particles outside the closed 50-neutron shell to produce many quasiparticle states with high angular momenta, so the deformed type of state is preferentially excited, and the bands are observed. Since $^{103}$Pd and $^{105}$Pd have more neutrons, higher angular momenta can be attained by the quasiparticle states; so even higher angular momentum must be brought into the nucleus before the deformed states can be preferentially selected.

Another important result of the threshold effect is that the absence of bands in $(\alpha, xn\gamma)$ reactions does *not* necessarily mean that the bands do not exist, but simply that the proper reaction may not have been used. Thus the existence of quasirotational bands in odd-$A$ nuclei may be more widespread than previously believed.

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# Upper Limits to Flare-Produced Deuterium and Tritium

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Using satellite data obtained over the polar regions during the solar active period of 30 October through 2 November 1972, we obtain upper limits to the $^2$H/$^1$H and $^3$H/$^1$H ratios: $1.4\times10^{-5}$ (3.1–30.6 MeV/nucleon) and $9\times10^{-6}$ (2.4–23.0 MeV/nucleon), respectively.

This paper describes the results of a satellite-borne electronic experiment specifically designed to measure deuterons and tritons ($^2$H and $^3$H) during solar events. Waddington and Freier,[1] using emulsions in a high-altitude balloon flight over Minneapolis, measured H:$^2$H:$^3$H as $1{:}\leq 2\times10^{-3}{:}\leq 6\times10^{-4}$ at $E > 50$ MeV/nucleon during the 18 July 1961 solar event. Previously Fireman, DeFelice, and Tilles[2] had set the $^3$H/H ratio at $4\times10^{-3}$ which is in clear disagreement with that of Waddington and Freier. Some arguments have been advanced by Lal, Rajagopalan, and Venkatavaradan[3] that Fireman's results represent an upper limit. The present results indicate that this is indeed the case, and that the actual H:$^2$H:$^3$H ratios have not yet been measured during solar events.

The S72-1 (1972-076B) satellite was launched on 2 October 1972 into a polar orbit with an inclination of 98.4°, an apogee of 749 km, and a perigee of 731 km. The H:$^2$H:$^3$H ratios measured over the poles during the solar event of 30 October through 2 November 1972 are discussed in this paper.

The particle identifier experiment flown on board the S72-1 satellite was designed to measure H, $^2$H, $^3$H from 5 to 70 MeV in five energy bins for each particle species. The detector assembly consists of four solid-state detectors with a plastic-scintillator anticoincidence shield.

The two frontmost detectors are 101 and 109 $\mu$m thick, respectively, and define the 6° half-angle view cone, giving a geometrical factor of 0.0257 $cm^2$ sr.

The bulk of the total-energy analysis is performed by the two 300-$mm^2$, 5-mm-thick lithium-drifted silicon detectors, which are electronically connected in parallel and treated essentially as a single 10-mm-thick detector. The plastic-scintillator anticoincidence shield inhibits accidental coincidences, and removes by anticoincidence those particles that satisfy the coincidence between the two frontmost detectors but pass completely through the "10 mm" detector. A 3-mil aluminum shield over the aperture prevents low-energy proton pileup and light contamination. A lead shield surrounds the anticoincidence scintillator and stops electrons (< 2 MeV), protons (< 25 MeV), and x rays.

The detector outputs are electronically combined to form a total-energy signal and a particle identifier signal, the latter being almost energy independent for a given isotope. Calibrations were performed at the Space Radiation Effects Laboratory, Newport News, Virginia, and at the Yale University heavy-ion accelerator. Details of the electronics, the geometry, and the calibration of this instrument are available.[4]

It is possible for random electronic noise in either the instrument or satellite signal systems to generate false deuteron or triton counts. To obtain a measure of these spurious counts, we scanned 122 hours of polar coverage data obtained during solar quiet periods. The criterion for a noise pulse was more than 7 counts in a proton channel or more than 1 count in an isotope channel during the 80-msec commutator sampling time. These noise pulses occurred $4.5 \times 10^{-4}$ time/sec and were rejected by a computer code. The more stringent requirement that all remaining single deuteron and triton counts recorded during the 122 hours of quiet-time coverage were background corresponds to an upper limit of $3 \times 10^{-5}$ ($^2$H, $^3$H)/sec. From this "background" flux, < 1 deuteron or triton is to be expected during the October–November 1972 solar event.

Mention should be made of the primary-cosmic-radiation abundance of tritons and deuterons. According to the upper limits given by Rao and Lavakare,[5] this source should not contribute to the present measurements.

Electronic gain shifts and overall instrument performance were checked by voltage monitors. In addition, good agreement is obtained between predicted and measured proton contamination of the 28–45-MeV deuteron channel in the South Atlantic anomaly. As a result of energy-loss fluctuations in the individual detectors and intrinsic detector noise, the particle identifier signal has a quasi-Gaussian shape about its mean value. Energy-loss fluctuations were calculated using the theories of Vavilov,[6] Tschalär,[7] and Bichsel,[8] and combined with laboratory measurements of the detector noise.[4] On the basis of these results we expect 2.0% of the 28.0–45-MeV protons to be recorded as deuterons with similar energy. This number is sensitive to shifts in gain.

Flare protons in this energy range are too few to utilize this criterion. In the South Atlantic anomaly, however, where there is a sufficient flux of trapped protons in the 28.0–45-MeV range, a 2–3% deuteron-to-proton ratio was measured. The excellent agreement of this value with the predicted value of 2%, together with the monitor voltages recording their proper values, indicates that electronic gain shifts did not shift by more than ~ 2%.

On the basis of the proton energy spectra measured during the flare period, the expected proton contamination of the 28–45-MeV deuteron channel from this effect is < 1 count, which is consistent with their observed absence.

The particle identifier instrument is sensitive to deuterons between 3.1 and 30.6 MeV/nucleon and tritons between 2.4 and 23.0 MeV/nucleon. During 2.254 hours of live coverage over the polar regions ($\Lambda \geq 65°$), during the period 30 October–2 November 1972, two deuterons and one triton were observed. The triton and one deuteron were in the atmospheric loss cone which implies either a "background" pulse or a particle of atmospheric origin. The remaining deuteron was in the mirror plane. It is, therefore, possible to conclude that ≤ 1 solar deuteron or triton was observed. During this same period, a total of 16 299 protons between 5 and 45 MeV were detected.

To obtain the correct H:$^2$H:$^3$H ratios, knowledge of the proton spectrum from about 2.4 to 28 MeV is required. The lower limit is 2.60 MeV below the present instrument's 5-MeV threshold. Fortunately, the OV5-6 satellite was simultaneously measuring protons from 1.3 to 28.0 MeV outside the magnetosphere.[9] (Details of the OV5-6 instrument are given by Hanser, Sellers, and Morel.[10]) Good agreement between overlapping channels (see Fig. 1) gives us confidence to use the

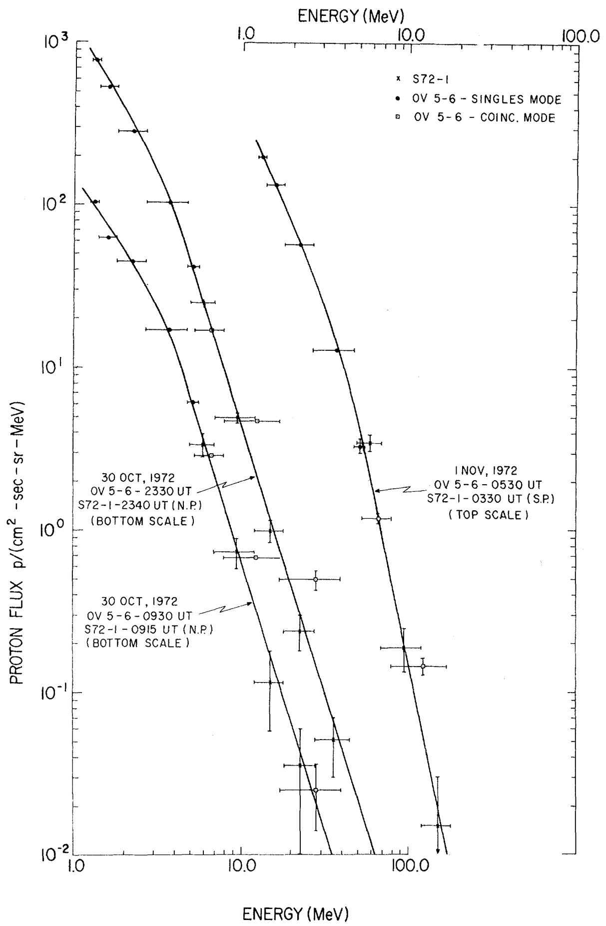


FIG. 1. Typical solar proton energy spectra used to calculate the upper limits to $^2$H/H and $^3$H/H. "N. P." and "S. P." refer to North Pole and South Pole passes of the S72-1 satellite.

OV5-6 spectrum below 5 MeV. The ratios H:$^2$H:$^3$H are then obtained as being $1{:}\leq 1.4\times10^{-5}{:}\leq 9\times10^{-6}$. These are a factor of 2 higher than one obtains by simple extrapolation of the S72-1 proton energy spectrum to lower energies. The difference between the low-energy spectra can be inferred by inspection of Fig. 1. The absence of deuterons and tritons contrasts with the abundance of helium. During the same October–November 1972 event, the alpha/proton ratio at 6.8 MeV/nucleon varied with time from 0.1% to 1.5%.[9]

Severny[11] spectroscopically determined the deuterium content of the sun to be $(3-5)\times10^{-5}$ times that of hydrogen. The present result of $\leq 1.4\times10^{-5}$ is consistent with that of Severny if one considers possible variations due to propagation through the interplanetary medium. Flare-produced $^4$He, relative to H, for example, varies more than an order of magnitude from flare to flare.

Upper limits for flare-produced deuterons and tritons were previously given by Waddington and Freier using emulsions flown in balloons. The measurements were limited to $E > 50$ MeV/nucleon and serious problems were encountered with secondary deuterons and tritons which were produced in the atmosphere. The present satellite results give upper limits of $1.4\times10^{-5}$ for $^2$H/H in the range 3.1–30.6 MeV/nucleon, and of $9\times10^{-6}$ for $^3$H/H in the range 2.4–23.0 MeV/nucleon for the October–November 1972 flare. These are to be compared with a $^2$H/H ratio of $\leq 6\times10^{-5}$ (10.4–13.3 MeV/nucleon) and a $^3$H/H ratio of $\leq 3\times10^{-5}$ (7.7–12.1 MeV/nucleon) recently obtained by Anglin[12] during a series of solar flares.

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# Mass Limit on a Positively Charged Heavy Muon*

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We report a preliminary search for a positively charged lepton ($Y^+$) coupled directly to the $\mu^-$ and $\nu_\mu$ (i.e., muon number = +1). Using the production process $\nu_\mu + N \rightarrow Y^+$ + anything, we have looked for the $\mu^+$ from the decay $Y^+ \rightarrow \mu^+ + \nu_\mu + \nu_\mu$. The expected number of $\mu^+$ events is given as a function of the heavy-lepton mass, the branching fraction to muons, and the heavy-lepton coupling. For typical gauge-theory predictions, we obtain the 90% confidence limit $M_Y > 2$ GeV/$c^2$.

One striking feature of weak interactions is the small number of members observed in the known lepton families. For example, the muon family presently contains only two observed members: $\nu_\mu$ and $\mu^-$. It is important to search for higher-mass members, whose existence could have profound implications.

Considerable theoretical work[1,2] in the past few years has focused on unified gauge theories to predict controlled high-energy behavior for the weak interactions and to unify the theoretical treatment of weak and electromagnetic interactions. Theories suggested thus far contain massive charged intermediate vector bosons ($M_w \sim 40$ GeV/$c^2$) together with neutral weak currents and/or heavy leptons. The suggested heavy leptons have the following properties: (1) They belong to existing lepton families (either electron or muon), and (2) they have different electric charge from existing charged leptons of the same lepton number.

The phenomenology of the proposed particles has been discussed at length by Bjorken and Llewllyn-Smith (BLS)[3] and by Llewellyn-Smith.[4] These authors mention several ways of searching for massive leptons. To date, we know that any heavy lepton must have a mass greater that that of the $K$ meson. Some calculations[3,5] have indicated that, were a positive heavy muon to exist with mass less than 1 GeV/$c^2$, it might have been observed in the CERN neutrino data.[6]

We emphasize here the production of heavy muons ($Y^+$), in a beam of high-energy muon neutrinos. The ordinary mode of interaction for neutrinos of high energy is

$$\nu_\mu + N \rightarrow \mu^- + \text{hadrons}. \tag{1}$$

The conjectured $Y^+$ would be produced by the process

$$\nu_\mu + N \rightarrow Y^+ + \text{hadrons}. \tag{2}$$

Reaction (1) has been observed and measured at CERN[6] with neutrinos of energy $E_\nu \approx 1$–10 GeV. The results are consistent with neutrino scattering from spin-$\frac{1}{2}$ fractionally charged pointlike constituents (quarks), with predominantly $V-A$ coupling (mainly scattering off quarks rather than antiquarks).[7] Preliminary National Accelerator Laboratory data are also qualitatively consistent with this picture at higher energies.[8,9]

In the quark model, the differential cross section for either (1) or (2) is given by

$$\frac{d^2\sigma_\pm}{dx\,dy} = \frac{g_\pm^{\,2} s}{\pi(sxy + M_w^{\,2})^2}\left[2xf(x)\left(1 - \frac{m_\pm^{\,2}}{sx}\right) + 2x\bar{f}(x)(1-y)\left(1 - y - \frac{m_\pm^{\,2}}{sx}\right)\right], \tag{3}$$