quoted to a higher precision than that to which the standard moment used in the experiment is known. Recent measurements of the proton moment, involving different physical principles, give:

$$\mu_p = (1.4100 \pm 0.0002) \times 10^{-23} \text{ ergs/gauss}^{45}$$
$$\mu_p = (15.2106 \pm 0.0007) \times 10^{-4} (e\hbar/2mc)^{46}$$
$$\mu_p = (15.2100 \pm 0.0002) \times 10^{-4} (e\hbar/2mc)^{47}$$
$$\mu_p = 2.79273 \pm 0.00006 (e\hbar/2M_p c).^{48}$$

All of these values include the diamagnetic correction for atomic hydrogen ($H'/H_0 = 1.8 \times 10^{-5}$), although the proton was contained in a molecule (H_2O, NaOH, mineral oil, and H_2O, respectively). This is probably of no importance considering the precision of the first value of μ_p, but the last three values will be improved when the actual molecular shielding correction is determined by a comparison with H_2. §

I wish to express my appreciation to Professor F. Bitter for the encouragement and guidance he has given during this investigation. Thanks are given to Professor N. F. Ramsey and Dr. J. Benedict for the privilege of several valuable discussions.

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§ *Note added in proof:* This comparison has been made recently by H. A. Thomas, Phys. Rev. **80**, 901 (1950). On the basis of Ramsey's calculated magnetic shielding value of 2.68×10^{-5} for H_2, he obtains 2.62×10^{-5} for H_2O and 2.84×10^{-5} for mineral oil (Petrolatum U.S.P.—Light). Also, H. S. Gutowsky and R. E. McClure, Phys. Rev. (to be published), have measured these shifts. Again based on Ramsey's value for H_2, they obtain 2.71×10^{-5} for H_2O and 3.05×10^{-5} for mineral oil (Nujol). The discrepancy between the H_2O values is not appreciably greater than the probable errors involved in the two measurements. However, Gutowsky (private communication) finds that the greater part of the difference between the mineral oil values is real and due to the different types of mineral oil used. Using an average value for the H_2O and mineral oil corrections the last two values of μ_p given above become, respectively, 15.2101×10^{-4} and 2.79275.

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An Increase of the Primary Cosmic-Ray Intensity Following a Solar Flare*

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An increase of 15.4±4.3 percent has been detected in the intensity of cosmic rays at altitudes between 95,000 and 100,000 feet, occurring approximately 19 hours after the commencement of the outstanding solar flare of May 10, 1949. The observations were conducted with a quadruple-coincidence counter train inclined at a zenith angle of 60°, and containing an interposed absorber of 1 cm of Pb. Complications introduced by atmospheric absorption, possible directional asymmetry, and multiplicative effects preclude a precise evaluation of the increase in terms of absolute primary particle intensity. The effect of the particles emitted by the sun during the chromospheric eruption does not manifest itself at altitudes below approximately 55,000 feet.

I. INTRODUCTION

SUDDEN increases in the cosmic ray intensity coincident with the occurrence of a solar flare have been registered on four occasions by instruments operating near sea level or at relatively low altitudes.[1–6] From the variation in the effect with altitude and latitude, as recorded by Compton-Bennett ionization chambers, which were completely shielded by 12 cm Pb, it was concluded[6] that the largest of these increases was attributable to the nucleonic component produced by relatively low energy charged primary particles accelerated by some solar mechanism.

It has been reported[7] recently that the rate of production in photographic emulsions of stars having 3 to 8 prongs exceeded the normal value at an altitude of 95,000 feet by 50±13 percent during the period 18:48–22:30 GMT on May 11, 1949, about 23 hours following the occurrence of the outstanding solar flare[8] of May 10, 1949. This bright chromospheric eruption, of importance 3+, the greatest possible on the scale of the International Astronomical Union, commenced at 20:00–20:03 GMT. Solar noise radiometer, ionospheric, and magnetic field measurements had all returned to normal before 22:20 GMT May 10, 1949, at which time the flare had subsided, but not disappeared, on

* Assisted by the joint program of the ONR and AEC.
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TABLE I. Flight summary. Interposed absorber 1.0 cm of Pb. Geomagnetic latitude 52°N.

Date	Ceiling altitude (feet)	Time of arrival at ceiling (GMT)
April 12, 1949	117,000	15:04
May 11, 1949	110,000	15:14
January 5, 1950	110,000	15:54

H_α spectroheliograms.[9] An intense magnetic storm began at 06:24 GMT on May 12.

During an extensive program of investigation of the directional distribution of cosmic-ray intensity at very high altitudes,[10] a balloon flight was conducted in the interval between the occurrence of the solar flare and the launching of the aforementioned[7] flight which indicated the increased nuclear disintegration intensity.

II. EXPERIMENTAL ARRANGEMENT

The instrument was a standard quadruple-coincidence counter train of the type described previously[11] (designated apparatus A in reference 11) inclined at a zenith angle of 60°, and containing an interposed absorber of 1 cm Pb. The flight reached a maximum altitude of 110,000 feet at 15:14 GMT, 19¼ hours after the onset of the solar flare. A similar instrument had been released one month earlier, and a third check flight was subsequently conducted in accordance with the observation that the counting rate, near the "top of the atmosphere," of the instrument released on May 11 was higher than that of the previous ascent.

The tape records of the three flights summarized in Table I have just been analyzed, and the distinct increase in the primary cosmic-ray intensity during the period following the solar flare is apparent in Fig. 1. The solid circles represent averages of all data obtained during both ascent and descent of two flights on normal days, whereas the square points represent data based on the flight conducted during the post-flare period. In each case, points obtained during the ascent and descent are in good agreement. Furthermore, the data from the flights of April 12, 1949, and January 5, 1950, were in agreement within the expected statistical uncertainties. No corrections or normalizations have been applied to the data. The instruments were identical within a statistical uncertainty of less than 1 percent, as may be seen in the ground-run summary of Table II. A statistical analysis of the counts obtained at one-minute intervals in each of the flights revealed that in each case the distribution was normal.

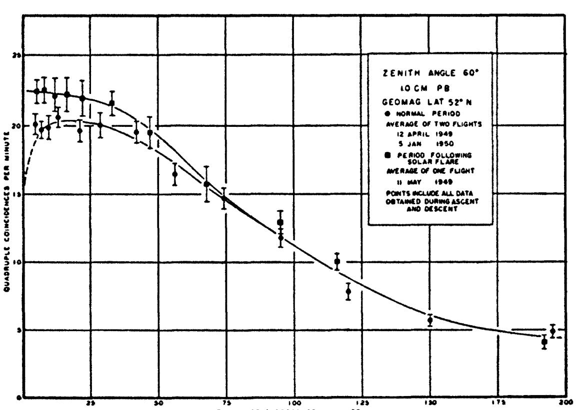

FIG. 1. *Intensity vs altitude* curves for cosmic radiation capable of penetrating 1 cm of Pb, and passing through the counter train at a zenith angle of 60°, at geomagnetic latitude 52°N, during normal and disturbed periods, respectively. The indicated uncertainties represent statistical standard deviations.

The magnitude of the effect near the top of the atmosphere may best be determined from a comparison of the quadruple-coincidence rates based upon all counts recorded in a particular pressure interval during the disturbed and normal periods respectively. Table III lists the average value for each flight in the region between 95,000 feet and 110,000 feet. The uncertainties indicated are statistical standard deviations. The increase during the disturbed period amounts to 15.4 ±4.3 percent. From the *statistical* point of view, the odds against the fortuitous observation of such an increase are roughly 6000 to 1. Furthermore, the value of the difference is reduced only slightly, if the interval over which the averages are taken is increased by an extension of the lower altitude limit.

TABLE II. Ground run summary. No interposed absorber. Swarthmore, Pennsylvania, altitude 296 feet.

Flight date	Ground counting rate (counts/min)
April 12, 1949	0.913±0.010
May 11, 1949	0.918±0.013
January 5, 1950	0.925±0.012
Average	0.918±0.007

TABLE III. Average counting rates based upon all data obtained during three flights in the pressure interval 4.8 to 10.0 mm of Hg.

Date	Counting rate (counts/min)
April 12, 1949	18.5±0.7
January 5, 1950	20.4±0.7
Average of above	19.5±0.5
May 11, 1949	22.5±0.7

The aforementioned magnitude of the effect is regarded as a conservative lower limit. As may be seen in Table III, the flight on January 5, 1950 yielded slightly higher counting rates (near the top of the atmosphere only) than that of April 12, 1949, although the difference is not inconsistent with expected statistical fluctuations. If only the latter flight, which chro-

[9] H. W. Dodson, Astrophys. J. **110**, 382 (1949).
[10] M. A. Pomerantz, unpublished. A preliminary account of some of these experiments was given in abstract form—Phys. Rev. **75**, 1335 (1949).
[11] M. A. Pomerantz, Phys. Rev. **75**, 1721 (1949); see also **75**, 69 (1949); **77**, 830 (1950).

nologically is much closer to the flight released during the disturbed period, is considered, the increase is, in fact, enhanced.

III. DISCUSSION

It is not possible to express the increase in terms of absolute primary particle intensity for several reasons. In the first place, the counter trains were inclined at an angle of 60° with the vertical, as a consequence of which particles propagating their original direction traverse an air path corresponding to twice the pressure at the point of observation. Thus, the effective atmospheric absorber thickness for such a primary is about 10 g/cm^2. In addition, the interposed lead and counter walls amount to 16 g/cm^2. This effectively attenuates the enhanced incident beam to an extent contingent upon the energy distribution upon arrival at the earth's atmosphere of the additional group of particles emitted by the sun during the flare. On the other hand, multiplicative effects in the atmospheric layer above the detecting instrument would amplify the intensity.

If the directional distribution of the particles emitted during the solar eruption is not isotropic at the top of the atmosphere (a possibility which seems quite reasonable), then the actual effect is much greater than is indicated by the measurement. The counter train rotates freely about a vertical axis, and the results actually represent an average over-all azimuths, at a specific zenith angle. Hence, a very great increase in a favored direction would be smeared out.

No measurable change was observed with ionization chambers or counters at ground stations[12] while any of these balloon flights were aloft. Statistical considerations preclude an accurate determination of the atmospheric depth to which the disturbance was propagated. At altitudes lower than 55,000 feet, however, the points representing the normal and post-flare periods ostensibly overlap.

The counting rate of a single G-M counter was observed by Johnson and Korff[13] to remain constant within 2 percent at the 20-km level (about 42 mm of Hg), on July 27, 1938, for a period of 7 hours, during which a solar flare of intensity 2 occurred. Even if every flare were effective in increasing the primary cosmic-ray intensity, (a matter which remains to be investigated), the presence of particles having the requisite energy for penetration even to this depth, and with sufficient intensity to be detectable above the extremely high soft component background rate characteristic of a single counter, may be a relatively infrequent phenomenon.

Comparison of the data of Lord, Elston, and Schein[7] with the present results, (on the questionable assumption of an isotropic distribution and constancy during the period between 15:30 GMT and 18:50 GMT on May 11, 1950), reveals that the increase in the rate of production of nuclear disintegrations is 3 ± 1 times as great as that of the charged-particle intensity. Of course, it must be remembered that a substantial fraction of the stars are produced by neutral particles.

The time lag which ensues between the solar eruption and the arrival at the earth of charged particles emitted by the sun suggests a slowly acting mechanism of acceleration, rather than the direct action of Menzel-Salisbury[14] low frequency electromagnetic waves originating in the extreme outer edge of the solar corona, as postulated by McMillan.[15]

Grateful acknowledgment is made for the continued sponsorship by the National Geographic Society of certain phases of the program of cosmic-ray investigations during the course of which these experiments were performed.

Note added in proof: Previously available information (Table I, reference 8) had indicated a return to normalcy before 22:20 GMT on May 10, 1949, of all the observed solar characteristics. In a search for relationships between cosmic-ray and solar phenomena, we have just examined the records of measurements of solar noise characteristics at 205 Mc obtained by the Cornell University Radio Astronomy project.† Midday observations on May 11, 1949, averaged over a period of two hours and centered about local noon (1700 GMT, and very close to the time of the balloon flight reported here) revealed the following characteristics:

(1) Base level = 10. (Ratio of average minimum power radiated by the sun during averaging period to the average power radiated by the sun when it is very quiet).

(2) Relative number of bursts = C, the highest rating, denoting large number of bursts per hour (momentary increases in solar radiation, the time between significant increase and significant decrease being less than three seconds).

(3) Burst distribution in time = X, indicating moderate tendency toward burst grouping.

(4) Amplitude of bursts = 1–2 times average base-level (average amplitude of large bursts during averaging period).

Intensities of this magnitude are relatively rare. For example, of 264 observations tabulated during 1949 only four exceeded the aforementioned base level (three being on successive days), four more were higher than 8.0, whereas 230 were less than 3.0. On April 12, 1949, the base level value was 1.3 and there were no bursts (code notation 1.3*Q*). No solar noise observations were made on January 5, 1950, the date of the other normal flight, but protracted periods before and after were characterized by minimum activity (1.0*Q*).

This is the first instance of a simultaneous correlation between a solar phenomenon and the cosmic-ray intensity near the top of the atmosphere. Although any generalization based upon a single observation would obviously be premature, the relationship is extremely suggestive, and cooperative efforts now in progress to obtain additional evidence of this nature should be very fruitful.

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