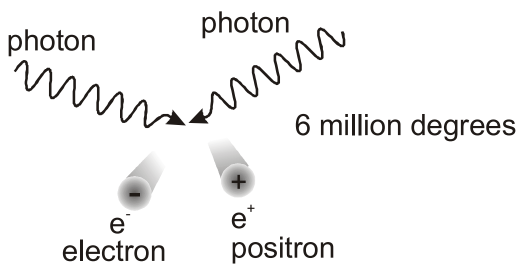
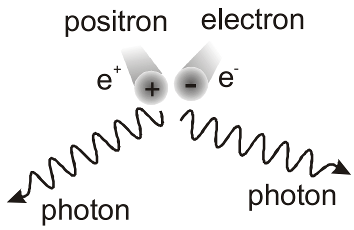
Big Bang – the first three minutes

Steven Weinberg: The First Three Minutes, Basic Books 1993

Physicists cannot say anything about the very beginning (time t = 0 until time t = 0.01 seconds). Supposition: Temperature $T > 10^{12}$ K (Kelvin); Temperature infinite? Only pi-mesons with strong interaction?

TT = Threshold Temperature. This is the temperature that must be reached before particles of a distinct type can be created out of radiation energy.





$TT(e^+, e^-) = 6 \times 10^6\ K = 6 \times 10^6\ K$

$TT(\mu^+, \mu^-) = 1{,}226 \times 10^6\ K = 1.226 \times 10^9\ K$

$TT(\pi^+, \pi^-) = 1{,}566 \times 10^6\ K = 1.566 \times 10^9\ K$

$TT(p, \bar{p}) = 10{,}888 \times 10^6\ K = 1.089 \times 10^{10}\ K$

$TT(n, \bar{n}) = 10{,}903 \times 10^6\ K = 1.090 \times 10^{10}\ K$

First Frame

Time t = 0.01 s, Temperature $T = 10^{11}$ K

Temperature is higher as TT of electrons, protons and neutrons.

Matter and radiation are in perfect *thermal equilibrium*, that means in every moment an equal number of **matter** (electrons, protons and neutrons) **out of radiation** and **radiation out of matter** is created.

number of electrons = number of positrons

number of neutrinos = number of antineutrinos

number of protons = number of neutrons

neutrino + **neutron** ↔ electron + **proton**

antineutrino + **proton** ↔ positron + **neutron**

total energy density = $21 \times 10^{44}\ \frac{eV}{dm^3}$

total mass density = $3.8 \times 10^{9}\ \frac{kg}{dm^3}$

$$1 \begin{Bmatrix} \text{proton} \\ \text{neutron} \end{Bmatrix} \text{ per } 10^9 \begin{Bmatrix} \text{photons} \\ \text{electrons} \\ \text{neutrinos} \end{Bmatrix}$$

Complex nuclei (as helium, carbon …) are destroyed as fast as they are formed.

How big was the universe?

If the universe at that time was **infinite**, if it is **infinite now**, it was **finite** then, it is **finite now**.

If the universe is finite now, it's circumference would be 10^{11} Ly (lightyears).

The circumference at a temperature of 10^{11} K would have been 4 Ly.

The universe doubles in size every 10^{-34} seconds.

Second Frame

Time t = 0.11 s, Temperature T = 3×10^{10} K (three times less than 10^{11} K)

Electrons, positrons, neutrinos an antineutrinos in thermal equilibrium, high above TT.

mass density = $30 \times 10^{6} \frac{kg}{dm^3}$

38 % neutrons and 62 % protons

Third Frame

Time t = 1.089 s, Temperature T = 10^{10} K (three times less than 3×10^{10} K)

Electrons and positrons begin to annihilate more rapidly than they can be recreated out of radiation.

24 % neutrons and 76 % protons

Still **no atomic nuclei**.

Forth Frame

Time t = 13.8 s, Temperature T = 3×10^{9} K (three times less than 10^{10} K)

T is below TT(electrons, positrons) = 5.9×10^{9} K

Electrons and positrons annihilate to energy, no new electrons and positrons are createt by radiation. So most electrons and positrons disappear.

Chief constiuents of the universe: Photos, neutrinos, antineutrinos.

Universe is not cool anough to form ${}^{2}_{1}H$ (deuterium nucleus; proton and neutron cannot hold together).

14 % neutrons, 86 % protons.

A little later:

Time t = 3 min 46 s, Temperature T = 0.9×10^{9} K

Temperature drops at a point at which deuterium nuclei can hold together.

Heavier nuclei can be built up (nucleosynthesis):

$${}^{2}_{1}H + n \rightarrow {}^{3}_{1}H$$

$${}^{3}_{1}H + p \rightarrow {}^{3}_{2}He$$

$${}^{3}_{2}He + n \rightarrow {}^{4}_{2}He$$

13 % neutrons, 87 % protons.

Almost all neutrons are cooked into helium nuclei.

Sixth Frame

Time t = 34 min 40 s, Temperature T = 3×10^8 K

Electrons and positrons are now completely annihilated except for the small excess of electrons needed to balance the charge of the protons.

The universe consist of neutrinos, antineutrinos, a small percentage of protons (hydrogen), electrons and helium nuclei.

The ratio between protons and helium nuclei is about 4 to 1.

For the next 700,000 years not much of interest will occur. Electrons join nuclei to form stable atoms (hydrogen, helium). The universe gets transparent for radiation. We can look back only to the time of nucleosynthesis.

Matter begins to form stars and galaxies.

The maaterial left over from the first three minutes: 22 – 28 % helium
72 – 78 % hydrogen
huge amount of photons, neutrons

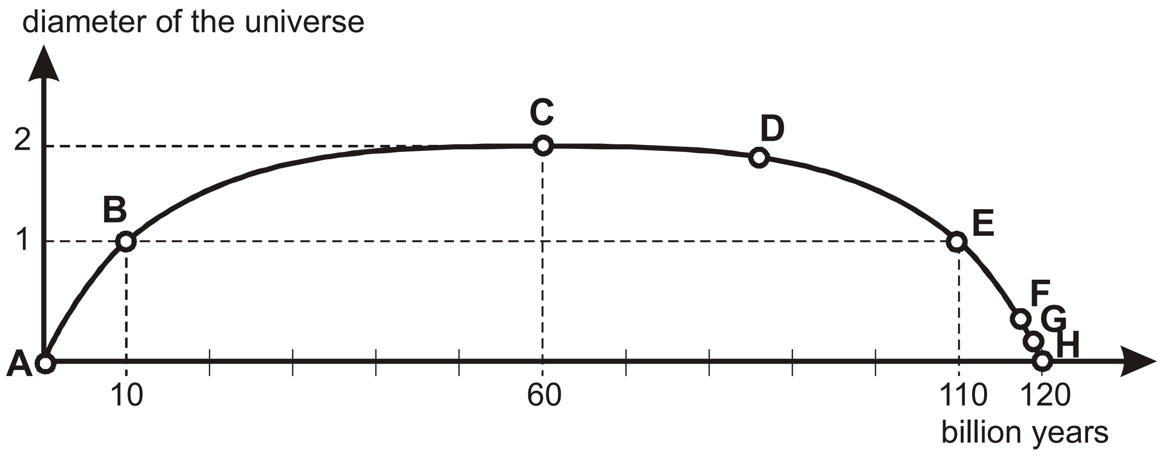
About 10^9 neutrinos and antineutrinos for every nuclear particle in the universe.

The sun and the stars start their live with 20 – 30 % helium and 80 – 70 % hydrogen.

THE PROSPECT AHEAD

The cosmic density (seems to be) less than the critical value. So the universe will expand forever. In the end there will be only *black dwarf stars*, *neutron stars*, *black holes*. Planets will continue to orbit (slowing down a little). There will be still background radiation, still neutrinos.

Asumption: cosmic density twice the critical value.



A Big Bang

B background radiation of 3 Kelvin, red shift because of expansion

C universe begins to shrink, background radiation of 1.5 Kelvin

D red shift and blue shift

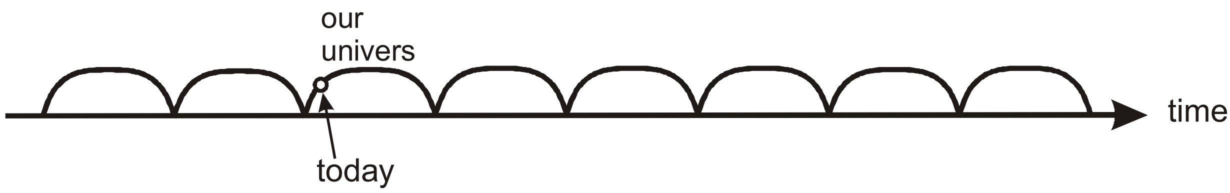
E background radiation of 3 Kelvin, blue shift because of contraction

F the universe has contrated to one-hundredth of his persent size, background radiation 300 Kelvin, the night sky will be as bright as todays daytime

G sky intolerable bright, molecules and atoms dissoziate into nuclei and electrons

H Temperature 10^7 Kelvin, cosmic soup of radiation, electrons, nuclei
last hundredth second ???
finaly the “Big Bounce”, maybe **reexpansion …???**

If the Big Bounce and reexpansion is our future, it presumable is also our past. the present universe would be only the phase following the last contraction and bounce. There would be no beginning, no end.



There is not much comfort in any of these theories. The earth faces a future of extinction of endless cold or intolerable heat.