THE POSITRON SPECTRUM OF ^{22}Na AND THE NEUTRINO REST MASS

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Since Pauli formulated the neutrino hypothesis the neutrino rest mass has been assumed to be very small with respect to the mass of the electron, or even equal to zero[1]. In the beta continuum the influence of a finite rest mass is most striking near the end-point. The most accurate values from tritium measurements yield a certain upper limit of the antineutrino mass of 1 keV[2,3]. However, no β^+ spectrum has been measured for the determination of the neutrino mass. Of course, the reason are better experimental conditions of β^- decay, namely the small tritium end-point energy of 18.6 keV.

In the last few years a new interest in the neutrino mass has resulted from the following facts:

1. The two-component theory of the neutrino can be applied only in the case of vanishing rest mass.

2. The μ-neutrino has been found to be different from the e-neutrino.

3. As has been shown by Weinberg[4] some cosmological

models imply that the universe is filled with a degenerate neutrino or antineutrino gas. Since neutrinos obey the Fermi statistics, there can exist a Fermi energy E_F up to which all neutrino levels are occupied. The effect of a degenerate neutrino gas on a β spectrum is qualitatively the same as that of a finite rest mass.

Measurements on the β^+ continuum of ^{22}Na have been carried out at the Heidelberg $(\pi/2)\sqrt{13}$ iron-free β-ray spectrometer[5]. Contrary to the usual double focusing spectrometer the Heidelberg spectrometer has no axial focus at the exit slit which is curved. Figure 1 shows a schematic drawing of some electron orbits. The focusing angle is $\theta = (\pi/2)\sqrt{13} = 324.5^0$. The radius of the stationary orbit is $r_o = 30$ cm. The whole spectrometer is built up without iron in an iron-free building. The

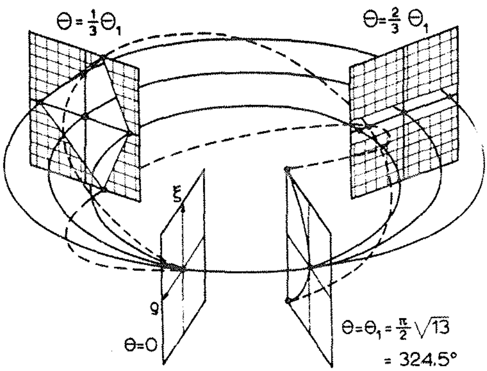

Fig. 1. Drawing of some electron orbits.

earth's magnetic field is compensated by two Helmholtz coil systems for the horizontal components and a system of four coils for the vertical component. At a resolution of $\eta = 0.1$ per cent the fractional solid angle is $\omega = 1.5$ per cent. The sources were prepared by vacuum evaporation of carrier-free NaCl.

In figs. 2 and 3 a momentum spectrum of ^{22}Na and the Fermi plot are shown, respectively. The end-point energy E_0 and the rest mass $m_\nu c^2$ have been determined simultaneously by a least square fit. The results of three independent measurements at two different sources are:

1. The end-point energy is $E_0 = 545.7 \pm 0.5$ keV.
2. The most probable value of the rest mass is zero, with a standard deviation of 4.1 keV.

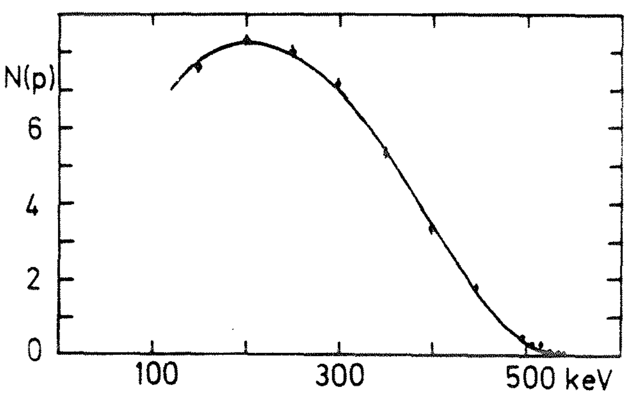

Fig. 2a. Momentum spectrum of ^{22}Na.

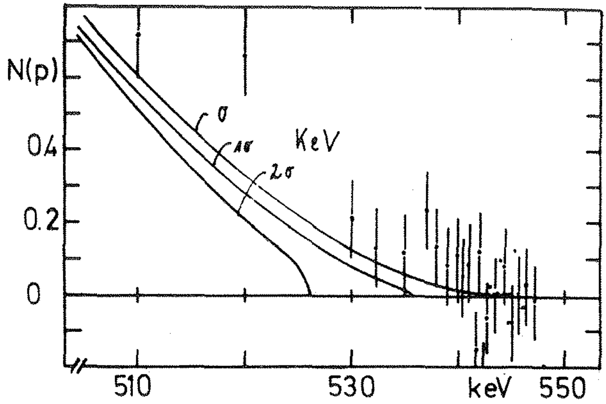

Fig. 2b. Momentum spectrum of ^{22}Na in the vicinity of the end-point energy

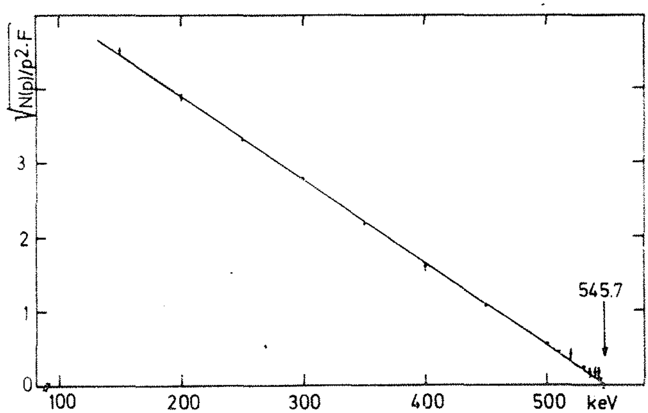

Fig. 3. Fermi plot of a ^{22}Na spectrum

Furthermore, the experimental results were analysed with a x^2 test. The mass turned out to be smaller than 6 keV with 90 per cent confidence. The minimum of x^2 corresponds to zero rest mass. Table 1 shows a comparison of the end-point energy

TABLE 1

End-point energy E_0 (keV)	Authors and references
542 ± 5	Macklin et al. ref. 6
540 ± 5	Wright ref. 7
545 ± 2	Daniel ref. 8
547.4 ± 1.0	Nichols et al. ref. 9
543 ± 3	Hamilton et al. ref. 10
543 ± 3	Leutz and Wenninger ref. 11
545.7 ± 0.5	this work

of this measurement with the result of other authors. The agreement is good.

As Weinberg has pointed out, a possible neutrino degeneration causes qualitatively the same effect in a β spectrum as a finite neutrino mass[4)]. The upper limit of 4.1 keV for the rest mass may therefore be also regarded as an upper limit of the Fermi degeneration energy E_F. Of particular interest are the consequences for an oscillating universe. If it undergoes a periodic cycle of expansion and contraction, then during every cycle as many neutrinos must be absorbed as are emitted. From this condition the following relation can be derived

$$\frac{E_F}{E_a} \cong \frac{R_m}{R} ,$$

where E_F is the Fermi energy, E_a is the threshold of the endothermic neutrino absorption, and R_m and R are the smallest and the present radius of the universe, respectively. From known β decays one obtains the estimate $E_a \cong 5$ MeV.

The limit for the Fermi energy, $E_F \lesssim 4.1$ keV, therefore, gives the ratio

$$\frac{R_m}{R} \leq 8 \cdot 10^{-4} ,$$

if the universe oscillates at all.

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