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Bound Muon Decay-Rate Anomaly

J. V. Allaby, A. Chisholm, J. Eades, and B. M. Townes*
Nuclear Physics Research Laboratory, University of Liverpool, Liverpool, England
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Chilton has suggested that the presence of an unusually large fraction of high-energy γ rays in the spectrum emitted following muon capture in nuclei in the region $Z\sim 26$ could account for the anomalous decay rates of muons bound in such nuclei as measured by Yovanovitch. We have examined these spectra and find that the high-energy γ rays are not sufficiently abundant to account for the effect observed by Yovanovitch.

MEASUREMENTS[1–4] of the decay rates of negative μ mesons bound in atoms have shown an unexpected peak in the ratio of bound to free muon decay rates for elements with atomic number near to that of iron. So far, no good physical reason has been put forward to account for this anomaly.[5–7]

A possible instrumental cause of this anomaly has recently been suggested by Chilton.[8] He gives reasons for supposing that, for elements in the neighborhood of iron, there may be a peak in the 7-Mev region of the γ-ray spectrum from nuclear capture of μ mesons. Such photons could produce electrons, indistinguishable from the muon decay electrons, and thus indicate an enhanced decay rate. In the case of zinc, such γ rays would be expected to be much less intense.

Since the discrepancy is at a maximum for iron, but has disappeared in zinc, it is of interest to compare the capture γ-ray spectra of iron and zinc. We have done this, but have found no evidence for a difference between these spectra sufficiently large to account for the decay-rate anomaly.

Negative muons were stopped in the target and identified by using a counter telescope consisting of scintillators and a water Čerenkov counter to reduce the effects of electron contamination of the muon beam. The capture γ rays were detected with a 5-in.-diam NaI crystal in an arrangement similar to that used, for example, by Sens.[9] The spectra were displayed on a 180-channel pulse height analyzer.

The capture spectra of iron and zinc between 4 Mev and 10 Mev, normalized to the same number of stopped muons, are shown in Fig. 1.

There is no evidence for a strong γ-ray peak in the 7-Mev region of the iron spectrum, and the two spectra are very similar. Details of the γ-ray yields between 4 and 10 Mev are shown in Table I. ϵ the total detection efficiency is slightly different for the two cases because of the different capture rates in the two elements.

The errors shown both in the spectra and in Table I are due to counting statistics only in order to compare the two cases. There is a 10% absolute uncertainty in the efficiency times solid angle for the NaI crystal which is the same for both cases.

There is a further uncertainty in the total number due to background. No attempt was made to correct for this because of the unknown contribution caused by the possible detection of neutrons from the muon

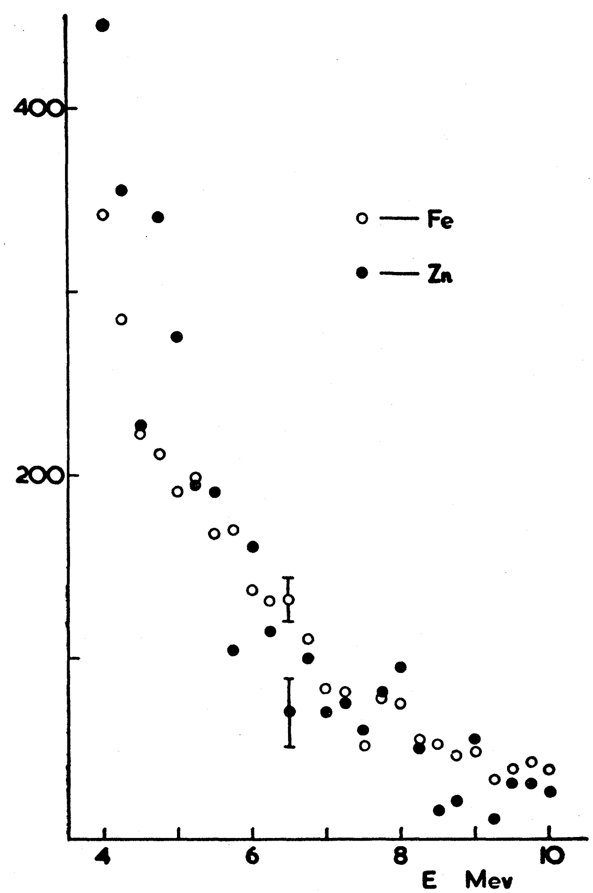

FIG. 1. The capture spectra of iron and zinc between 4 and 10 Mev, normalized to the same number of stopped muons.

* Our preliminary results were reported at the "Conférence Internationale sur les Particules Elémentaires," Aix-en-Provence, September, 1961.

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TABLE I. Comparison of results for Fe and Zn. N_μ=number of stopped muons; N_γ=total number of γ rays between 4 and 10 Mev; ϵ=total detection efficiency; Y=γ-ray yield per capture muon.

Element	N_μ	N_γ	ϵ	Y
Fe	9.0×10^5	2997	1.21×10^{-2}	0.302 ± 0.005
Zn	1.8×10^5	638	1.34×10^{-2}	0.285 ± 0.010

capture events. Since the neutron multiplicity is $\cong$1 per muon capture, even a small probability of a neutron's being captured in the NaI crystal and producing γ rays in the 4–10 Mev region could produce an appreciable background. For this reason, one must regard the yield as an upper limit.

However, if one assumes that this yield is purely capture γ rays which might be detected in an electron telescope of the type used by Yovanovitch,[1] and a detection efficiency of 1% for such γ rays is assumed (again an upper limit), then the maximum possible error that could be caused by such a spurious process in the bound muon decay rate for iron would be $\cong$3%. Furthermore the same effect would occur for zinc, where there is no decay-rate anomaly.

We conclude that the mechanism suggest by Chilton cannot be the cause of the decay-rate anomaly.

Since completing this work, we have learned that a CERN group (G. Culligan, D. Harting, N. H. Lipman, and G. Tibell) have searched again for the decay-rate anomaly in iron, but have failed to find it.

ACKNOWLEDGMENT

We wish to thank Dr. H. Muirhead for suggesting that we use our mesonic x-ray equipment for investigating these capture spectra.

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$C^{12}(p,pn)C^{11}$ Cross Section at 28 Gev*

J. B. CUMMING, G. FRIEDLANDER, AND S. KATCOFF
Chemistry Department, Brookhaven National Laboratory, Upton, New York

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The $C^{12}(p,pn)C^{11}$ cross section has been measured in the 28-Gev diffraction scattered proton beam of the Brookhaven AGS. Proton fluxes were determined using nuclear emulsions and the C^{11} activity induced in plastic scintillators was measured by internal scintillation counting. The cross section at 28 Gev is 25.9±1.2 mb, not significantly different from the values at 2 and 3 Gev.

INTRODUCTION

THE cross sections of the $C^{12}(p,pn)C^{11}$ and $Al^{27}(p,3pn)Na^{24}$ reactions have been used as the primary standards for a large number of radiochemical and physical measurements of cross sections for high-energy-proton interactions. In the Gev region, only the $C^{12}(p,pn)C^{11}$ cross section has been measured absolutely.[1,2] The present paper reports the results of measurements of this cross section[3] at 28 Gev in the external diffracted beam of the Brookhaven AGS. Nuclear emulsions were used to measure the proton fluxes incident on plastic scintillator targets. The 20.4 min C^{11} activity produced in the plastic was measured by internal scintillation counting.

EXPERIMENTAL ARRANGEMENT

The beam was ejected from the machine by diffraction scattering in a 1.5-mm aluminum target. It emerged through a collimator in the main shielding wall and was then magnetically analyzed. There was no collimation after the magnetic analysis. This experiment was performed ~65 ft beyond the analyzing magnet; at this point the full-energy protons were ~29 in. from the undeflected beam line. Emulsion studies[4] in this region had shown a peak at the predicted location for full-energy protons and a tail of degraded charged particles. This peak accounted for ~$\frac{1}{3}$ of the intensity of the entire beam emerging from the collimator.[4] Exposure of emulsions and plastic scintillators at $\frac{1}{2}$ degree below the main beam (8 in.) indicated that the background flux both of minimum-ionizing particles and of C^{11}-producing radiations was considerably less than 1% of the main beam. Thus the number of

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[3] In this paper the small but unknown contribution of C^{13} (natural abundance 1.1%) to C^{11} production is ignored, and the cross section for the formation of C^{11} in proton irradiation of normal isotopic carbon is taken to be the $C^{12}(p,pn)C^{11}$ cross section. The notation $C^{12}(p,pn)C^{11}$ does not imply the emission of a proton and neutron, but is meant to include any other mechanism for C^{11} formation, such as deuteron emission or processes involving pions, etc.

[4] J. Hornbostel (unpublished data).