IL NUOVO CIMENTO VOL. 112 B, N. 2-3 Febbraio-Marzo 1997

Effect of neutrino oscillation on primordial nucleosynthesis (*)

H. W. LEE (1) and D. J. SONG (2)

(1) *Department of Physics, Inje University*
607 Obang-dong, Kimhae, Kyungnam 621-749, Korea
(2) *Korea Astronomy Observatory - 36-1 Whaam-dong, Yusong-ku, Taejon 305-348, Korea*

(ricevuto il 30 Luglio 1996)

Summary. — Primordial nucleosynthesis is one of the best tools to investigate the early-universe model. Standard big-bang nucleosynthesis (SBBN) could predict or determine some important cosmological parameters, baryon-to-photon ratio, number of neutrino species, etc. After remarkable success of SBBN , there was a lot of variant nucleosynthesis, that is degenerate neutrinos, inhomogeneous matter distribution, varying gravitational constant, etc. All of these models assume that all neutrinos are massless, but actually we have only the upper bound for those masses. If we allow neutrino to get a non-zero mass, the picture will be changed. Non-zero neutrino mass causes neutrino oscillation between neutrino species. This neutrino oscillation is well studied to solve the solar-neutrino problems. Here we will study the basic theoretical background for the effect of massive neutrinos on primordial nucleosynthesis.

PACS 95.35 – Dark matter (stellar, interstellar, galactic, and cosmological).
PACS 95.30.Cq – Elementary particle processes.
PACS 26.35 – Big Bang nucleosynthesis.
PACS 14.60.Pq – Neutrino mass and mixing.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

The standard big-bang nucleosynthesis (SBBN) is widely used to obtain limits on some cosmological parameters [1]. Nucleosynthesis bounds are obtained by tight agreement between primordial abundances of light elements deduced from the observations and the theoretical predictions based on the SBBN. Various extended SBBN (ESBBN) models are studied to determine some particle properties, which cannot be obtained by the SBBN [2].

(*) Paper presented at the Fourth Italian-Korean Meeting on Relativistic Astrophysics, Rome-Gran Sasso-Pescara, July 9-15, 1995.

In this work, we focus our attention on how massive neutrinos can modify the SBBN results. Of course, one has worked on this effect with different viewpoints [3, 4]. Our purpose is to duly integrate this effect on the nucleosynthesis reaction channels. For this purpose, we study a preliminary background for neutrino oscillations in sect. **2** and the possible effect on the reaction channels in sect. **3**. Full analysis about this subject will appear elsewhere.

2. – Neutrino oscillation

Theoretically, in the standard model of particle physics, neutrinos are usually assumed to be purely left-handed and massless. However, there is no compelling reason to assume this. In the above standard model, one generally does have massive neutrinos. If neutrinos are massive, then there should be mixing between flavours. This mixing can be used to solve solar-neutrino problems [5].

Neutrino oscillations can be specified by mixing angle and squared mass diffrence, defined as follows:

$$|\nu_{\mathrm{L}}\rangle = \cos\theta(x)\,|\nu_{\mathrm{e}}\rangle - \sin\theta(x)\,|\nu_{\mu}\rangle, \tag{1}$$

$$|\nu_{\mathrm{H}}\rangle = \sin\theta(x)\,|\nu_{\mathrm{e}}\rangle + \cos\theta(x)\,|\nu_{\mu}\rangle, \tag{2}$$

where $|\nu_{\mathrm{L(H)}}\rangle$ is the light (heavy) local mass eigenstate and $\delta m^2 = m_2^2 - m_1^2$. Restrictions on the neutrino oscillations are represented on the plane $\delta m^2 - \sin^2\theta$. It is well known that resonant neutrino oscillation occurs when neutrinos pass through dense matter [6].

3. – Effect on primordial nucleosynthesis

Basically, nucleosynthesis starts from the chemical equilibrium between leptons and photons via rapid weak reactions,

$$\nu_{\mathrm{e}} + \mathrm{n} \leftrightarrow \mathrm{p} + \mathrm{e}^-, \tag{3}$$

$$\mathrm{e}^+ + \mathrm{n} \leftrightarrow \mathrm{p} + \bar{\nu}_{\mathrm{e}}, \tag{4}$$

$$\mathrm{n} \leftrightarrow \mathrm{p} + \mathrm{e}^- + \bar{\nu}_{\mathrm{e}}. \tag{5}$$

The freeze-out machanism of these reactions yields the final ^{4}He abundances. Hence density change of ν_{e} affects this mechanism and the ralative number density between neutrons and protons, which is a crucial parameter to determine ^{4}He abundance. Electron neutrino density depletion is possible in the early universe by flavour mixing. Therefore, neutrino oscillation can modify SBBN results, which can be used to determine δm^2 and $\sin^2\theta$ by comparing the predictions and observations. The most important effect comes from the change of electron neutrino density change. For other neutrino types, they affect only small fractions, for their effects appear only through the total density of universe.

Further numerical study will appear elsewhere. This numerical study should be performed carefully with correct integration of neutrino oscillation and nuclear reactions.

* * *

One of us (HWL) is supported by the Basic Science Research Institute Program, Korean Ministry of Education, Project No. BSRI-94-2441.

REFERENCES

[1] WAGONER R. V., FULLER W. A. and HOYLE F., *Astrophys. J.*, **148** (1967) 3; WALKER T. P., STEIGMAN G., SCHRAMM D. N., OLIVE K. A. and KANG K., *Astrophys. J.*, **376** (1991) 51.
[2] BIANCONI A., LEE H. W. and RUFFINI R., *Astron. Astrophys.*, **241** (1991) 343; KIM J. B. and LEE H. K., *Astrophys. J.*, **448** (1995) 510; SATO K. and TERASAWA N., *Phys. Scr.*, **36** (1991) 60; MALANEY R. A. and MATHEWS G. J., *Phys. Rep.*, **229** (1993) 145.
[3] KOLB E. W. *et al.*, *Phys. Rev. Lett.*, **67** (1991) 533.
[4] ENQVIST K., KAINULAINEN K. and MAALAMPI J., *Phys. Lett. B*, **249** (1990) 531.
[5] KUO T. K. and PANTALEONE J., *Rev. Mod. Phys.*, **61** (1989) 937 and references therein.
[6] MIKHEYEV S. P. and SMIRNOV A. Y., *Nuovo Cimento C*, **9** (1986) 17; WOLFENSTEIN L., *Phys. Rev. D*, **17** (1978) 2369; **20** (1979) 2634.