YU ISSN 0015—3206
FZKAAA 22 (2) 423 (1990)

SEARCH FOR NEUTRINOS WITH MASSES IN THE RANGE OF 15 TO 45 keV

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Received 20 December 1989

UDC 539.143

Original scientific paper

Internal bremsstrahlung in the electron capture decay of ^{55}Fe has been studied to investigate the possible existence of neutrinos in the mass range of 15 to 45 keV. At the 95.5% confidence level, our limit for the fraction of emitted neutrinos in the mass range of 15 to 45 keV ranges from < 1.6% in the lower mass region to < 0.1% in the higher mass region.

1. Introduction

In the 1985 Simpson[1] interpreted a distortion of the low energy part of the tritium β-spectrum as evidence for the existence of an antineutrino of mass 17 keV and with a mixing ratio relative to the light antineutrino of about 3%. This result was not supported by several investigations of β-decay of ^{35}S[2] and ^{63}Ni[3], and internal bremsstrahlung in electron capture (IBEC) with ^{125}I[4] and ^{55}Fe[5]. The experiments on ^{35}S and ^{63}Ni have been criticized and some of them were reinterpreted by Simpson[6,7]. In a more recent work, Simpson and Hime reported evidence for the existence of an antineutrino of mass 17 keV, with a mixing ratio with respect to the light antineutrino of $(0.73 \pm 0.09 \pm 0.06)\%$ in the case oj ^{35}S[7] and 0.6 to 1.6% in the case of tritium[8].

In our previous work[5] we studied the IBEC spectrum of ^{55}Fe in order to investigate the possible existence of 17 keV mass neutrinos and obtained a negative result. At the 99.7% confidence level, our limit for the fraction of emitted neutrinos in the mass range 16.4 to 17.4 keV is >0.0074. In this work, we have extended our analysis of the same set of experimental data to investigate the possible existence of neutrinos in the mass range 15 to 45 keV.

2. Experimental procedure

The characteristics of the sourcc (4.2-mCi ^{55}Fe), Ge(Li) detector (56-cm^3, with resolution of 2 keV at 200 keV) and conditions of the measurement are described in our previous work[5]. Measurements were made of the source and of the background for 181 hours in each case and allowances were made for the contributions from room background, pile-up and radioactive impurities in the source. A detailed measurement of the response function was made and it was found that response function could be described by a sum of two Gaussians and an arctg function. As in Ref. 5, the basis of the method involves looking for a kink in the efficiency curve.

3. Analysis and results

If the existence of two types of neutrinos (light and heavy) in EC decay is assumed, the IBEC spectrum will be given by:

$$\frac{d\omega(k)}{dk} = \frac{d\omega(k, m_L)}{dk} \cdot \cos^2 \vartheta + \frac{d\omega(k, m_H)}{dk} \cdot \sin^2 \vartheta. \tag{1}$$

k is the photon energy, m_C and m_H are the masses of the light, and the heavy neutrino, respectively, and ϑ is the mixing angle. R, the fraction of heavy neutrinos, is given by $R = \sin^2 \vartheta$.

Each term in Eq. (1) consist of contributions from different atomic shells (in our case only capture from K and L shell is taken into account). The theoretical distribution of IBEC spectra for different values of the mixing angle ϑ (i. e. R) and the heavy neutrino mass m_H (m_C is assumed to be zero) was calculated on the basis of the theory developed by Glauber and Martin[9] and De Rujula[10]. In practice, in the energy regions relevant in this analysis, the IBEC spectrum is dominated by is capture contributions.

The 1s-end-point energy of IBEC spectra $E_{1s}^{end\text{-}point}$ is determined by

$$E_{1s}^{end\text{-}point} = Q_{EC} - B_{1s}. \tag{2}$$

Q_{EC} is the Q-value of electron capture decay of ^{55}Fe and B_{1s} is the binding energy of the 1s electron.

The position of the kink is determined by

$$E_{1s}^{kink} = Q_{EC} - m_\nu^H - B_{1s}. \tag{3}$$

The theoretical expressions were convoluted with the help of the experimentally determined response function of the Ge(Li) detector. From the number of detected photons with energy k, $N_{exp}(k)$, and the convoluted theoretical energy spectrum, $P_T(k; R, m\ )$, the efficiency, $\varepsilon_{exp}(k; R, m\ )$, was estimated. The mixing ratio R was varied from —0.03 to 0.03 and the mass of heavy neutrino was varied in the energy range from 15 to 45 keV. The experimental efficiency was fitted with an efficiency function[5,11,12].

$$\varepsilon_{fit}(k; R, m_\nu^H) = a \cdot k \ \cdot \exp(c \cdot k^{-3}). \tag{4}$$

We employed the same method as in our previous work: the coefficients a, b and c were determined in the energy region above the kink (where there is no influence of the heavy neutrino) and the extrapolated to the lower energy range. The same number of channels was used for the fit and the extrapolation, but the number was increased linearly with the assumed mass of the heavy neutrino.

The coefficients a, b and c were determined by searching for the minimum of the expression

$$\chi^2(R, m_\nu^H) = \sum_{\text{above kink}} \frac{[\varepsilon_{exp}(k; R, m_\nu^H) - \varepsilon_{fit}(k; R, m_\nu^H)]^2}{\sigma^2(k)} \tag{5}$$

for different values of fraction of heavy neutrinos R and for different masses of heavy neutrino m . For each mass between 15 and 45 keV, the procedure was repeated in steps of 0.001 from R values ranging from $R = -0.01$ to 0.02.

The upper limits of the mixing ratio values obtained from the best agreement between the experimental and theoretical efficiency curve are shown in Fig. 1. The values correspond to a 95.5% confidence level.

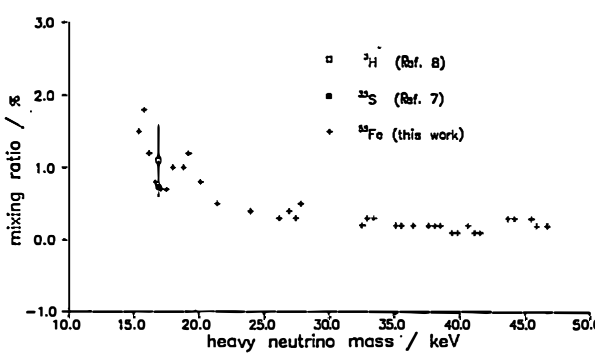

Fig. 1. The upper limits of the mixing ratio values for neutrino masses.

4. *Conclusions*

We have no evidence for the existence of a heavy neutrino with a mass larger than 20 keV. Although our results confirm that any possible heavy neutrinos in the 15—20 keV region have relative intensities well below the value of 3% of Ref. 1 they do not exclude the new results of Simpson and Hime[7,8]. New detailed measurements are needed in this energy range. Our analysis also shows, that over a wide mass range, IBEC investigations of neutrinos have a sensitivity comparable with that of β-decay investigations.

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POTRAGA ZA NEUTRINIMA U MASENOM PODRUČJU OD 15 DO 45 keV

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UDK 539.143

Originalni znanstveni rad

Proučavan je spektar unutrašnjeg kočnog zračenja u raspadu ^{55}Fe elektronskim uhvatom da bi se istražila mogućnost postojanja neutrina u rasponu masa od 15 do 45 keV. Granica na udio neutrina navedenog raspona mase je: $< 1.6\%$ u nižem području masa do $< 0.1\%$ u višem području masa.