

AS2001

Nucleosynthesis and the Chemical Evolution of the Universe

Tutorial 3 – Answers

Question 1

Quantum gravity (TOE) era – before the Planck time when quantum corrections to gravity were important.

Baryogenesis – origin of matter – anti-matter asymmetry during GUT era.

End of GUT era – the strong nuclear force separates from the electro-weak force.

Electro-weak transition – electromagnetism and the weak nuclear force separate.

Quark-hadron transition – quarks get together to form neutrons and protons.

Primordial nucleosynthesis – neutrons and protons get together to form the light nuclei D, ^3He , ^4He and ^7Li .

Matter-radiation equality – the energy densities of matter and radiation are equal, from now on matter dominates the dynamics of the universe.

Recombination – protons and electrons combine to form H atoms.

Structure formation – structures such as galaxies, clusters of galaxies form by gravitational instability.

Stellar nucleosynthesis – all other elements are synthesized inside stars or during supernova explosions.

The sequence of the last two points is not well known; they might have occurred simultaneously.

Question 2

Since electrons and protons combine into H for the first time in the history of the universe the term ‘combination’ might be more appropriate than ‘*re*-combination’.

Question 3

$$\begin{aligned} 0.25 &= Y = \frac{m_{\text{He}}n_{\text{He}}}{m_{\text{H}}n_{\text{H}} + m_{\text{He}}n_{\text{He}} + m_{\text{Li}}n_{\text{Li}}} \\ &= \frac{4m_{\text{H}}n_{\text{H}}\frac{n_{\text{He}}}{n_{\text{H}}}}{m_{\text{H}}n_{\text{H}}(1 + 4\frac{n_{\text{He}}}{n_{\text{H}}} + 7 \times 10^{-6})} \end{aligned}$$

and so

$$\begin{aligned}\frac{n_{\text{He}}}{n_{\text{H}}} &= \frac{0.25}{4} \left(1 + 4 \frac{n_{\text{He}}}{n_{\text{H}}} + 7 \times 10^{-6} \right) \\ \frac{n_{\text{He}}}{n_{\text{H}}} &= \frac{\frac{0.25}{4} (1 + 7 \times 10^{-6})}{0.75} = \frac{1 + 7 \times 10^{-6}}{12} = 0.083\end{aligned}$$