Neutrinos and arrow time in cosmology

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Letters to the Editor

Neutrinos and arrow of time in cosmology

Abstract. The arrow of time in the case of neutrinos is investigated taking into account photon–neutrino weak-coupling theory. It is shown that in both steady-state and Einstein–de Sitter cosmological models, the advanced effect can be avoided.

It is well known that Maxwell's fundamental equations of electromagnetism exhibit perfect time symmetry. But the observed electromagnetic phenomena, on the other hand, are asymmetric with respect to time. Schwarzschild (1903) and Fokker (1932) proposed that an accelerated charge does not simply produce a retarded field but a field which is half retarded and half advanced. Tetrode (1922) suggested that the effect of the absorber is just as important as that of the emitter in determining the radiation in spite of the fact that the absorption occurs after the radiation has already propagated. By taking that view, Wheeler and Feynman (1945, 1949) showed that the absorber can play an essential role in the process of radiation. In fact, if an accelerated charge is placed inside a complete absorber which absorbs waves propagating towards the future (but not those which propagate towards the past), then the advanced wave originating in the absorber has three effects. First, it completely cancels the advanced wave due to accelerated charge; secondly, it interferes constructively with the retarded wave due to the accelerated charge, bringing the retarded wave to full strength; thirdly, it slows down the accelerated charge. Hogarth (1962) pointed out that the absorber theory of radiation of Wheeler and Feynman is deficient in its explanation of the arrow of time. This deficiency is related to the assumed static nature of the universe. In view of the deficiency related to the arrow of time, Hogarth suggested that the observed asymmetry of the electromagnetic phenomena is a consequence of cosmology rather than the basic electromagnetic equations. The asymmetry is introduced by the expansion of the universe, which causes the future absorber to be different from the past absorber. The total contribution of the two absorbers to the basic field

$$F_0 = \tfrac{1}{2}(F_{\mathrm{ret}} + F_{\mathrm{adv}}) \tag{1}$$

at 0 gives the field near 0:

$$F_{\mathrm{tot}} = F_0 + AfR - BpR \tag{2}$$

where

$$R = \tfrac{1}{2}(F_{\mathrm{ret}} - F_{\mathrm{adv}}). \tag{3}$$

For the case of static Euclidean universe $f = p = 1$. From equations (1), (2) and (3) the condition $f = 1$ gives only the retarded solution whatever the value of p may be, similarly $p = 1$ gives only the advanced solutions. Hogarth examined the various cosmological models with a view to determining whether they satisfy the required criterion $f = 1 \neq p$. He found that the general model which maintains a constant density in spite of expansion (and therefore involves continuous creation of matter) is more favourably placed than a model based on the conservation of matter. He called the above two types of models class I and class II universes respectively. In the class I universe there is in general a sufficient number of scatterers per unit proper volume to ensure the eventual scattering of every photon emitted by 0. The class II universe does not have this advantage and therefore fails to satisfy the condition $f = 1$ in general.

To distinguish the cosmological model, Narlikar (1962) extended Hogarth's approach in the case of neutrinos. The most important scatterers for neutrinos are likely to be electrons and protons. Narlikar considered their interactions with neutrinos on the basis of the current–current coupling theory of weak interactions. In a recent paper, Bandyopadhyay (1968) has suggested that photons can interact weakly with neutrinos. On the basis of the photon–neutrino weak-coupling theory, Ray Chaudhuri and Bandyopadhyay (1969) have considered the electron–neutrino scattering. Also Bandyopadhyay *et al.* (1969) have considered the proton–neutrino elastic scattering on the basis of this photon–neutrino coupling theory and have shown that the cross section for the process $\nu + \mathrm{p} \to \nu + \mathrm{p}$ is at least an order smaller than that of the process $\nu + \mathrm{p} \to \mathrm{n} + \mathrm{e}^+$, which is well within the experimental upper limit. The main interesting feature of the photon–neutrino coupling theory is that the cross section σ is of the order of $1/E^2$ whereas according to the current–current coupling theory σ is of the order of E^2. In view of this interesting result, we have considered the arrow of time taking into account neutrino interactions on the basis of the photon–neutrino weak-coupling theory.

As neutrinos going into the future are red-shifted, their scattering at very low energies is of interest. The scattering cross section for electron–neutrino scattering, according to current–current coupling theory (Bahcall 1964), is

$$\sigma = \sigma_0 E^2 \qquad \text{for } E \ll 1 \tag{4}$$

where $\sigma_0 = 1{\cdot}7 \times 10^{-44}\ \mathrm{cm}^2$ and E is the incident energy of the neutrino (in units $m_e c^2$). According to the photon-neutrino coupling theory (Ray Chaudhuri and Bandyopadhyay 1969)

$$\sigma' = \frac{\sigma_0'}{E^2} \qquad \text{for } E \ll 1 \tag{5}$$

where

$$\sigma_0' = 3{\cdot}59 \times 10^{-47}\ \mathrm{cm}^2.$$

The energy of the scattered neutrino is

$$E' = \frac{E}{1 + E(1 - \cos\theta)} \tag{6}$$

so that

$$E \to 0, \qquad \frac{E'}{E} \to 1. \tag{7}$$

Also

$$E \to \infty, \qquad \frac{E'}{E} = 0 \qquad \text{if } (\theta \neq 0) \tag{8}$$

which greatly simplifies the discussion of the past absorber. The scattering length a is related to the cross section σ by

$$\sigma = 4\pi|a|^2$$

since

$$\sigma \propto \begin{cases} E^2, & \text{according to current–current coupling theory} \\ \dfrac{1}{E^2}, & \text{according to photon–neutrino coupling theory} \end{cases}$$

for the neutrino going into the future.

We can write

$$a = a_0 \begin{cases} e^{-\zeta} = (\alpha_0 + i\beta_0)e^{-\zeta} & \text{(current–current coupling theory)} \\ e^{\zeta} = (\alpha_0 + i\beta_0)e^{\zeta} & \text{(photon–neutrino coupling theory)} \end{cases} \tag{9}$$

where a_0 is the value of a at $\tau = \tau_0$. As absorption is also present

$$\beta_0 > 0.$$

No such simple expressions are available for neutrinos going into the past. To evaluate the value of f and p ,we have from Narlikar (1962)

$$f = \int_0^{R_1} \frac{2\pi a_0 N_0 c}{\omega_0} \exp(M\zeta_1 + i\chi_1)\, dr_1 \tag{10}$$

where R_1 is the radius of the absorber and

$$\chi = \int_0^{r_1} \frac{2\pi a_0 N_0 c}{\omega_0} \exp(M\zeta')\, dr'. \tag{11}$$

Now f can be written as

$$f = 1 - \exp\{iU(R_1)\} \tag{12}$$

where

$$U(r_1) = \chi(r_1).$$

Thus, a necessary and sufficient condition for f to be unity is that the imaginary part of $U(R_1) = \infty$.

Since $\beta_0 > 0$ this condition reduces to

$$\int_0^{R_1} \exp(M\zeta_1)\, dr_1 = \infty. \tag{13}$$

According to the current–current coupling theory

$$M = \begin{cases} 1 & \text{for class I universes} \\ -2 & \text{for class II universes} \end{cases} \tag{14}$$

whereas according to photon–neutrino coupling theory

$$M = \begin{cases} 3 & \text{for class I universes} \\ 0 & \text{for class II universes.} \end{cases} \tag{15}$$

As the incident neutrinos going to the past increase, the energy increases owing to the red shift and hence from (8) the scattered neutrinos have negligible energy. In other words the condition $p = 1$ can not be satisfied.

From (14) and (15), we can say that both the steady-state model and the Einstein–de Sitter model satisfy the condition $f = 1$ according to photon–neutrino coupling theory whereas only the steady-state model satisfies the condition $f = 1$ according to current–current coupling theory. This situation is also present in the case of photons: by using Thompson scattering theory it can be shown that $M = 2$ for class I and $M = -1$ for class II universes. Thus, according to the photon–neutrino weak-coupling theory, neutrinos can easily satisfy the condition for photons. Our results also show that it is not appropriate to distinguish the cosmological model of the universe just by experiments involving neutrinos.

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