ENERGY SPECTRUM AND TIME DEPENDENCE OF THE INTENSITY OF SOLAR COSMIC-RAY PROTONS

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Data obtained in the stratosphere are presented on the energy spectrum and time dependence of the total intensity of solar flare protons.

INTRODUCTION

It has been established that cosmic ray bursts recorded in northern latitudes of the stratosphere are produced by primary protons generated during large solar flares. For example, in July, 1959 three large class 3+ flares occurred separated by one and two days, respectively. Large increases of cosmic ray intensity with the same time sequence were recorded in the stratosphere during July.[1,2] However, there are instances when it is difficult to associate a definite solar flare uniquely with a registered cosmic ray outburst. This apparently results from the fact that occasionally some relatively small flares are cosmic ray sources. Solar flares below classes 2 and 3 in importance occur more frequently, so that it is not always possible to associate individual solar flares and cosmic ray bursts uniquely. Nevertheless, cosmic ray bursts in the stratosphere that are not associated with any specified flares are also attributed to solar-emitted protons.

The pattern of effects associated with a cosmic ray burst can be outlined as follows. In most instances cosmic ray bursts are observed a few hours later than a solar flare.[1] A period of magnetic storms, ionosphere disturbances, and in some instances aurorae begins about a day after a flare. At the onset of a magnetic storm or a little later a decrease of high-energy cosmic ray intensity is registered on the ground (the Forbush decrease). In some instances the cutoff energy of primary particles also changes.[3] There are also cases when a cosmic ray burst in the stratosphere is not accompanied by geophysical effects. The associated flares ordinarily erupt at the edge of the solar disk, emitting corpuscular streams that miss the earth. It is naturally of interest to investigate cosmic ray intensity increases in these instances.

It has been found from the study of bursts in the stratosphere that the Forbush decrease becomes more pronounced with increasing amplitude of the bursts induced by solar protons,[1] thus indicating that some relation exists between these two diverse events. It has also been found that sudden magnetic storms accompanying a Forbush decrease (according to measurements at sea level, where most of the cosmic ray intensity is due to high-energy primary particles of galactic origin) were not associated with reduced proton intensity in bursts.[4] A proposed explanation is that solar protons registered during the Forbush decrease do not move outside of the corpuscular streams but are carried by the latter.[4] Another step forward in accounting for this interesting property of solar corpuscular streams has been an investigation of the flare proton energy spectrum before and during the Forbush decrease.

If it should be assumed that during a Forbush decrease solar protons strike the earth outside of the corpuscular streams, we would expect a flatter proton energy spectrum during this time than before the Forbush decrease, as occurs in the energy spectrum of galactic cosmic rays.[5,6] The bursts actually present the reverse of this picture, —a steep spectrum during the Forbush decrease, followed by a flat portion. This effect, which we first noticed in July, 1959, also suggested the aforementioned property of solar corpuscular streams.[1] We shall here present new data on the energy spectrum of solar flare protons.

We also investigated the time dependence of primary proton intensity. The burst of May 4, 1960 in the stratosphere furnished data for the initial, as well as for the following, period of burst de-

Table I

Date	Time*	m	τ, hrs	Data	Time*	m	τ, hrs
April 1, 1960	10^h 30′	4	2	May 12, 1960	08^h 30′	3	2
April 28, 1960	08 30	7		May 13, 1960	08 30	5	
	10 43	3	12		11 30	2	6
	13 27	7			14 30	1	
	20 45	1		September 3, 1960	08 30	50	
May 4, 1960	11 28	34			13 15	70	
	13 55	30			18 48	20	
	16 30	16		September 4, 1960	08 15	20	
	19 29	10			13 26	11	
May 5, 1960	02 30	4	30	September 5, 1960	08 23	2	
	08 31	2.8			13 47	1.5	
	11 32	2			19 30	0.5	
	14 30	2					
	18 29	1.5					

*Universal time.

velopment. These data suggest certain conclusions regarding the propagation of low-energy solar protons in interplanetary space.

MEASUREMENTS

Measurements were obtained with a radiosonde[7] carried into the stratosphere by balloons. Altitude dependences were measured for single-counter readings and for double coincidences in a telescope consisting of two Geiger counters separated by 7 mm Al.

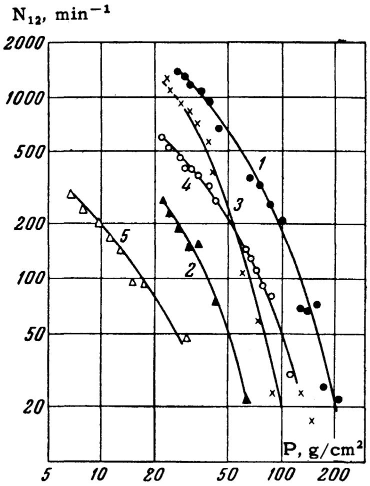

FIG. 1. Number N_{12} of double coincidences (with normal background subtracted) vs pressure P.

Curve	Date	Onset
1	September 3, 1960	07^h 00′
2	September 4	11 56
3	May 4, 1960	9 58
4	May 4	15 00
5	May 5	10 20

Table I contains the data on the registered bursts. The third column gives the relative intensity increase of primary radiation $m = (N_{exc} - N_0)/N_0$, where $(N_{exc} - N_0)$ is the excess, and N_0 is the normal primary cosmic ray intensity. The values of $N_{exc} - N_0$ were obtained by extrapolating the measurements to a pressure of 5 g/cm^2. The fourth column gives the duration τ of the observed bursts. The events of May 4, 12, and 13, 1960 were not accompanied by a Forbush decrease.

The event of April 1 was registered by the Winckler[8] and Simpson[9] groups, with equipment installed in the American space probe Pioneer V, at 5×10^6 km from the earth, and by the Van Allen group[10] using the American satellite Explorer VII. The combined data for the event of April 1 provide good confirmation of the extraterrestrial origin of the stratosphere bursts. The event of May 4-5, 1960 was also registered on the ground.

SPECTRUM OF PRIMARY PROTON RANGES

The bursts of May 4 and September 3, 1960 are of greatest interest with regard to the energy spectrum of primary protons and the time dependence of their intensity. These bursts had large amplitudes and the most prolonged duration.

Figures 1 and 2 show the measurements obtained with a telescope and with a single counter during the events of May 4 and September 3. The experimental points are the averages over three minutes. The slopes of the absorption curves for different times during a burst differ only slightly. The steeper slope of curve 3 is associated with the time dependence for the beginning of the event (see below). Curve 2 in Fig. 1 was obtained 29 hrs after the measurements on September 3 (curve 1). After this period the amplitude of the burst was

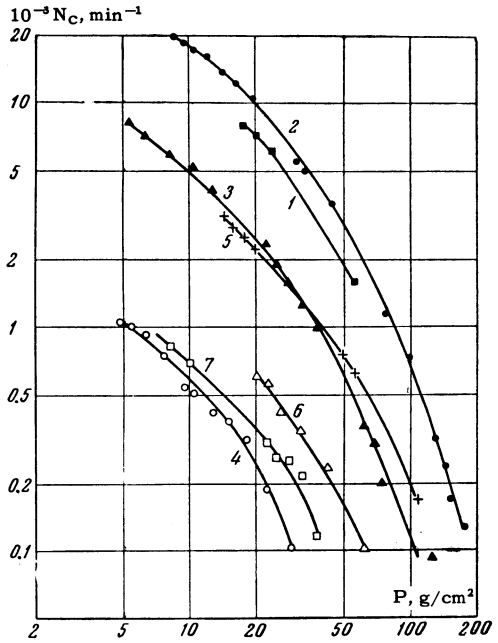

FIG. 2. Proton count N_c (after background subtraction) obtained with a single counter vs pressure P.

Curve	Date	Onset
1	Septemper 3, 1960	07^h 00′
2	September 3	11 45
3	September 4	6 45
4	September 5	6 53
5	May 4, 1960	15 00
6	May 5	1 00
7	May 5	7 00

reduced to less than one-fourth without much change in the slope of the absorption curve. The same applies to curves 4 and 5 in Fig. 1 for May 4 and 5. Curves 1—4 in Fig. 2 for the September burst, based on measurements with a single counter, also have similar slopes.

Curves 5, 6, and 7 in Fig. 2 present a similar picture for the single-counter measurements of May 4 and 5, although segments of the curves in the long-range region exhibit a tendency toward a gradual increase of steepness. This indicates that high-energy flare protons disappear somewhat sooner than protons with lower energies. We thus arrive at the general conclusion that there is no essential change in the primary-proton absorption curve throughout the duration of a burst (30—50 hrs).

Figure 3 shows the energy spectra of primary protons in different bursts measured with the telescope. Here we took into account the ionization losses and proton absorption due to nuclear colli-

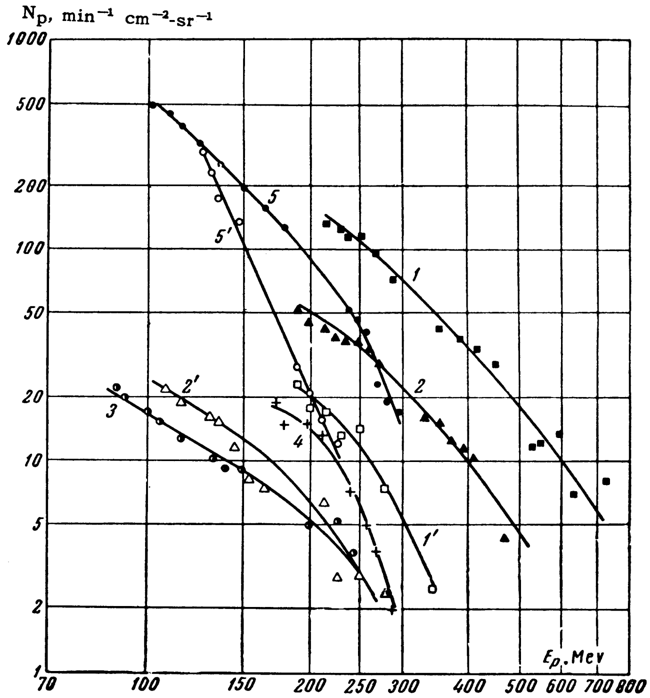

FIG. 3. Integral proton spectra. Curves 1 and 1′—September 3 and 4, 1960; 2 and 2′—May 4 and 5, 1960; 3—May 13, 1960; 4—April 28, 1960; 5 and 5′—July 11 and 12, 1959. N_p is the number of protons and E_p is the proton kinetic energy.

sions in air. The figure also includes the measurements of July 11 and 12, 1959 (curves 5 and 5′). The slope of curve 5 is somewhat less steep (for $E_p < 200$ Mev) than that shown in [1]; this is associated with the subsequent improvement of the altitude graph of the measurements.

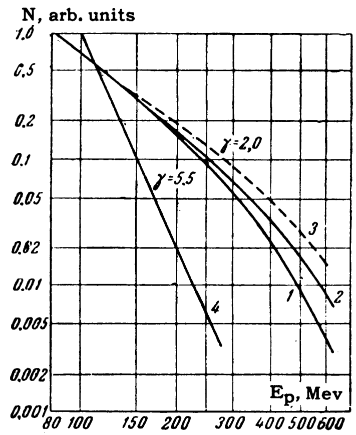

FIG. 4. Integral proton energy spectra. 1—average spectrum in the absence of magnetic storms and Forbush decrease; 2—the same, allowing for proton absorption resulting from nuclear collisions in air, as well as ionization losses; 3—derived from curve 2 by taking into account approximately the proton diffusion time in space as a function of velocity; 4—average spectrum during magnetic storms and Forbush decrease.

Table II

Date	Time	P, g/cm²	N′, min⁻¹	N″, min⁻¹	N′/N″	Remarks
May 4, 1960	17^h 03′ 16 28	18 53	2 600 680	2 900 580	1.9 1.2	Magnetic storms and Forbush decrease absent
September 3, 1960	8 32 8 04	20 57	7 500 1 600	8 000 1 600	0.94 1.0	"
May 12, 1959	13 23	23	900	320	2.8	Magnetic storm and Forbush decrease present
July 12, 1959	13 42 13 11	17 52	2 950 82	1 440 48	2.0 1.7	"
July 15, 1959	13 20 13 01	21 57	13 200 2 180	2 200 60	6 36	"

The spectra in Fig. 3 (with the exception of curve 5′) were registered at a time when no magnetic storm nor Forbush decrease was observed. The average spectra from these data are represented by curves 1—3 in Fig. 4. Curve 1 takes only ionization losses by protons into account. Curve 2 was derived from curve 1 by also taking into account proton absorption in nuclear collisions. The nuclear absorption coefficients for protons as functions of energy were obtained from the literature.[11–13] The absorption coefficient in air, converted from data in nuclear emulsion and copper, is 300 g/cm^2 for 350—400 Mev protons[11,12] and 170 g/cm^2 for 660-Mev protons.[13] Curve 3 was derived from curve 2 by taking into account approximately the proton diffusion time in space as a function of velocity. With these corrections, the spectrum 3 in the 100—400 Mev range has an exponent γ close to 2.0. Spectrum 4, recorded during Forbush decreases (May 12, July 12, and July 15, 1959) has $\gamma \approx 5.0$.

INTENSITIES FROM TELESCOPE AND SINGLE-COUNTER MEASUREMENTS

Our measurements were performed with a single STS-6 counter having 0.05 g/cm^2 wall thickness, and with a telescope incorporating a 7-mm Al absorber. As reported in[4], the emission intensity registered by the single counter considerably exceeded that registered with the telescope. This indicates that during the event particles with ranges under 7 mm Al were also present in the stratosphere. It was noted in[4] that this effect could be attributed qualitatively to hard gamma rays from inelastic collisions of evaporation neutrons in the stratosphere. R. R. Brown of the University of California has informed us in a private communication that the unusually high intensity of 2—3 Mev photons registered by him in the stratosphere during the burst of July 15, 1959 can hardly be attributed to evaporation neutrons. Our data for July 15 also exclude this interpretation.

A Gross transformation of the number N_{12} of double coincidences gave the total proton flux at different altitudes. N_{12} and the single-counter readings were obtained during the same flight. In the absence of a Forbush decrease the single-counter and telescope measurements agreed. However, during a Forbush decrease the single-counter intensities exceeded the expected transformed values. This is illustrated by Table II, where P is the pressure, N′ is the single-counter reading, and N″ is the transformed number of protons. The sixth column gives the ratio of the measured to the expected transformed count. The seventh column indicates the absence or presence of magnetic storms and Forbush decreases.

The data for May 4 and September 3, 1960 show satisfactory agreement with the measurements and the transformation. However, for May 12, July 12, and July 15, 1959 during magnetic storms and Forbush decreases the single-counter result

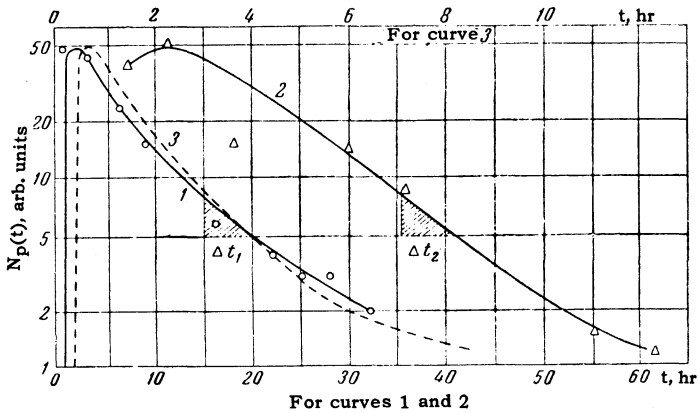

FIG. 5. Flare proton intensities during bursts in the stratosphere. Curve 1 – May 4, 1960; curve 2 – September 3, 1960; curve 3 – burst registered February 23, 1956 at sea level in Chicago.

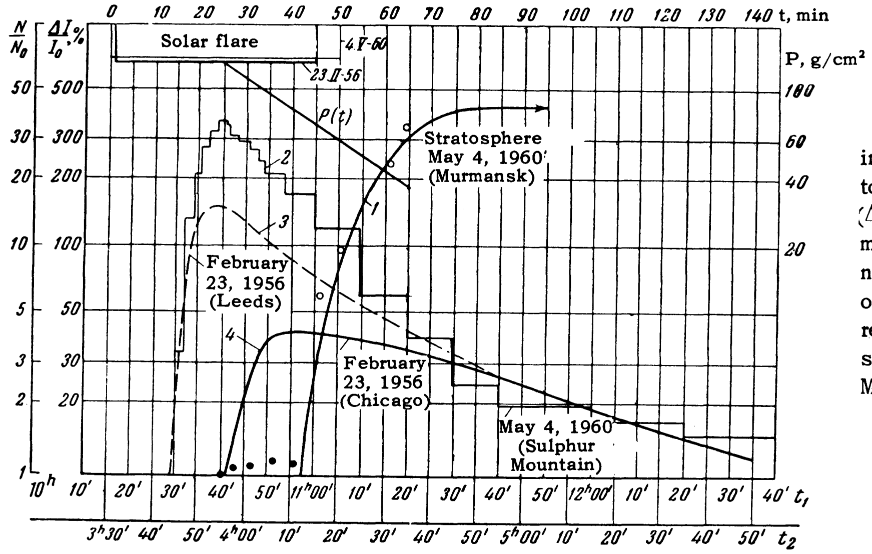

FIG. 6. Time dependence of the relative increase of cosmic ray intensity in the stratosphere (N/N_0, curve 1) and at sea level ($\Delta I/I$, curves 2, 3, 4). t_1 – time of stratosphere measurements on May 4, 1960; t_2 – time of neutron monitor measurements; t – time after onset of solar flare. The rectangular steps represent the duration of the solar flares. The straight line represents pressure vs time on May 4, 1960.

was three times greater than the transformed (telescope) proton count for May 12, twice as large for July 12, and six times greater for July 15. Thus during a Forbush decrease the stratosphere is penetrated by particles with ranges under 7 mm Al in addition to protons. It is also possible that these short-range particles in the stratosphere are associated with outer Van Allen belt electrons.[14]

TIME DEPENDENCE OF PRIMARY PROTON INTENSITY

The foregoing results furnish information regarding the time dependence $N_p(t)$ of primary proton intensity. Figure 5 shows $N_p(t)$ for May 4-5 and September 3-5, 1960. The onset of the corresponding solar flares was taken as t = 0. On May 4 the solar flare had the coordinates $\varphi = +10°$, $l = +90°$ and lasted from 1015 to 1117 UT. The flare of September 3 had the coordinates $\varphi = +17°$, $l = -90°$ and began at 0040 UT. Curve 3 represents $N_p(t)$ at Chicago for the event of February 23, 1956.[16] The peaks of all three curves are seen to agree in height.

The errors in the data represented by Fig. 5 resulted mainly from the extrapolation of the measurements to the top of the atmosphere, and for most points do not appear to exceed 20—30%.

The curves in Fig. 5 exhibit segments of approximately constant intensity lasting 3—5 hrs for May 4 and 10—20 hrs for September 3. The longer duration of the September burst compared with the May event is represented by the flat segment of curve 2. The slopes of $N_p(t)$ on the descending portions of the curves are similar ($\Delta t_1 \approx \Delta t_2$ for the shaded triangles in the figure). This is in accordance with proton diffusion in interplanetary space. The decrease of proton intensity at any given energy depends only on the medium of propagation. Here we must consider that interplanetary space contains scattering centers of cosmic rays in the form of magnetic clouds.[15,16]

On this basis it is interesting to compare the data for $N_p(t)$ in the stratosphere for primary protons above 0.1 Bev with the data for 3-4 Bev protons registered in the event of February 23, 1956. Figure 5 shows that the rate of decrease in this instance (curve 3) is about four times faster than for curves 1 and 2. It will be shown subsequently that this difference resulted in the fact that the diffusion coefficients for primary protons at low and high energies differ by a factor of 4.

Our measurements of May 4 were obtained at 15 km. At this same time neutron monitors registered a 10 ± 2% peak of enhanced cosmic ray intensity at Prague[17] and 8% at Leeds.[18] Curve 3 in Fig. 1 represents the progress of the stratosphere burst, based on the altitude dependence of N_{12}. A sharp rise of N_{12} with decreasing pressure was observed when the pressure on the instruments was under 90 g/cm^2. The arrival of low-energy primary protons in the stratosphere must be assigned to this period.

For $P < 90$ g/cm^2 the measurements of N_{12} were converted to the initial intensity of protons above 100 Mev (the open circles in Fig. 6). For $P > 90$ g/cm^2 unconverted values of N_{12} are given (filled circles). Figure 6 also includes the data for May 4, 1960 at Sulphur Mountain[19] and for February 23, 1956 at Leeds[15] and Chicago.[16] The latter data are compared with those in [19] for t = 115 min. We observe that on May 4 and February 23 cosmic rays lagged approximately 15 min. behind the onset of the solar flare. Maximum cosmic ray intensities are reached in 8—10 min. Low-energy protons lag 25—30 min behind the arrival of high-energy protons. This is a short period of time, considering the fact that most protons in the atmosphere have velocities $\beta = 0.5$, while on the ground $\beta \approx 1.0$. It is therefore possible that on May 4, 1960 low-energy and high-energy protons were generated simultaneously on the sun.

DISCUSSION OF THE TIME DEPENDENCE $N_p(t)$

On the basis of the data for February 23, 1956 many authors have stated that for a long period following the peak of a burst the cosmic ray intensity is described by $A/t^{3/2}$, and that during this time the spatial distribution of primary protons is isotropic. Both effects were accounted for by the diminishing primary proton intensity registered on the ground as a result of diffusion in interplanetary space. On the basis of the fact that the buildup time of the burst of February 23, 1960 was very much shorter than its decay, Meyer, Parker, and Simpson[15] have constructed the following model for the spatial distribution of scattering centers: The diffusing magnetic field is situated mainly outside of the earth's orbit and there are no scattering centers between the sun and the earth. We shall show below that the experimental results can be accounted for without recourse to this special model, as was pointed out by Dorman.[20] We shall now attempt to describe our results in the stratosphere on the basis of proton diffusion in interplanetary space.

The differential equation of diffusion in a spherically symmetrical uniform space, $\partial N_p/\partial t = D\nabla^2 N_p$, with the injection of a number B of particles at the point $r = 0$ and time $t = t_0$ has the solution

$$N_p(R,\ t-t_0) = \tfrac{1}{8} B\,[\pi D(t-t_0)]^{-3/2} \exp[-R^2/4D(t-t_0)]. \quad (1)$$

Here $N_p(R,\ t-t_0)$ in our case is the primary-proton intensity as a function of time on the earth; R is the sun—earth radius, t is the observation time; t_0 is the flare onset time; and D is the diffusion coefficient

$$D = lv/3 \quad (2)$$

where l is the mean free proton path for scattering, and v is the proton velocity.

Efficient scattering of protons by magnetic clouds at the distance l requires the condition $H > p/300l$, where H is the magnetic field strength in the clouds and p is the proton momentum.

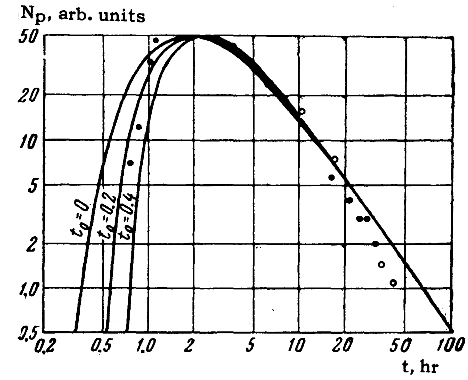

FIG. 7. Primary-proton intensity calculated from Eq. (1) for $D = 5.5 \times 10^{21}$ cm²/sec and $t_0 = 0$, 0.2 and 0.4. ● – May 4, 1960; ○ – September 3, 1960.

The hypothesis that magnetic clouds are distributed uniformly around the sun is not only unsupported by any experimental data, but actually makes it impossible to account for some observations. However, this simplification is apparently justified as a means of explaining the principal features of the phenomena.

The behavior of $N_p(t-t_0)$ in (1) for $t - t_0 \ll R^2/4D$ is basically exponential. For this case it is extremely important to note the exact value of t_0. The maximum of $N_p(t-t_0)$ appears at $t - t_0 = R^2/6D$. When $t - t_0 \gg R^2/4D$, we have

$$N_p(t-t_0) = B/8\,[\pi D(t-t_0)]^{3/2}. \quad (3)$$

The constant B is determined experimentally from the maximum of $N_p(t)$. For the burst of May 4, $B = 2.5 \times 10^{32}$ protons, and the energy carried off by the protons was 6×10^{28} ergs.

The curves in Fig. 7 were plotted from Eq. (1) for three values of t_0 with $D_1 = 5.5 \times 10^{21}$ cm²/sec, and are compared with the data for May 4 and September 3. For May 4 time is measured from the onset of the solar flare. For the data of September 3 zero time is 20 hrs after the flare onset. This was done because the greater duration of the September 3 event resulted from the prolonged emission of protons directly from the source (Fig. 5). In order to have approximately identical initial conditions for diffusion in connection with both bursts, this period of time must, of course, be excluded. With D known we thus obtain from (2) the mean free path of low-energy protons, which is about one-tenth of the sun-earth radius. From the condition $H_1 > p/300l_1$ and $p_1 = 5 \times 10^8$ ev/c we obtain $H_1 > 1.5 \times 10^{-6}$ gauss.

From (3) and the recorded data along the descending segments of the curves in Fig. 5 we find that the diffusion coefficient D_2 for 3—4 Bev protons is about four times larger than D_1. The mean free path of high-energy protons is $l_2 = 2.2 \times 10^{12}$ cm. The magnetic field in clouds for the high-energy case is correspondingly $H_2 > p_2/300 l_2 = 7.6 \times 10^{-6}$ gauss ($p_2 = 5 \times 10^9$ ev/c).

The data for l_1 and l_2 and the corresponding values of H_1 and H_2 lead to the conclusion that the density of magnetic clouds in space is inversely proportional to the magnetic field strength.

For $t < 1$ Fig. 7 shows the best agreement between the data and calculation for $t_0 = 0.3$, but the significance of this agreement is not clear. The cosmic ray burst at Sulphur Mountain was registered 15 min after the onset of the solar flare. Taking into account the time required for protons to reach the earth, we obtain a period 0—7 min or ~ 0.1 hr during which protons could begin to flow from the solar source. Assuming the simultaneous generation of low- and high-energy protons, we have $t_0 \sim 0.1$ hr. However, for $t_0 = 0.1$ hr the first two experimental points in Fig. 7 lie off the calculated curve. It is difficult to determine whether this means that slow protons are generated later ($t_0 = 0.3$ hr), or whether it results from neglecting the nonuniform spatial distribution of magnetic clouds, which are somewhat denser near the sun than near the earth. We note that the observed disagreement between the cosmic ray burst onset on the earth and the presumed beginning of proton flow from the sun also characterizes high-energy protons (February 23, 1956). It is reasonable to assume that this disagreement results from neglecting the higher magnetic cloud density near the sun.

For high values of t the experimental points lie below the straight line in Fig. 7. This result can also be attributed to lower cloud density at great distances outside of the earth's orbit.

ENERGY SPECTRUM OF HIGH ENERGY FLARE PROTONS

The low-energy protons registered in the stratosphere and the high-energy protons responsible for the cosmic ray spike at sea level on May 4, 1960 were clearly generated during the same solar flare. It remains to determine whether both high- and low-energy protons were generated by a single mechanism and therefore belong to a single energy spectrum.

Let us consider the data for the proton spectrum. We assume that the 10% peak cosmic ray increases registered by a neutron monitor at Prague on May 4 can be attributed to primary protons above 3 Bev (the cutoff for primary protons at the latitude of Prague is 2.0 Bev). This increase corresponds to a flux of 0.5 primary protons per cm^2-min-sr. From stratosphere data the primary-proton intensity above 400 Mev was 30 protons per cm^2-min-sr. These results indicate that in the 0.4—3.0 Bev range the spectrum had the exponent $\gamma = 2.0$. Data for the February 23, 1956 event lead to about the same result.[21] This is an improbably low value of γ, since the measured primary-proton energy spectrum at sea level usually has $\gamma = 5.0$. The low value of γ can possibly result from the incorrect assumption that low- and high-energy solar protons belong to a single spectrum. Independent generation mechanisms for low- and high-energy protons are also indicated by the stratosphere event of September 3, when the primary-proton spectrum practically coincided with that of May 4, although the amplitude was about twice as great, whereas there was almost no cosmic ray increase at sea level on September 3.

CONCLUSIONS

1. The energy spectra of primary protons from the sun were measured during the bursts of April 28, May 4, May 13, and September 3, 1960. The spectra were similar and underwent no essential change throughout the two to three day duration of each burst. It follows that solar generation of primary protons occurs during a time considerably shorter than the duration of the observed bursts. The proton generation mechanism also seems to be the same in all of these bursts. The integral proton energy spectrum as a function of their kinetic energy E_p can be described by a power law with the exponent $\gamma = 2.0$ for E_p from 100 to 400 Mev.

2. The energy spectrum of solar flare protons was moderated during a Forbush decrease ($\gamma \approx 5.5$). This effect combined with the simultaneous harder spectrum of cosmic rays of galactic origin during the Forbush decrease shows that solar corpuscular streams carrying frozen-in magnetic fields are carriers of solar-generated protons. In accounting for this effect we must assume the existence of magnetic traps in the solar corpuscular streams.

3. During a Forbush decrease the stratosphere is penetrated by other particles with ranges under 7 mm Al, in addition to protons. The origin of these short-range particles appearing in the stratosphere only during a Forbush decrease is not clear.

4. The time dependence of primary-proton in-

tensity in stratosphere bursts agrees satisfactorily with the theory of proton diffusion in interplanetary space containing magnetic clouds as scattering centers. Data were obtained characterizing the density and magnetic fields of magnetic clouds responsible for the scattering of ~ 0.2-Bev protons in interplanetary space.

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Translated by I. Emin
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ERRATA

Vol	No	Author	page	col	line	Reads	Should read
13	2	Gofman and Nemets	333	r	Figure	Ordinates of angular distributions for Si, Al, and C should be doubled.	
13	2	Wang et al.	473	r	2nd Eq.	$\sigma_\mu = \frac{e^2 f^2}{4\pi^3} \omega^2 (\ln \frac{2\omega}{m_\mu} - 0.798)$	$\sigma_\mu = \frac{e^2 f^2}{9\pi^3} \omega^2 \left(\ln \frac{2\omega}{m_\mu} - \frac{55}{48} \right)$
			473	r	3rd Eq.	$(e^2 f^2/4\pi^3)\, \omega^2 \geqslant \ldots$	$(e^2 f^2/9\pi^3)\, \omega^2 \geqslant \ldots$
			473	r	17	242 Bev	292 Bev
14	1	Ivanter	178	r	9	1/73	1.58×10^{-6}
14	1	Laperashvili and Matinyan	196	r	4	statistical	static
14	2	Ustinova	418	r	Eq. (10) 4th line	$[-\frac{1}{4}(3\cos^2\theta - 1)\ldots$	$-[\frac{1}{4}(3\cos^2\theta - 1)\ldots$
14	3	Charakhchyan et al.	533	Table II, col. 6 line 1		1.9	0.9
14	3	Malakhov	550	The statement in the first two phrases following Eq. (5) are in error. Equation (5) is meaningful only when s is not too large compared with the threshold for inelastic processes. The last phrase of the abstract is therefore also in error.			
14	3	Kozhushner and Shabalin	677 ff		The right half of Eq. (7) should be multiplied by 2. Consequently, the expressions for the cross sections of processes (1) and (2) should be doubled.		
14	4	Nezlin	725	r	Fig. 6 is upside down, and the description "upward" in its caption should be "downward."		
14	4	Geĭlikman and Kresin	817	r	Eq. (1.5)	$\ldots\left[b^2 \sum_{s=1}^{\infty} K_2(bs)\right]^2$	$\ldots\left[b^2 \sum_{s=1}^{\infty} (-1)^{s+1} K_2(bs)\right]^2$
			817	r	Eq. (1.6)	$\Phi(T) = \ldots$	$\Phi(T) \approx \ldots$
			818	l	Fig. 6, ordinate axis	$\frac{\varkappa_s(T)}{\varkappa_n(T_c)}$	$\frac{\varkappa_s(T)}{\varkappa_n(T)}$
14	4	Ritus	918	r	4 from bottom	two or three	2.3
14	5	Yurasov and Sirotenko	971	l	Eq. (3)	1 < d/2 < 2	1 < d/r < 2
14	5	Shapiro	1154	l	Table	2306	23.6