end-point energy. Sakurai[2] has noted that this is of course valid only if one has the true end-point energy but not for the extrapolated value. The spread in β end-point data reported in the literature, however, is large, i.e., 1.3 kev, when compared with the magnitude of extrapolation from the last experimental points in any one of the β spectra. Consequently the difference between the experimental lower limit for the true β end point and extrapolated end point is comparable with or less than experimental error and at present trivial. If one takes the experimental lower limit of the true end point, i.e., the last experimental point in the β spectrum, and subtracts this from the H^3 - He^3 mass difference, the result is an empirical upper limit for the neutrino rest mass. This upper limit is independent of any theory of β decay and requires only the assumption of conservation of mass and energy. This was the basis of the estimate of the order of 1 kev for the upper limit of the neutrino rest mass by Friedman and Smith.

The considerations of Sakurai will become relevant only when the β end-point (true or extrapolated) can be measured with much higher accuracy than it is now known.

*Research performed under the auspices of the U. S. Atomic Energy Commission.

[1] L. Friedman and L. G. Smith, Phys. Rev. 109, 2214 (1958).

[2] J. J. Sakurai, Phys. Rev. Lett. 1, 40 (1958).

EXPERIMENTAL EVIDENCE FOR THE INFLUENCE OF ATOMIC BINDING ON THE DECAY RATE OF NEGATIVE MUONS*

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The entire body of observations on the rate of disappearance (Λ_{dis}) of negative muons in matter,[1] in particular the striking Z dependence of this rate, can be described by attributing the disappearance to a competition between nuclear capture (at a rate Λ_{cap}) and decay (at a rate Λ_{dec}), both taking place from the mesic K orbit. Λ_{cap} depends primarily on the probability of finding the muon inside the nucleus (Z, A) and thus strongly on Z (Wheeler's Z^4 law); on the other hand, one assumes customarily that Λ_{dec} is uninfluenced by the fact that the decay takes place from a bound orbit, i.e., one puts $\Lambda_{dec}(Z) = \Lambda_{dec}(0) \equiv \Lambda_{dec}(\mu^+)$. This assumption is in particular made when capture rates are calculated from the experimentally accessible disappearance rates.[2]

It is, however, clear that the ratio $R \equiv \Lambda_{dec}(Z)/\Lambda_{dec}(0)$ should differ from unity for several reasons: (a) reduction of the number of final states through the decrease in available energy; (b) Doppler effect and time dilatation caused by the motion in the K orbit; (c) distortion of the outgoing electron wave by the nuclear electric potential. Effects (a) and (b), which jointly lead to $R<1$, have been considered by various authors[3] for the case of point-like nuclei, while effect (c), which works in the opposite direction, has so far been consistently neglected.

In view of this situation and in order to enable one to make precise determinations of Λ_{cap} from Λ_{dis}, we are now measuring R directly for a variety of elements. Some preliminary results will be given here.

Our measurements are based on the following: Two quantities are, in principle, directly measurable: (1) $\Lambda_{dis}(Z, A)$, and (2) $N_e(Z)$, the number of electrons per N_μ muons stopping in a target (Z, A). As $N_e = N_\mu[\Lambda_{dec}(Z)/\Lambda_{dis}(Z, A)]$, an absolute measurement of these quantities would yield R directly. Such a measurement is however difficult as far as N_e is concerned. On the other hand, it is sufficient to count the N_e's from pairs of targets (Z_1, Z_2) with the same relative efficiency to determine the Z dependence of R. With the assumption that, say $\Lambda_{dec}(Z_1) = \Lambda_{dec}(0)$, R itself may be determined.

"Sandwich" targets were built up from alternating layers of elements Z_1 and Z_2. Each comprised about 5 sheets of either material and had a total thickness (6 - 8 g/cm^2) sufficient to stop most of the local high-purity μ^- beam.[4] The ratio $S \equiv N_\mu(Z_1)/N_\mu(Z_2)$ was determined directly with an anticoincidence range telescope that included, just behind the target, a thin (1/16 in.) scintillator. S could be obtained to an accuracy of ± 2%. The ratio $N_e(Z_1)/N_e(Z_2)$ was measured by observing the composite time distribution of decay electrons from the sandwich by means of the time-converter arrangement which had also served to measure $\Lambda_{dis}(Z)$ for pure targets.[2] A coincidence telescope consisting of three scintillators separated by two 1.8-g/cm^2 Al absorbers was used now to detect the electrons. Such a telescope has a negligibly small detection efficiency for gamma rays of less than 10-Mev energy. This was essential for a correct determination of R, as a large number of gamma rays, N_γ, appear to be produced per muon capture, presumably from the de-excitation of capture products. N_γ may, in particular in the case of heavy nuclei, exceed N_e by a factor 100.

Table I summarizes the results obtained so far. The errors quoted for R make some allowance for systematic uncertainties. These stem mainly from two causes: (1) differences in the shape of the decay electron spectra[5] from Z_1 and Z_2, (2) differences in the value of the asymmetry parameter a which governs the angular distribution of the electrons. We have some evidence, obtained by varying target thickness, that (1) is probably unimportant. While no good determinations of a are available for the targets and the beam used here, it may be anticipated that a will be nonzero only for spinless nuclei and in their case will not exceed 0.06, the local value for $Z = 6$ in good geometry. Thus (2) should be unimportant also, in particular when the strong multiple scattering in the thick targets used is taken into account.

It appears from our results that R is, with the exception of Fe ($Z = 26$), less than unity. For this element, effects (a) and (b) would give $R \cong 0.80$. It may be inferred that effect (c) dominates near this Z value,[6] but is overshadowed by the other two effects as Z increases. While the trend of $R(Z)$ found here is not unreasonable, comparison with theory must await the completion of computations using exact muon and electron wave functions.[7]

A practical conclusion from our measurements is that the corrections to Λ_{cap} do not exceed a few percent, when Λ_{dis} is the experimentally measured quantity. The determination of Λ_{cap} from N_e, such as was used by Lederman and Weinrich,[8] involves however corrections directly proportional to R, as was recognized by these workers themselves.

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Table I. Determination of R for various elements.[a]

Sandw.	Z_1/Z_2	S	$\frac{N_e(2)\Lambda_{dis}(2)}{N_e(1)\Lambda_{dis}(1)}$	Lifetimes used ($\times 10^{-9}$ sec)	R[c]
C-Al[b]	6/13	0.543 ± 0.015	1.82 ± 0.05	$\frac{2010 \pm 20}{880 \pm 20}$	0.99 ± 0.04[d]
C-Fe	6/26	0.218 ± 0.005	5.57 ± 0.14	$\frac{2010 \pm 20}{202 \pm 7}$	1.21 ± 0.05
C-Zn	6/30	0.136 ± 0.004	7.09 ± 0.20	$\frac{2010 \pm 20}{161 \pm 6}$	0.96 ± 0.05
Al-Mo	13/42	0.469 ± 0.010	1.98 ± 0.06	$\frac{880 \pm 20}{105 \pm 4}$	0.93 ± 0.05[e]
C-Cd	6/48	0.121 ± 0.003	7.42 ± 0.30	$\frac{2010 \pm 20}{96 \pm 4}$	0.90 ± 0.05
C-W	6/74	0.175 ± 0.008	3.03 ± 0.20	$\frac{2010 \pm 20}{81 \pm 4}$	0.53 ± 0.05

[a] We assume throughout that the process $N + \mu^- = N + e^-$ does not occur; see S. Lokanathan and J. Steinberger, Phys. Rev. 100, 1490 (1955).

[b] $Z = 6$ in the form of CH_2 sheets; assumed to behave like elemental C.

[c] $R(6)$ assumed to be unity.

[d] Done to check consistency of method, as $R(13) = 1$ is expected.

[e] $R(13)$ assumed to be unity.

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[1] R. D. Sard and M. F. Crouch, in Progress in Cosmic-Ray Physics, edited by J. G. Wilson (North-Holland Publishing Company, Amsterdam, 1954), Vol. 2.

[2] J. C. Sens *et al.*, Phys. Rev. 107, 1464 (1957); J. C. Sens (to be published).

[3] C. E. Porter and H. Primakoff, Phys. Rev. 83, 849 (1951); T. Muto *et al.*, Progr. Theoret. Phys. Japan 8, 13 (1952); N. D. Khuri and A. S. Wightman (private communication).

[4] N. Campbell and R. A. Swanson (to be published).

[5] Reference 3, in particular Muto *et al.*

[6] J. C. Sens *et al.*, Bull. Am. Phys. Soc. Ser. II, 3, 198 (1958); recent preliminary results obtained at Liverpool also seem to indicate that $R > 1$ near $Z = 26$ [H. Muirhead (private communication)].

[7] Numerical calculations yielding such functions are now in progress at Los Alamos Scientific Laboratory.

[8] L. Lederman and M. Weinrich, Proceedings of the CERN Symposium on High-Energy Accelerators and Pion Physics, Geneva, 1956 (European Organization of Nuclear Research, Geneva, 1956), Vol. 2, p. 427.

COSMIC-RAY INCREASES PRODUCED BY SMALL SOLAR FLARES*

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This note reports the first observations of two unusually short-lived increases in the low-energy portion of cosmic rays. They appear to be produced by small solar flares. Some indications of effects of small solar flares have been previously reported,[1] but have not been widely accepted, possibly because the connection was only statistical and an isolated increase could not be discerned.

We therefore designed an experiment whose purpose it was to detect short-lived or small increases in the low-energy component of total cosmic-ray intensity, observe their structure and study their correlation in time with small solar flares. In order to improve the chances of detecting such events we constructed a detector with very large sensitive area so that the counting rate was high enough to be recorded directly through a ratemeter. Furthermore, since it seemed likely that the low-energy portion of cosmic rays would be most affected, we operated this detector at high latitudes (55° geomagnetic) and at high altitudes (up to 45 000 feet) in an aircraft operated by the Rome, New York, Air Force Base.

The detector was a cosmic-ray counter telescope 1 square meter in area. It consisted of two trays of geiger tubes spaced 1 inch apart. The trays were operated in coincidence. No absorber was used.

Flights were made at various altitudes on August 8th and 9th, 1957. No rapid fluctuations in the total cosmic-ray intensity were observed during the three hours the aircraft was at altitude on August 8th. On the 9th of August, however, two unusual events were observed.

The first event (see Fig. 1) occurred while the aircraft was flying straight and level at an altitude of 25 000 feet. It started at 1349 UT and lasted for nearly three minutes. During this time the intensity increased from its normal value by approximately 30%. The second event started at 1433 UT while the aircraft was still at an altitude of 25 000 feet. It lasted for almost

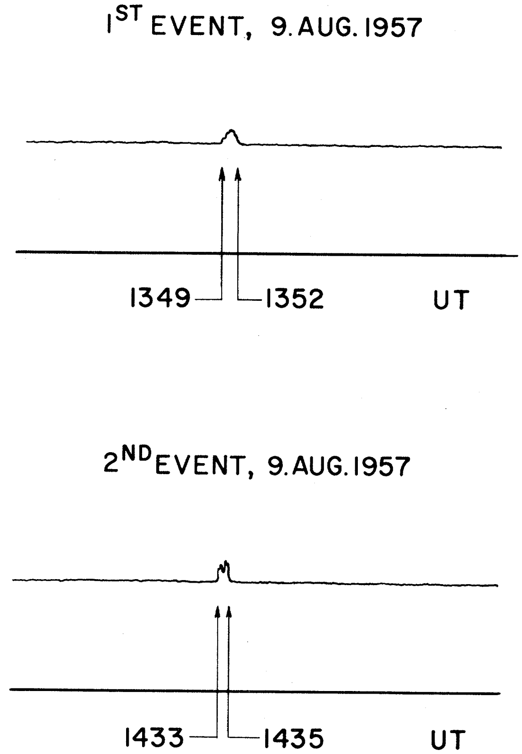

FIG. 1. Cosmic-ray increases observed on August 9, 1957 at $\lambda = 55°$ at altitude of 25 000 feet. A small solar flare was observed on the west limb of the sun starting at 1330 UT and reported by the High Altitude Observatory, Boulder, Colorado. Note the unusual "humped" shape of these increases, as well as their extremely short duration.