Homework XI: Big Bang Cosmology

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Remember that $c = 1$.

Problem 1 Kasevich Lab Tour

Describe in your own words the purpose of the experiment you saw today. What are the challenges that the experiment must overcome? What are the possible outcomes and the implications for physics of each possibility? Which result would you find most interesting?

Problem 2 Timeline of the Big Bang

Make a timeline of the various stages of the big bang. Give energies, temperatures, and times for each of the major epochs. Describe which symmetries are applicable, which particles are in equilibrium, and which bound states can be formed.

Problem 3 An extra neutrino

At temperatures near 10^{10} K, the relationship between the age and temperature of the universe is given by

$$t = \sqrt{\frac{3}{16\pi G \mathcal{N} a_B}} \frac{1}{T^2} + \text{constant} \tag{1}$$

where a_B is a combination of fundamental constants called the *Stefan-Boltzmann constant* and $\mathcal{N}$ is the number of relativistic particles, counting particles and antiparticles and each spin state separately. Fermions get a funny factor of $\frac{7}{8}$. For example, if we have

- Photons with two spin states.

- Three species each of neutrinos and antineutrinos, but no right handed neutrinos.
- Electrons and positrons with two spin states each.

then $\mathcal{N} = 2 + \frac{7}{8}(6 + 4) = \frac{43}{4}$.

Suppose there was a fourth neutrino. Qualitatively, how would this effect the rate of cooling? Does this effect the ratio of neutrons to protons? Remember that neutrons are unstable to β-decay until they form nuclei.

Problem 4 Looking back in time

Explain why it makes sense to say that cosmic microwave background radiation allows us to look at what happened at a very early time in the universe. When and where did the photons being observed today last interact?

Problem 5 Reading

Read pages 200-239 of Oerter.