could have been detected, this gives an upper limit of 5×10^{-32} cm^2/atom. The number of atoms/cm^3 in the counter was calculated to be 6×10^{18}. The number of disintegrations per second in the tritium was 1.8×10^{11}, and it was estimated that one-twentieth of these passed through the counter. The average path length through the counter was 1.2 cm. Supposing the main means of scattering would be by the electrons and assuming eight electrons per atom would be effective in scattering, this gives an upper limit of 6×10^{-33} cm^2/electron.

Using another Geiger counter filled with twenty atmospheres of helium, a gross counting rate of (28.95 ± 0.31) counts/min. and a background counting rate of (29.12 ± 0.34) counts/min. were obtained. The net counting rate in this case was (-0.17 ± 0.65) count/min. Using 0.65 count/min. as an upper limit on the counting rate, 7×10^{-34} cm^2/atom was the upper limit on the cross section. In calculating this figure, the number of neutrinos and the fraction which passed through the counter were the same as above. The number of atoms/cm^3 was 5×10^{20}, and the average path length through the counter was 3.5 cm. Assuming the two electrons in helium to be equally effective for scattering, the upper limit of the cross section is 4×10^{-34} cm^2/electron.

* This work was supported by the joint AEC and ONR program.

[1] H. R. Crane, Rev. Mod. Phys. **20**, 278 (1948).

[2] M. E. Nahmias, Proc. Camb. Phil. Soc. **31**, 99 (1935).

Neutron Binding Energies

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Up to the present, authors[1] who have calculated neutron binding energies in the heavy isotopes have bridged between the radioactive series by smooth interpolations or by use of the mass formula. There are now sufficient data to give unambiguous energy differences between the $4n$, $4n+3$, and $4n+2$ series, apart from experimental error. Although the possible formation of excited states casts doubt on the result of any single type of experimental neutron binding energy measurement, agreement between the results of two properly chosen methods removes it. In a (d,p) reaction, if (Z,A) is the target nucleus, then $E_n(Z,A+1)=Q_R+Q_d+E_\gamma$, where $E_n(Z,A+1)$ is the neutron binding energy in $(Z,A+1)$, Q_R is the Q-value for the reaction, Q_d is the deuteron binding energy and E_γ is the *total* gamma-energy emitted by the product nucleus, if formed in an excited state. Thus, if the total gamma-energy between the excited and ground states is not included, the calculated binding energy would be equal to or *less* than the true binding energy.

Conversely, for the (d,t) reaction, $E_n(Z,A)=-Q_R+Q_t-Q_d-E_\gamma$. Here the target nucleus is still called (Z,A), and Q_t is the triton binding energy. If an excited state were formed and the total gamma-decay energy not included, the calculated binding energy would be *greater* than the true binding energy. Therefore agreement between the neutron binding energies in a given nucleus as measured by the (d,p) and (d,t) reactions gives this energy unambiguously. Similar considerations show that a (γ,n) reaction gives a result greater than or equal to the true energy, while the result from an (n,γ) reaction is ambiguous unless the gamma-decay scheme is determined. The energies listed in Table I are the results of various investigations for the last neutron in the isotope given. The last column gives conclusions based on the above reasoning. Thus the energy differences between the $4n$, $4n+3$, and $4n+2$ series are known.

Now it seems rather certain that the disintegration energies of Pb^{209}, Pb^{210}, and Bi^{210} are 0.69 Mev, 0.07 Mev, and 1.17 Mev, respectively.[2] The use of these, the disintegration energy[2,3] of Po^{214} and the neutron binding energies in Pb^{208} and Pb^{207}, shows that about 0.4 Mev must be added to the sum of the measured binding energies in Pb^{209} and Bi^{210}. If it is assumed that *only one* of these measurements is in error, the following arguments lead to the choice of 3.87 Mev for the binding energy of Pb^{209}. First, if the 0.4 Mev were added to the experimental binding energy in Pb^{209}, the resultant energy would be greater than that in Bi^{210}. However, it is expected that the addition of an odd proton outside the closed Pb^{208} shell would *increase* the binding energy of an odd neutron outside that shell. Second, the neutron binding energy in Pb^{209} would be only 0.5 Mev less than that of the neutron in Pb^{210}. This difference is expected to be 1.0 Mev or more. Third, if 4.17 Mev were the binding energy of the odd neutron in Bi^{210}, it would be less than that in Bi^{212}, contrary to expectations. The latter (4.36 Mev) is derived from the binding energy in Pb^{208}, the disintegration energies of Th *C* (2.25 Mev), Ac *C''* (1.44 Mev),[4] and known alpha-energies.[2,3]

Table I. Neutron binding energies.

Isotope	Neutron binding energy (Mev) measured by (d,p)[a]	(d,t)[a]	(γ,n)[b]	(n,γ)[c]	Neutron binding energy (Mev)
83^{210}	4.14 ± 0.03			4.170 ± 0.015	≥4.17
83^{209}		7.44 ± 0.05	7.45 ± 0.2		≤7.44
82^{209}	3.87 ± 0.05				$\geqq3.87$
82^{208}	7.37 ± 0.03	7.37 ± 0.05	7.44 ± 0.10	7.380 ± 0.008	7.38
82^{207}	6.71 ± 0.03	6.69 ± 0.05	6.95 ± 0.10	6.719 ± 0.016	6.72
82^{206}		8.10 ± 0.05	8.25 ± 0.10		$\leqq8.10$

[a] J. A. Harvey, Phys. Rev. **79**, 241 (1950).

[b] McElhinney, Hanson, Becker, Duffield, and Diven, Phys. Rev. **75**, 542 (1949); H. Palevsky and A. O. Hanson, Phys. Rev. **79**, 242 (1950).

[c] Kinsey, Bartholomew, and Walker, Phys. Rev. **78**, 77 (1950); Phys. Rev. **78**, 481 (1950); private communication.

These experimental energy differences between the four series make it possible to determine other binding energies using energy cycles. Knowledge of these energies may serve as a means of refining the empirical mass formulas. More importantly, they can provide a check on the validity of total decay energies. Arguments like those in the preceding paragraph are also being made for the latter purpose. Work along these lines at present indicates that some of the most critical decay energies are those of Ra *B*, Ra *C*, Bi^{213}, *Ms*Th$_1$ and *Ms*Th$_2$.

[1] A. Berthelot, J. de phys. et rad. (VIII) **3**, 17 (1942); K. Way, Phys. Rev. **75**, 1448 (1949); M. O. Stern, Rev. Mod. Phys. **21**, 316 (1949); A. H. Wapstra, Physica **16**, 33 (1950).

[2] See G. T. Seaborg and I. Perlman, Rev. Mod. Phys. **20**, 585 (1948) for references.

[3] Perlman, Ghiorso, and Seaborg, Phys. Rev. **77**, 26 (1950).

[4] H. D. Evans, Proc. Phys. Soc. London **63**, 575 (1950).

The Solar Flare of November 19, 1949 and Cosmic Rays

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Within recent years a great number of physicists, among them Forbush,[1] Ehmert,[2] and Unsöld,[3] have investigated extensively with ion chambers and counters the sudden variations in cosmic-ray intensity coincident with disturbances of the earth's magnetic field, changes in radiofrequency waves from the sun, and ionospheric disturbances and their correlation with solar flares.

As to our contribution to the investigation with the former method, our recording apparatus consists of 3 ion chambers containing Ar at up to 60 atmospheres; one of the chambers is unshielded, one shielded with 12 cm Fe, and one with 110 cm Fe. Normally we have a fourth vessel, likewise under 110 cm Fe, but this one was not in use for the moment. The charge required to compensate the ionization in the vessels is measured every two hours for the unshielded vessel, every hour for the other two, in the form of an excess over a well-known compensation charge.

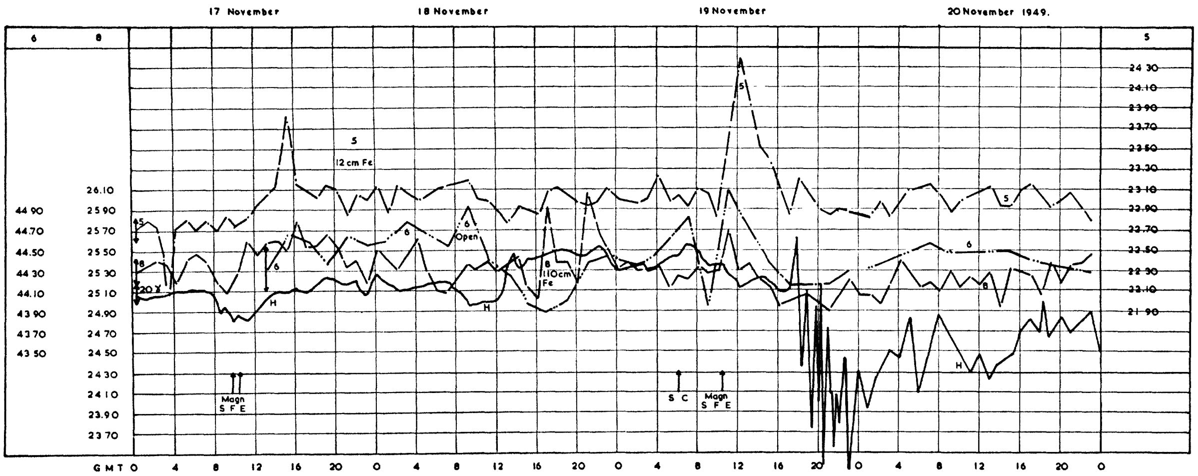

FIG. 1. Observed cosmic-ray intensity and horizontal component of the earth's magnetic field for the period November 17 to 20, 1949.

In this way it is possible to reach an accuracy of 0.1 percent; the last half year however our accuracy has been lowered to 0.2 percent due to frequency changes of the electric network, for which we have corrected as well as possible.

The use of different layers of absorbing material affords us a notion of the energies of the cosmic-ray particles which occur during solar flares. We know at the moment that the observed solar flare effects show great differences in this respect.

The normal case seems to be the following: frequently a small decrease in cosmic-ray intensity and a "sudden commencement" earth magnetically are observed shortly before the flare. But in any case immediately after the flare the earth's magnetic field shows the characteristic solar flare effect, followed within 20 min. to 2 hr. by a steep increment of cosmic-ray intensity, the size of which, however, differs greatly in the cases observed. Then in a decrease generally extending over several hours, the intensity comes down to a level below normal. In most cases considerable magnetic disturbances or a magnetic storm is simultaneously observed. The normal intensity is not regained till one or two days afterward.[4]

Variations of this general behavior of cosmic rays in a case of solar flare have been reported; e.g., by Broxon and Boehmer and by Rose. Broxon and Boehmer[5] found no increment during the flare of May 10, 1949. Our observations on this day give only an excess smaller than one percent in both the unshielded vessel and the one shielded with 12 cm Fe, with a retardation of many hours, but no increment was found under 110 cm Fe. During this flare apparently only particles of low energies were ejected, the greater part of them not being able to penetrate the atmosphere. This is confirmed by Schein's observation on the same day of an increment of 75 percent at very great height.

After the flare of November 19, 1949, Rose[6] did not find a decrease of cosmic-ray intensity, but during the magnetic disturbance setting in about 19.00 found an intensity higher than normal. On November 19 a solar flare of importance 3 was observed by the Wendelstein Solar Observatory (Bavaria), beginning at 10.29 and ending at 11.19 G.M.T. with a maximum at 10.34. Magnetic Station Witteveen of the K.N.M.I., Holland, reports on the same day a sudden commencement of 15γ in *H* at 6.04 G.M.T., followed by a solar flare effect at 10.30 to 11.00. This solar flare effect is confirmed by a Dellinger fade-out of the Noordwijk radio station (NDRA). After 19.00 on November 19 a magnetic disturbance set in with a maximal range in *H* of 215γ.

In Fig. 1, which is corrected for changes in barometric pressure, we give the intensities for the various chambers in terms of the compensation voltages, and also the horizontal intensity of the earth's magnetic field. The intensity changes of the cosmic rays here are curious. Before the point marked S.C. there is a small decrease until 6.00 G.M.T., except in the unshielded chamber. Then a minor maximum occurs, followed immediately by a dip, which is negligible, however, in the hard component. The influence of the solar flare of 10.29 G.M.T. is different in our three vessels. The hard component shows an increase of one percent in the period 10.30–11.30, and in the interval 10.00–12.00 the total intensity attains a value somewhat higher than that before the dip. The behavior of the component observed under 12 cm Fe is remarkable. Here we find in the two intervals 10.15–11.15 and 11.15–12.15 a steep increase of nearly seven percent in total. The decrease to normal values lasts in all of the vessels until 17.00 G.M.T. We cannot confirm the observation of Rose, however, that during the magnetic disturbance following the flare the cosmic-ray intensity is higher than before the flare, our mean hour values for the three chambers being somewhat larger on November 18 than on November 20, although we must agree that after such an important flare a larger decrease would be expected.

The Cosmic Relations Bulletin No. 7 (1949) of New Zealand mentions on November 19, 1949 an increment of 15 percent in cosmic-ray intensity followed by a more or less exponential decrease to *normal* values.

Taken all in all, we should conclude that no difference is to be observed between the intensities before and after this flare, which is abnormal.

We are very much indebted to Mr. A. J. Dijker for his help with the classification of the bulky material on this subject for the last four years.

[1] Forbush, Gill, and Vallarta, Rev. Mod. Phys. **21**, 44 (1949).
[2] Ehmert, Zeits. f. Naturforsch. **3a**, 264 (1948).
[3] A. Unsöld, Zeits. f. Astrophys. **26**, 176 (1949).
[4] Clay, Jongen, and Dijker, Proc. Amsterdam **LII**, 897, 923 (1949).
[5] J. W. Broxon and H. W. Boehmer, Phys. Rev. **78**, 411 (1950).
[6] D. C. Rose, Phys. Rev. **78**, 181 (1950).

The Photo-Disintegration of the Deuteron

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IN a previous paper[1] L. Hulthén and the present writer have given results of theoretical calculations on the photo-disintegration of the deuteron for the γ-energies 2.62, 2.76, and 6.2 Mev. As experiments are being carried out using γ-rays from radio