JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-II, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-3B-24. Solar Protons in November 1960*

E. P. NEY and W. STEIN

University of Minnesota Minneapolis, Minnesota, U.S.A.

In addition to presenting the paper of Ney and Stein on solar cosmic rays in November 1960, I have been asked to give a brief review of high altitude experiments on this event carried out by various groups in the United States. The other high altitude experiments done on this event were the rocket experiments of Oglivie and Davis[1] in which counter measurements were made of the intensity and energy spectrum of primary protons down to several Mev; the photographic emulsion work of Fichtel and Guss[2] in which medium nuclei of solar origin were detected and accurately measured; and the counter experiments of Winckler and Bhavsar (private communication) on balloons in which some flights were carried out at Churchill, Canada as well as Minnesota.

During the November 12 and 15 events, the University of Minnesota group flew 16 balloons in a five-day period in order to get relatively short emulsion exposures at various phases of the two flare events. Most of these balloons were flown from Minneapolis, Minnesota but two flights were obtained at Churchill, Canada. The NASA group flew seven rockets from Churchill, Canada. The results of these flights have been presented by Fichtel and Guss[2] and Ogilvie and Davis.[1] The high altitude analysis has been considerably aided by the excellent study of Steljes, Carmichael, and McCracken[4] on the early anisotropies which existed in these events and the general pattern of the neutron monitor data obtained at various stations throughout the world. The work of McCracken has led to some definite ideas about the magnetic configuration existing in space at the time of the November event. One of the most important features of this work has been the demonstration of rather good magnetic connection with the sun, with early propagation of solar cosmic rays showing a preferred direction of approximately 50° to the west of the earth-sun line. In addition, McCracken has reported at this meeting that in the November 15 event, the early anisotropies showed not only in the initial impact from the direction 50° west of the earth-sun line but in a somewhat delayed but also well-collimated impact from a direction just opposite to this one, indicating the propagation of cosmic rays to the earth by two alternate routes. The anisotropies observed with the neutron monitors disappear within several hours after the beginning of both the November 12 and November 15 events, and, as will be seen later, at all times in which balloon experiments were made isotropy of low energy cosmic rays at the earth is observed. The classification and connection between solar flares, sudden commencements, and Forbush decreases which will be used throughout this discussion is that suggested by Obayashi.

To give an idea of the order of magnitude of the intensities in this event, we show in Figs. 1A and 1B photomicrographs of emulsions exposed for four hours on May 10, 1959 (Fig. 1A), and for two hours in the middle part of the November 12 event (Fig 1B). The event represented in Fig. 1A was the first very intense solar proton beam which was observed with balloon-borne nuclear emulsions. It is easy to see, however, that the November event produced much larger particle intensities. The peak fluxes observed in the November 12 event were of the order of 400 particles/cm^2·sec·sr. In the November 15 event, the peak flux was as high as 1000 particles/cm^2·sec·sr above an energy of 80 Mev in both cases. It should be remembered that the normal cosmic ray flux at this time is represented by 1 particle/cm^2·sec·sr, and therefore, particle fluxes of the order of 1000 times cosmic rays with energies above 80 Mev were observed in this event. The work of Ogilvie and Davis[1] showed that the energy spectrum extended down to at least an energy of 2 Mev, and in the November 12 event the particle flux above 2 Mev is between 10^4 and 10^5particles/cm^2·sec·sr. The flux data

* Including a discussion of other high altitude measurements in this event.

obtained from photographic emulsions in the range of 80–500 Mev must be represented as a power law. The power law exponent varied in these events from 3 to 6 in a systematic way which will be discussed later. The total energy emitted by the sun in the form of corpuscular radiation exceeded 10^{31} ergs in both the November 12 and the November 15 events. The general profile of the event will be discussed from the standpoint of the energy spectrum and flux of the charged particles, the geomagnetic modulation observed at Minnesota, the isotropy of the radiation as inferred from balloon observations and finally the composition of the particles with respect to proton, alpha, and medium muclei inferred from a combination of Minnesota experiments of Fichtel and Guss[2)] in Churchill, Canada.

Fig. 3 is a slide showing much of the pertinent information which has been obtained in this event. On this figure are shown the times when the magnetometer at Minnesota showed large disturbances, the neutron

Fig. 1a. Photomicrograph of emulsion exposed at 8 g/cm² for four hours on May 12, 1959. Area represented is approximately 200 microns by 250 microns.

Fig. 1b. Photomicrograph of emulsion exposed at 6 g/cm² for two hours.

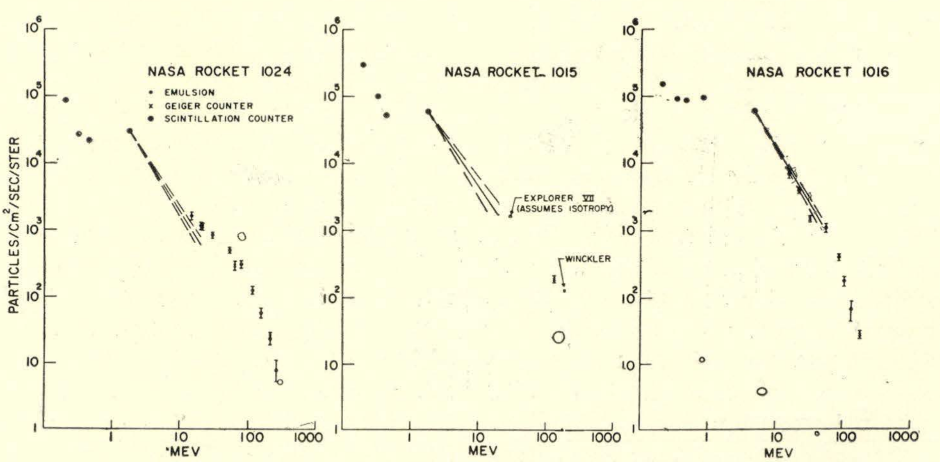

Fig. 2. Energy spectra of Ogilvie and Davis. 20 hours after the flare of November 12, 1960.

monitor reading at Minnesota, the sequence of solar flares and sudden commencements, an indication of polar cap absorption times, and vertical fluxes and energy spectra obtained from the balloon flights. We should first point out that the solar flare events all occurred in the same region of the sun which rotated with the solar rotation as time went on. By November 20 this region had passed the limb, but all of the flares which are shown in Fig. 3 are flares which occurred on the visible disc and Fig. 3 also shows the presence and duration of Type IV radio noise, presmably arising from synchrotron radiation of electrons accelerated together with the solar protons. In Fig. 2, the logarithmic scale labeled Nv and R/HR shows respectively the vertical fluxes above 80 Mev, and above 300 Mev in particles/cm^2·sec·sr, and the number of roentgens/hour at balloon depths. The vertical fluxes are obtained by counting individual particles and the R/HR by determining the grain density in the emulsion. Also shown on this scale are the vertical fluxes above an energy of 300 Mev in the November 15 event. The inset labeled n shows the energy spectrum exponent determined in the range of 80 to 300 Mev, and the bottom scale, Nv/ε is the ratio of the vertical flux above 80 Mev to the density of ending particles, the units being per cm^2·sec·sr for vertical flux and enders/cc·sec for ε. The usefulness of this latter ratio is that it determines very sensitively the presence of geomagnetic modulation on the cosmic ray beam. If geomagnetic cutoffs at Minnesota are inoperative and all particles can enter, the value of Nv/ε turns out to be 0.6 at a pressure altitude of 6 gm/cm^2. Whenever, geomagnetic cutoffs are imposed the ratio of vertical flux to enders rises abruptly and this can be seen in the November 15 event where the value of Nv/ε rises to approximately 4 at the time that geomagnetic cutoffs are present.

We will discuss first the profile of the November 12 event which is observed with balloons. During the period between 2100 U. T. on November 12 and 1500 U. T. on November 13 the neutron monitor on the ground shows the intensity of the solar cosmic rays to be steadily decreasing with

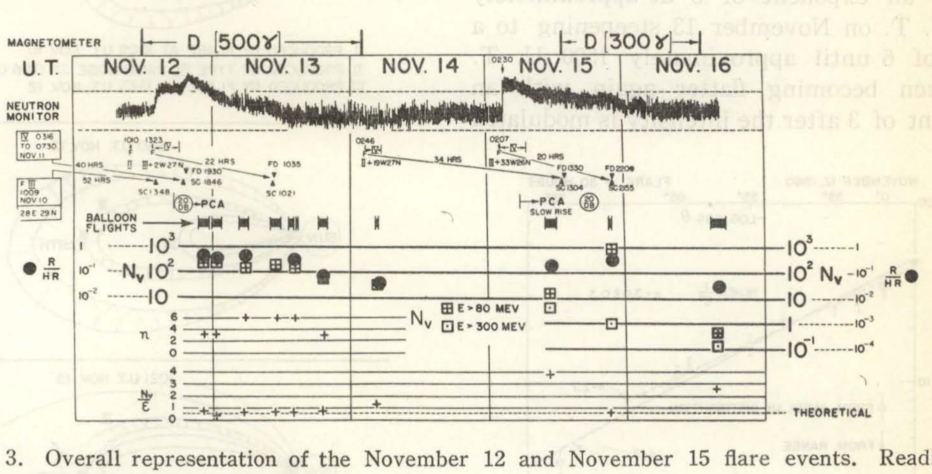

Fig. 3. Overall representation of the November 12 and November 15 flare events. Reading from top to bottom:

1. Magnetometer disturbed periods at Minnesota.
2. Minnesota neutron monitor—displays the reciprocal of the counting rate.
3. Relation of flares, sudden commencements, and Forbush decreases according to Obayashi.
4. Rough indication of P.C.A.'s.
5. Times of balloon flights at Minnesota.
6. Nv and R/hour are vertical flux in particles/cm^2·sec·sr above 80 and 300 Mev and roentgens/hour as indicated.
7. *n* is the exponent in the integral energy spectrum.
8. Nv/ε is the ratio of vertical flux to ender density at the balloon altitude. When cutoffs are absent, this ratio should have the theoretical value of 0.6. The ratio rises when geomagnetic cutoffs are present.

time but the vertical flux measurements at the top of the atmosphere show that up to approximately 1500 U. T. on November 13 the intensity of solar protons of energy greater than 80 Mev stays essentially constant. After approximately 1500 U. T. and following the Forbush decrease and sudden commencements at 1035 U. T. the intensity at the top of the atmosphere at Minnesota drops abruptly and has decreased by a factor of 10 in a matter of several hours. We interpret this rapid decrease at the top of the atmosphere to be due to the sweeping out of the trapped solar cosmic rays by the plasma cloud emitted at the time of the cosmic ray flare which occurred at 1323 U. T. on November 12. During the entire period of observation of the November 12 event from late on November 12 to early on November 14, the magnetic activity at Minnesota was sufficient to destroy the normal geomagnetic cutoffs operative at this latitude. This is shown by the ratio of Nv/ε on the bottom lines of Fig. 3. A rather interesting change in the energy spectrum of the particles is observed with the integral energy spectrum having an exponent of 3 at approximately 0100 U. T. on November 13 steepening to a slope of 6 until approximately 1500 U. T. and then becoming flatter again with an exponent of 3 after the intensity is modulated downward by the sweepout. The phenomena of sweepout in this event has first been suggested by Roederer and co-workers.[4] It does not seem to be indicated by changes in riometer absorption but is clearly shown for the particles which we observe of energy in excess of 80 Mev.

The isotropy of the low energy particles in the energy range of 80 to 200 Mev was accurately tested 30 hours after the flare of November 12 by comparing the energy spectrum directly measured in the emulsions with the angular distribution of the particles observed at the balloon altitude of 6 gm/cm². We compare the flux of particles reaching a given depth in the emulsion with the flux of particles which have to pass at an inclined angle through the corresponding range of air above. This is shown in Fig. 4 where the points from the angular distribution and from range in the emulsion agree well and

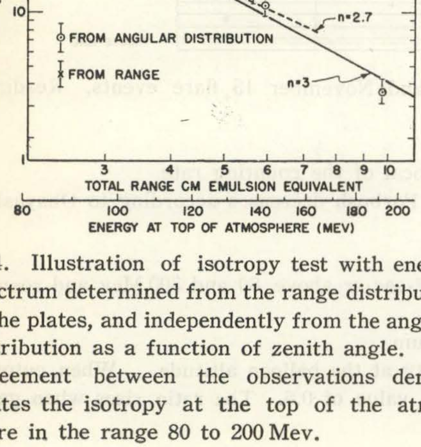

Fig. 4. Illustration of isotropy test with energy spectrum determined from the range distribution in the plates, and independently from the angular distribution as a function of zenith angle. The agreement between the observations demonstrates the isotropy at the top of the atmosphere in the range 80 to 200 Mev.

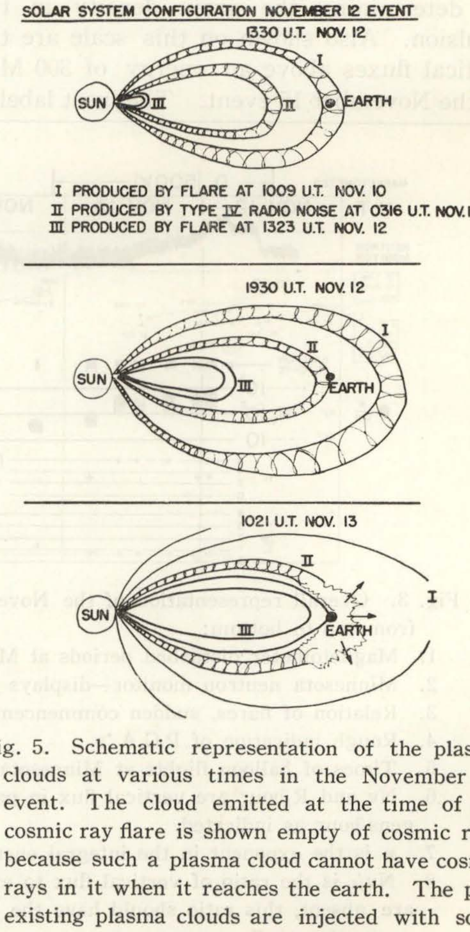

Fig. 5. Schematic representation of the plasma clouds at various times in the November 12 event. The cloud emitted at the time of the cosmic ray flare is shown empty of cosmic rays because such a plasma cloud cannot have cosmic rays in it when it reaches the earth. The pre-existing plasma clouds are injected with solar cosmic rays and act to guide them.

both indicate an integral energy spectrum exponent $n=3$.

Fig. 5 shows a schematic representation based on the model of T. Gold which seems to be completely consistent with the observations in this event. In this figure are shown three plasma clouds emitted by the sun, the first plasma cloud being emitted by the flare occuring at 1009 U. T. on November 10 and arriving at the earth at the same time that the cosmic flare occurred on November 12, i.e. at approximalely 1320 U. T. The upper drawing in Fig. 4 shows the earth at approximately 1320 U. T. enveloped in this cloud at the time of injection of the solar cosmic rays at the sun. Cloud 2 which is intermediate between the sun and the earth has been emitted by the flare of 0316 U.T. on November 11 and is the one which is responsible for the trapping of solar injected cosmic rays producing the second rise in the November 12 event at 1930 U. T. The middle drawing in Fig. 5. shows the position of the the earth at 1930 U. T. intersecting the second plasma cloud which has solar injected cosmic rays trapped in it. It was at this time that the emulsion and rocket measurements were beginning to be made. While the earth is in this plasma cloud the intensity at the top of the atmosphere of low energy particles stays constant showing their effective trapping while the neutron monitor records decrease as high energy particles leak out of the cloud. This change in character of the trapped particles is also reflected in the steepening energy spectrum exponent observed for the particles of energy greater than 80 Mev. The third drawing in Fig. 5 shows the configuration at the time when low energy cosmic rays become rapidly diminished in intensity at the top of the atmosphere presumably from the sweeping out by cloud 3 emitted at the time of the cosmic ray flare. The arrival of this cloud is presumed to destroy the trapping condition after approximately 1500 U.T. on November 13.

We now pass to discussion of the event of November 15. There are only two pertinent flares and plasma clouds associated with this event. The first flare occurred at 0246 U.T. on November 14 and gave rise to Forbush decrease and sudden commencement at 1330 U. T. on November 15. The cosmic ray flare occurred at 0207 U. T. on November 15 and gave a Forbush decrease and sudden commencement at 2200 U. T. and 2155 U. T. on November 15. Balloon measurements were made 9 hours, 19.5 hours and 39 hours after the flare. They are represented in Fig. 6 where the general profile of the two flares, sudden commencements, and the neutron monitors are displayed across the top and the flights are labeled A, B, and C. The

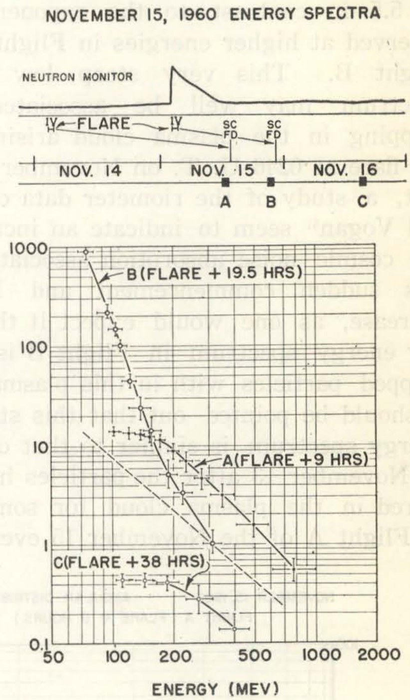

Fig. 6.

first, Flight A occurred before the sudden commencement from the flare on November 14, Flight B after that sudden commencement, and Flight C considerably later on November 16. In this figure we show the integral flux in particles/cm^2·sec·sr as function of the energy and it can be seen that in Flights A and C at magnetically quiet times the normal geomagnetic cutoffs at Minnesota are operative. Actually these two flights were at slightly higher latitude than Minneapolis and their slight difference in latitude accounts for a cutoff in Flight A at about 180 Mev and in Flight C at approximately 190 Mev. It should be pointed out here that the magnetic cutoffs observed are not sharp and that this lack of sharpness is believed to be associated with the effect of the earth's cutoff rather than with experimental measurement of the cutoff. The magnetic storm beginning with a sudden commencement at 1304 U. T. on November 15 destroys the geomagnetic cutoffs at Minneapolis, and at the time of Flight B, Fig. 5 shows a very steep low energy spectrum extending from 80 Mev to approximately 150 Mev. The slope of this spectrum has an integral energy exponent of 5.5 in contrast to the exponent of 3 observed at higher energies in Flight A and Flight B. This very steep low energy spectrum may well be associated with trapping in the plasma cloud arising from the flare at 0246 U. T. on November 14. In fact, a study of the riometer data of Hartz and Vogan[5] seem to indicate an increase in the cosmic noise absorption associated with this sudden commencement and Forbush decrease, as one would expect if the steep low energy spectrum in Flight B is due to trapped particles with in this plasma cloud. It should be pointed out that this steep low energy spectrum is similar to that observed on November 13 after the particles had been stored in the plasma cloud for some time. In Flight A of the November 15 event, it is possible to again check the isotropy of the incoming solar cosmic rays and this is show for protons in Fig. 7. This figure shows the angular distribution between 0 and 75 degrees of the particles which are incident at balloon altitudes at this time. Because of the geomagnetic cutoff very few protons are present below an energy of 180 Mev. At all zenith angles measured, the proton of 180 Mev are able to penetrate to balloon altitudes, since the vertical depth was 6 gm/cm². With an isotopic angular distribution outside the atmosphere and a cutoff operative we therefore see isotropy at the balloon depth.

The presence of geomagnetic cutoff is strikingly displayed by a comparison of this angular distribution with that shown in Fig. 4 for the November 15 event where no geomagnetic cutoff is operative. Both angular distributions, it should be emphasized, indicate isotropy of the cosmic rays above the atmosphere. The magnetic rigidity corresponding to the cutoff indicated by these deta is 0.65 BV. At this magnetic rigidity, α-particles do not have range enough to reach the nuclear emulsions from the vertical direction, but protons have sufficient range to penetrate the air above even at angle of 75°. This is shown in Fig. 7 where the measured angular distribution of protons is isotropic and the α-particles show in their angular distribution the energy spectrum

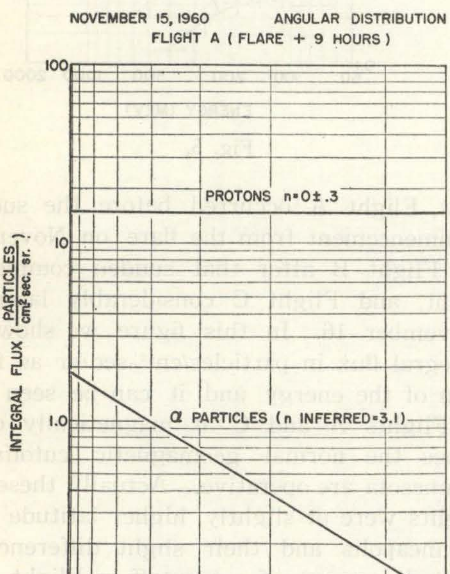

Fig. 7.

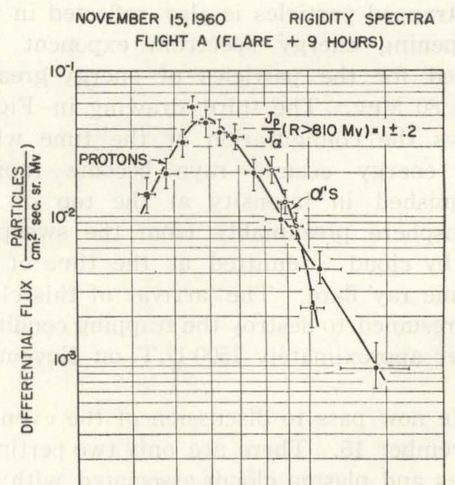

Fig. 8.

exponent. The flux of α-particles has been measured in Flights A and C and the results of the differential flux measurement on protons and alpha particles for Flight A, nine hours after the flare of November 15 are shown in Fig. 8. This figure shows clearly the lack of sharpness of the geomagnetic cutoff on the protons and also shows that the protons and α-particles have very similar rigidity spectra. If one attempts to plot differential fluxes as a function of energy per nucleon, or energy per charge, the α-particles do not show a similar spectrum as they do when plotted against rigidity. This has been previously demonstrated in other events, for example, the September event in which Phylis Freier showed very similar rigidity spectra for protons and α-particles. We will return to this point later in the discussion of the very interesting observations on heavy nuclei acquired by Fichtel and Guss[2] and their relation to the problem of generation and propagation of solar cosmic rays.

Fig. 9 shows a schematic presentation of the supposed interplanetary environment during the November 15 event. The upper figure shows the earth outside of both plasma clouds at the time of Flight A, at which time geomagnetic cutoffs are operative, and we see only the leakage of high energy cosmic rays out of the trapping region. During Flight B the earth is immersed in a plasma cloud which has been injected with cosmic rays, and a steep energy spectrum is observed at low energies. Still later, at the time of Flight C, both plasma clouds I and

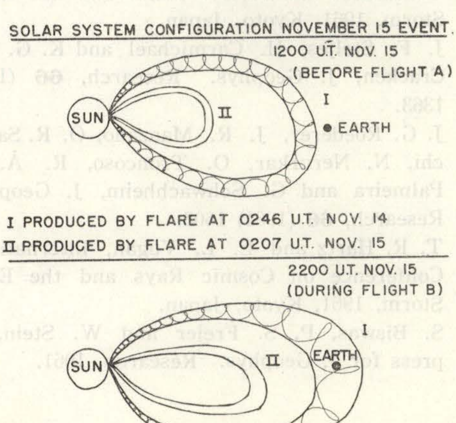

Fig. 9.

II have passed and again only the leakage of cosmic rays out of the trapping volumes is observed.

We now pass to a discussion of the abundance of protons, α-particles, and medium nuclei (CNO nuclei) in the November 15 event and in the event of September 3, 1960. Fichtel and Guss[2] have reported measurements of medium nuclei in both of these events, and Table I show the result of their measurements of the ratio of protons to medium nuclei, and our measurements of the protons to α-particles. The proton to alpha

Table I. Proton to alpha and proton to medium ratios in the September 3,* 1960 and the November 15, 1960 flare events.

	Sept. 3, 1960 Flare+14 hours	Nov. 15, 1960 Flare+40 hours
P/γ	40	2
P/M	1400	83
$\frac{\gamma}{H}$	40	41

* Proton to Medium ratios determined above a rigidity of .2 BV by Fichtel and Guss. The proton to alpha ratio above rigidity .8 BV measured by Biswas, Freier and Stein in September 3 event. The proton to alpha ratio above .8 BV measured by Ney and Stein in the November 15 event.

ratio is measured in the September 3 flare by Biswas, Freier and Stein[6]. It should be emphasized that, because of the experimental conditions, the protons to medium ratio must be measured above a rigidity of 0.2 BV whereas the proton to alpha ratio is measured above a rigidity of 0.8 BV. Fichtel and Guss[2], however, have established that the rigidity spectrum of the medium nuclei is similar to the rigidity spectrum of protons in the same rigidity interval. Our measurements indicate that the rigidity spectra of proton and α-particles are also alike. Therefore, it seems meaningful to compare the proton to alpha, and the proton to medium ratios in terms of particle rigidity. It can be seen in Table I that, whereas the proton to α-particle ratio in the September 3 event was 35, the proton to α-particle ratio late in the November 15 event was as high as 2, in other words, the beam was approximately 17 times richer in α-particles than the September 3 solar beam. A reference to the proton to medium ratios for the two events shows the same effect, that is, the proton to medium ratio on September 3 was 1400 and on November 15 it was 83. In both cases it was measured relatively late in the event. It is evident, therefore, that the α-particle to medium ratio in both events has essentially the same value and is equal to 40.

Fichtel and I believe that this constancy of the α-particle to medium ratio the presence of a great variation in the proton to α-parficle ratio shows the effect of the propagation of solar cosmic rays either at the sun or in the interplanetary medium. The argument can be made in the following way: if we consider particles of the same rigidity as we are here, α-particles and medium nuclei have at the same rigidity, the same velocity as well; but at the same rigidity, a proton has twice the speed of an α-particle or a medium nucleus. If one were to imagine a static magnetic field, then particles of the same rigidity would traverse exactly the same paths. Particles of different velocities, however, at the same rigidity would traverse these paths at different speeds. We see, therefore, that in the propagation of solar cosmic rays, if we choose the same rigidity and the same velocity for the particles, the particles are propagated in the same way as evidenced by the constant α-particle to medium ratio. When, however, the particles have the same rigidity but differing velocities they are propagated in such a way that fractionation of protons from the α-particles and medium nuclei can occur.

The large variation in the medium to proton or α-particle to proton ratio is interpreted as a fractionation process occurring either because of transit times associated with gradient drift, magnetic scattering or time-varying magnetic fields. We cannot, however, state from this data that time-varying fields are necessary; we can only assert that both rigidity and velocity are involved in the propagation of the solar cosmic rays. We believe that the reason that α-particles are so rich in the November 15 event, with the proton to α-particle ratio only 2, may be because of the very good magnetic coupling in this event between the earth and the region where the cosmic rays were injected. Because of their higher velocities, the protons are able to diffuse out of the trapping region more rapidly and in this process produce a beam which is rich in α-particles. It may be realled that the September 3 event was quite different in the sense that the magnetic coupling to the sun was very poor and the earth was not immersed in the plasma cloud into which the cosmic rays are injected. It is possible in this case that the relative paucity of the α-particles is produced because we are observing the particles that leak out of the trapping region, and since the protons have higher velocities they are able to leak out faster.

The data of both November 15 and September 3 events are consistent with the proton to α-particle ratio at the source of 8 to 1 and an α-particle to medium ratio of 40 to 1. This would give a medium to proton ratio of 320 to 1 at the source. The helium abundance on the sun is not well known; however, the ratio to medium nuclei to hydrogen is believed to between 300 and 600. The data here presented on solar cosmic rays seem to favor the lower ratio.

References

1) K. W. Ogilvie and L. R. Davis, International Conference on Cosmic Rays and the Earth Storm, 1961, Kyoto, Japan.
2) C. E. Fichtel and D. E. Guss, International Conference on Cosmic Rays and the Earth Storm, 1961, Kyoto, Japan.
3) J. F. Steljes, H. Carmichael and K. G. McCracken, J. Geophys. Research, **66** (1961) 1363.
4) J. G. Roederer, J. R. Manzano, O. R. Santochi, N. Nerurkar, O. Troncoso, R. A. R. Palmeira and G. Schwachheim, J. Geophys. Research, **66** (1961) 1603.
5) T. R. Hartz and E. L. Vogan, International Conference on Cosmic Rays and the Earth Storm, 1961, Kyoto, Japan.
6) S. Biswas, P. S. Freier and W. Stein, In press for J. Geophys. Research, 1961.

Discussion

Dessler, A. J.: Have electrons been identified in any solar flare event, and, if, not, what upper limit can you place on their relative flux?

Ney, E. P.: No electrons have been detected with certainty yet. The upper limit at late times is about 10% of the proton flux. However no flights during early stages when type IV was being radiated have been available.

Singer, S. F.: Your particular acceleration mechanism may have much wider application, e. g. for electrons in the radiation belt. (The general idea of repeated acceleration with subsequent redistribution of degrees of freedom (magnetic pumping) was first suggested by Alfvén). We have considered your mechanism but find that energy loss is too important at relativistic energies. We prefer to believe that (at least for the radiation belt electrons) a push-pull acceleration mechanism of the general type suggested by Fan is applicable.

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-II, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-3B-25. Geomagnetic and Interplanetary Effects on Solar Cosmic Rays

J. R. WINCKLER

University of Minnesota, Minneapolis, Minnesota, U.S.A.

The energy spectra and the time variations for many of the larger solar cosmic ray events from 1958 to the present have been directly measured with balloons, satellites, and space probes. The direct measurements cover the range 10-300 Mev and show spectra to be characteristically steep compared with galactic protons. Small differences in the spectral shape and intensity determine whether the solar cosmic rays will be detected at sea level or only at high altitude. Spectra measured on the earth reflect energy sensitive propagation as well as the characteristics of the source. Large differences exist in the time variations of the flare particles. Direct and rapid propagation from the sun is frequently accompanied by a slow decay. Delayed propagation even in the high energy region appears in many events. These delays seem associated with complex propagation routes from the flare region to the earth, frequently because of magnetic plasma clouds in interplanetary space. The lowering of Störmer cutoffs during strong geomagnetic storms is shown by many events studied and occurs coincident with the main phase of storms. Periodic intensity variations of solar cosmic rays have been observed at Minneapolis which may be caused by large-scale oscillations in the main field of the earth.

Introduction

In the last three years, progress in the understanding of the production of cosmic rays by the sun has been rapid. This is because the period of high solar activity provided a large variety of events to study and because many new types of measurements were developed. At the present time we have data obtained on the solar cosmic rays at high altitude with nuclear emulsions both in balloons and rockets, Wilson cloud chambers carried in balloons, many types of counting instruments at various latitudes and longitudes, and, in a number of cases, with counters in an earth satellite. The cosmic rays have also been measured in space 5,000,000 km from earth with a space probe.