Early Universe: BBN physics

Review questions

1. What is the typical energy scale associated with nuclear fusion and fission processes?

   a) 10 keV

   b) 10 GeV

   c) 10 eV

   d) 10 MeV

2. Based on your answer to the previous question, what would be a rough estimate of the temperature required for deuterium synthesis?

   a) $\sim 10^4$ K

   b) $\sim 10^6$ K

   c) $\sim 10^8$ K

   d) $\sim 10^{10}$ K

3. Using the estimated temperature from the previous question, at what time after the Big Bang does deuterium synthesis occur?

   a) $\sim 10^{-3}$ sec.

   b) ~ 1 minute

   c) ~ 1 day

   d) ~ 1 year

4. Explain the reasoning behind the statement that an ideal or most stable universe would be one in which baryonic matter primarily consists of an iron-nickel alloy.

1. What is the theoretical maximum fraction of the baryon mass that can be converted into helium-4 (^{4}He) during Big Bang Nucleosynthesis?

   a) $\frac{1}{2}$.

   b) $\frac{1}{3}$.

   c) $\frac{1}{4}$.

   d) $\frac{1}{5}$.

2. The nucleosynthesis temperature is defined as:

   a) 1 MeV.

   b) $n_D(t_{\text{nuc}}) = n_n(t_{\text{nuc}})$.

   c) $n_p(t_{\text{nuc}}) = n_n(t_{\text{nuc}})$.

   d) $2n_D(t_{\text{nuc}}) = n_n(t_{\text{nuc}})$.

   e) $2n_p(t_{\text{nuc}}) = n_n(t_{\text{nuc}})$.

3. The deuterium bottleneck is a crucial phase in Big Bang Nucleosynthesis (BBN). What are its main consequences for the formation of light elements in the early Universe?

   a) It accelerates the formation of heavier nuclei.

   b) If the bottleneck were larger, more heavy elements like carbon and oxygen would have formed in the early Universe.

   c) The efficiency of helium-4 production depends on how quickly deuterium can form and survive.

   d) A weaker deuterium bottleneck could lead to an increased abundance of lithium-7.

4. The neutron half-life of approximately 900 seconds is crucial for Big Bang Nucleosynthesis (BBN). What would be the consequence for light element production if the neutron half-life were extremely short, such as a microsecond?

   a) Almost no neutrons would survive to participate in nucleosynthesis, drastically reducing the formation of helium-4.

   b) The Universe would be dominated by hydrogen, with very little helium and heavier elements.

   c) The deuterium bottleneck would be significantly affected, altering the overall element abundances.

   d) There would be no significant impact on nucleosynthesis, as protons would still fuse into heavier elements efficiently.

5. The "lithium problem" refers to the discrepancy between the predicted and observed abundance of lithium-7 in the Universe. What is the main cause of this problem?

   a) Uncertainties in the nuclear reaction rates involved in Big Bang Nucleosynthesis (BBN).

   b) The destruction of lithium-7 in stars over cosmic time.

c) A possible modification of standard cosmology or new physics beyond the Standard Model.

d) All of the above.

6. One of the Sakharov conditions is:

   a) Violation of charge conjugation symmetry (C).

   b) Violation of lepton number L.

   c) Departure from equilibrium.

   d) All of the above.

7. Big Bang nucleosynthesis is sensitive to the physical conditions in the first three minutes after the Big Bang. In this question, you will explore how this can be used to probe various types of physics beyond the Standard Model. You will be asked to assess how changes to the physics during BBN would affect the amount of helium and deuterium that is being produced.

   a) There were more relativistic species during BBN than we expected.

   b) The weak interaction strength was smaller than we thought.

   c) Newton's constant G is larger during BBN.

   d) The neutron-proton mass difference was larger than supposed.

   e) The neutron lifetime was shorter than assumed.

   f) There were many more neutrinos than anti-neutrinos.