutron (i.e., a deuterium nuclei) is 2.2 MeV.

Right around the 1 second point, the particle energy of the universe just happened to be right around 2.2 MeV. That meant that when deuterium nuclei were created, there was a possibility that 2.2 MeV protons might crash into them and split them.

Also at this point in time, deuterium nuclei were colliding and combining to make helium nuclei. Helium nuclei have a binding energy of 28 MeV, which means that unlike the deuterium nuclei, once a helium nuclei was created, no 2.2 MeV proton collision would split them. This is the reason why our universe has so comparatively few deuterium atoms, relatively to helium atoms.

Additional minutia: Deuterium nuclei had to overcome that 1 MeV charge barrier to bind to make helium. This would have been a formidable obstacle to overcome, but the high energy and density of the universe at the 1 second point allowed an interesting quantum mechanical phenomenon to occur. Deuterium in that high energy environment could easily "tunnel" through the charge barrier and combine to make helium nuclei.

Another additional bit of minutia: Because the binding energy of neutrons is 1 MeV higher than for protons, neutrons "froze out" earlier as the primeval universe's temperature dropped with expansion. With protons having the opportunity to form for a longer period of time, this is why there are more protons in the universe than neutrons.

If that hadn't been the case--if the rest mass energies had been the same--there would have been the same number of protons as neutrons and most of the universe would have ended up as helium.

As things stand, there is about 25% helium to 75% hydrogen in the universe.

By the 3 to 10 minute mark, initial nucleosynthesis stopped due to a fast drop-off of temperature and pressure as the universe expanded. Additionally, as a neutron will decay into a proton, electron and muon in about 10 minutes, nucleosynthesis stopped by this time because the universe simply ran out of free neutrons.

between 3 minutes and 380,000 years (era of nuclei):

During this period, the universe consists primarily of hydrogen nuclei, helium nuclei and electrons in an extremely hot (billion degrees Kelvin) plasma state.

Again, after 10 minutes there are no free neutrons left in the universe.

During this period, the universe is still expanding but is still dense with electrons. In fact, the electron density is so great that photons could not travel very far without running into and being deflected by collisions with electrons.

At 50,000 years, the radiation energy content and the mass energy content is approximately equal with the edge going to mass as time proceeded.

Why does the energy wrapped up in mass become dominant over energy wrapped up in radiation at this time?

Radiation frequency and wavelength are inversely related ($c = \lambda\nu$, where c is the speed of the light wave). That means that if the wavelength increase with time, the frequency decreases.

As the universe expanded, everything spread out, wavelengths included (I.e., they increased). As a consequence, radiation frequencies in the universe decreased

The energy content of a photon is proportional to the frequency ($E = h\nu$, where ν is the frequency and "h" is Planck's constant). So as frequencies go down, so also does the energy content of the photon population and the energy content of radiation.

In short, the energy content of radiation (light) decreases due to "red shift" as the universe expands, whereas the energy content of matter stayed the same with time.

The Production of Atoms

at the 380,000 year mark:

At this point, the universe had cooled enough for electrons to combine with protons and neutrons to make neutral atoms.

The removal of electrons allowed light to begin to free stream.

Note: Before this time, light from the sun would have appeared very dim to us due the inability of light to get through the dense accumulation of free electrons that existed in space.

This free streaming of photons is what is today observed as the universe's background cosmic microwave radiation.

Also, as long as radiation was coupled with matter (I.e., the situation before the 380,000 mark), it was impossible for gravity to attract large quantities of stuff--a prerequisite for the formation of protostars.

after the 380,000 year mark:

By 140,000,000 years, the universe has cooled enough through expansion to allow first generation stars to coalesce into existence.

Note: The first generation stars put out so much energy that they increased the energy content of the universe to the point that second generations stars production was stifled.

By 1,000,000,000 years after the Big Bang, the universe had cooled enough to allow second generation stars to come into existence

By 13,600,000,000 years after the Big Bang, the universe had cooled enough to allow third generation stars, our star the sun included, to come into existence

The Production of Forces

during the Planck era (before 10^{-43} seconds):

All forces are assumed to have been one.

at 10^{-43} seconds:

Gravity is believed to have separated from the strong and electroweak forces, which were still one at that time

at 10^{-38} seconds:

Strong force is believed to have separated from the electroweak force.

at 10^{-10} seconds:

The weak force and the electromagnetic force separate.

The strong force is 137 times stronger than the electromagnetic force, 100,000 times stronger than the weak force and 6,000 billion billion billion billion times stronger than gravity.

The strong force only operates over very small distances--1000th millionth millionth of a meter (this is close to the diameter of a proton). It is the consequence of "leakage" of the quark "flavor."

Time Line for Universe's Size

Note that there are two distances that are important when you are talking about the size of the universe in the past. The event horizon identifies how far out you would be able to see at the time if you existed at the time. The second quantity I identify as, "how far out was the material we can see now at the time in question." You will find both alluded to below.

at 10^{-38} seconds:

The event horizon was 10^{-38} centimeters and the material that would come to be within our current event horizon span out a distance of 2 meters.

at 10^{-10} seconds:

The event horizon was 6 centimeters and the material that would come to be within our current event horizon span out a distance equal to the distance between the Sun and Pluto.

at 1 second:

The event horizon was 350,000 miles and the material that would come to be within our current event horizon span out a distance equal to 200 light years.

at 13,600,000,000 years after the Big Bang:

It's now, and the event horizon is at 13.6 billion light years.

Progression for Theories

TOE: Stands for "Theory of Everything"--it is the theory that deals with the the possibility that all four forces were initially one.

GUT: Stands for "Grand Unified Theory"--it is the theory that deals with gravity as a separate entity with the strong, weak and electromagnetic (the last two being manifestations of the electroweak force) being one.

Time Progression for Inflation

sometime between 10^{-42} and 10^{-36} seconds:

The universe went through its first period of inflation.

It is possible that inflation was begun when energy was released when the strong force separated from the electroweak force at 10^{-38} seconds (maybe).

In any case, it is believed it did occur. The significance? Just after the Big Bang, everything was homogeneous and connected in the sense that everything was in thermal equilibrium. With inflation and the subsequent shrinking of the event horizon, large parts of the universe fell out of contact and, hence, out of thermal equilibrium with their neighbor. That meant that there were many, many sections of the universe that evolved independent of neighbors. When inflation stopped, the event horizon began to grow and the increasingly connected disparate parts of the universe emerged as individual clumps of stuff. We call these “galaxies.”

now:

We aren't sure why, but inflation is evidently happening NOW.

The estimate is that if this continues for the next 10 billion years, the only stars evident on earth (should earth still be here) would be those inside our own galaxy. That is, of the 200 billion galaxies (complete with 200 billion stars per) that are currently viewable and in range of the Palomar telescope, NONE of them will be visible on earth.

How's that for AWESOME!