There is also the possibility that the observed pair could have resulted from the internal conversion of a photon from a direct electromagnetic decay of the Λ^0, $\Lambda^0 \rightarrow \gamma + n$. A two-body decay, ${}_{\Lambda}\mathrm{He}^4 \rightarrow (e^+ + e^-) + \mathrm{He}^4$ is, however, incompatible with the noncolinearity of the pair and the He^4. Moreover, since the excess momentum is low (34 Mev/c), a reaction involving emission of only one neutron in addition to the pair and helium recoil implies an energy release $Q \ll 170$ Mev. Only a decay involving at least two neutrons, for example, ${}_{\Lambda}\mathrm{He}^{5,6} \rightarrow n + n + (e^+ + e^-) + \mathrm{He}^{3,4}$, could fit the kinematics. Since there exists no direct evidence for this electromagnetic decay (which should be expected to occur, although as a rather rare decay mode) and since, even with this decay mode, the configuration observed would have a rather low probability owing to the large momentum transfer to the neutrons, we consider this explanation to be very improbable.

We conclude that the present event does represent the π^0 decay of a hyperfragment, most probably proceeding by the mode

$${}_{\Lambda}\mathrm{He}^4 \rightarrow \pi^0 + \mathrm{He}^4.$$

The stack in which this event was found also yielded to date about 150 hyperfragments decaying via π^- emission.

ACKNOWLEDGMENTS

We wish to express our sincere gratitude to Dr. E. J. Lofgren and the Bevatron staff for making this exposure possible. Our thanks are due to Professor R. H. Dalitz and Professor V. L. Telegdi for useful discussions.

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Soft Radiation Events at High Altitude during the Magnetic Storm of August 29–30, 1957*

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During a balloon flight made from Fort Churchill on August 29, 1957, showers of x-rays were encountered at an atmospheric depth of about 11 g cm^{-2}. At times their flux was as high as 20 photons cm^{-2} sec^{-1} sterad^{-1}. The close connection between the appearance of these x-rays in the 100-kev energy region and storm-type decreases in the local geomagnetic field is shown. The one observation that bears on the point is consistent with these x-rays being produced by electron bremsstrahlung in the terrestrial atmosphere. There are features of the x-ray behavior which show that the primary electrons must be local in character quite apart from geomagnetic cutoff considerations. By "local" is meant that the electrons either acquire the main part of their kinetic energy in the neighborhood of the earth or that they are accelerated at the sun, are trapped in magnetic clouds, and drift to the earth where they are released. It is suggested that acceleration of electrons is a rather general characteristic of the region surrounding the earth and that their association with aurorae and geomagnetic storms may be special features.

I. INTRODUCTION AND TEMPORAL SEQUENCE OF EVENTS

On August 29, 1957 there began a quite intense geomagnetic disturbance as observed[1] at Fort Churchill, Manitoba, Canada and associated with it was a marked Forbush-type decrease in the cosmic-ray intensity as measured by ground-level neutron monitors.[2] Earlier on this day a balloon carrying cosmic-ray instrumentation was launched from Fort Churchill and it reached ceiling altitude about five hours before the onset of the storm. Several events of interest occurred in the cosmic-ray detectors at high altitude and in a variety of ground-level detectors operated by the Canadian Government's Defense Research Northern Laboratory (DRNL). The temporal sequence of these events and the principal observations will first be given. Most of these features to be described appear on Fig. 1.

(1) On August 28 there occurred a large solar flare of importance 3+ which is probably to be associated with the geomagnetic disturbance observed to begin about 34 hours later. According to the Boulder solar activity report it began at 0913 U.T., reached its maximum at 0955 and ended at 1213.

(2) The balloon reached ceiling altitude at 1420 U.T. on August 29 at an atmospheric depth of 8.3 g-cm^{-2}. The time-altitude record of the complete flight of about 17 hours duration is given in Fig. 2. From the time the balloon leveled at ceiling altitude, until about

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* This work was carried out as part of the Joint American-Canadian International Geophysical Year program. Financial assistance came from the National Science Foundation via the National Academy of Sciences. The Office of Naval Research provided administrative assistance as well as material loan and sale.

[1] Defense Research Board, Ottawa, Canada.

[2] The author wishes to thank J. A. Simpson for the notification that the cosmic-ray decrease was in progress.

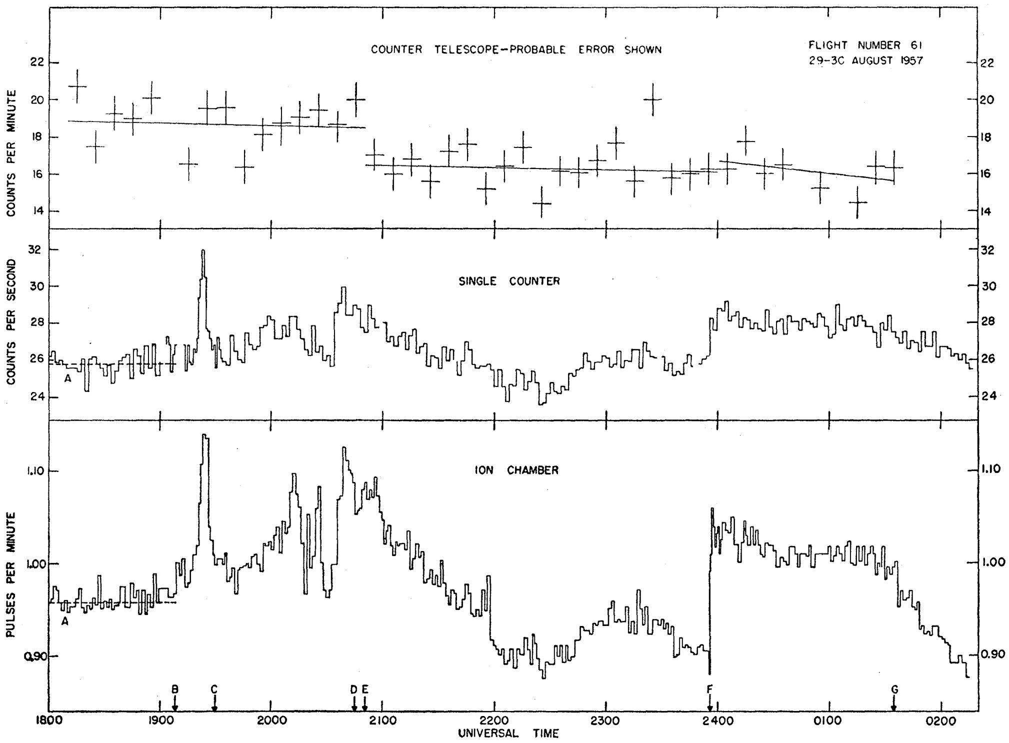

FIG. 1. Response of the three cosmic-ray detectors at high altitude during the time x-rays were present on the balloon flight of August 29–30, 1957. Local time (CST) is found by subtracting six hours from Universal Time. The dotted line designated by *A* is the average cosmic-ray level between 1800 and 1900. *B* denotes the time x-rays first begin to appear and also the time a geomagnetic disturbance begins outside the auroral zone. At time *C* the magnetic storm begins at Churchill. *E* is the beginning of the cosmic-ray decrease. At *F* the soft radiation increases very suddenly accompanied by a large decrease in the local magnetic field. At *G* the sun sets on the balloon and it begins to sink rapidly accounting for the disappearance of the x-rays after this time.

1730 U.T. the cosmic-ray intensity steadily increased, the magnitude being 3.7% in the ion chamber and 4.5±0.7% in the single counter. These data summed over hourly intervals are shown in Fig. 3. This change in intensity is believed to be part of the daily variation although some of the effect being due to changing geographic position cannot with certainty be ruled out. However, several other flights having somewhat different trajectories show a quite similar behavior. The amplitude of the variation which occurred on August 29 between 1420 and 1730 U.T. does not appear to be abnormally large nor does a first analysis of the effect show a shift in the phase.

(3) At 1908 U.T. a magnetic disturbance was observed to begin at Fredericksburg, Virginia.[3] This disturbance then became a magnetic storm having a sudden commencement. However, as observed from this station the storm was not particularly intense, the subsequent changes in the magnetic field components being not much larger than 100 γ. No disturbance of the geomagnetic field was present at Fort Churchill at this time. The ion chamber data and magnetometer data from both Fredericksburg and Fort Churchill are plotted on Figs. 4 and 5.

(4) At 1909±04 U.T. the ion chamber and single counter began to markedly increase their responses above the cosmic-ray intensity observed previous to this time. The increase became very rapid and reached a peak amplitude of 19% above the cosmic-ray intensity in the ion chamber and 24±3% in the single counter at 1925 U.T. After this time the radiation quickly fell away, the full width of this peak at half-height being about five minutes.

(5) At 1917±02 U.T. the magnetic disturbance appeared at Fort Churchill and developed into an intense storm with a sudden commencement. At 2000 U.T. the vertical component began to decrease very sharply resulting in a decrease of at least 450 γ at which point the variometer record shown in Fig. 4 went off scale. The ion chamber and single counter increased their responses at this time and for a considerable period followed the field changes quite closely. The intensity of the radiation remained above the cosmic-ray level observed earlier in the day for somewhat more than an hour although large and sudden fluctuations in the intensity did occur. During this interval the counter telescope counted at the cosmic-ray rate within the available statistical accuracy.

(6) At 2050±10 U.T. the counter telescope in the

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[3] U. S. Coast and Geodetic Survey, Washington, D. C.

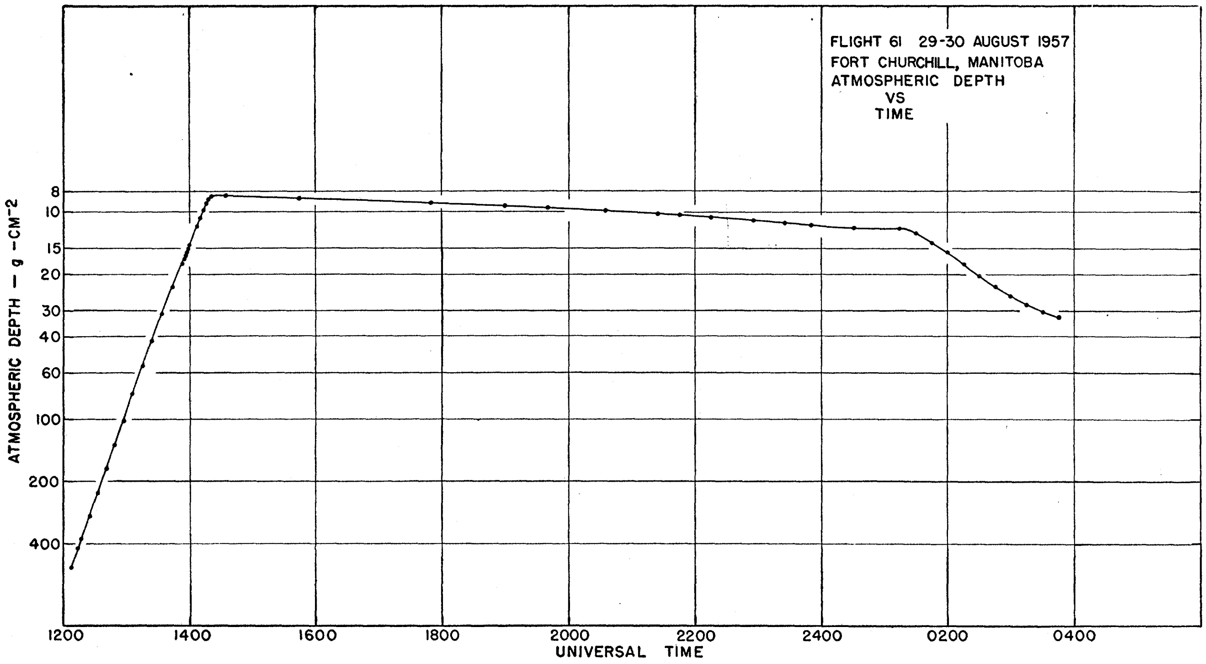

FIG. 2. Atmospheric depth *versus* time record for the flight of August 20–30, 1957 (Flight 61).

balloon-borne equipment abruptly decreased its counting rate indicating a cosmic-ray decrease.

(7) Beginning at 2356 U.T. the radiation in excess of the cosmic-ray intensity increased by several fold within a period of 30 seconds then remained nearly constant until 0135 U.T. on August 30, when the sun set on the balloon and it began descending quite rapidly. This sudden increase was accompanied by a large and rapid decrease in the vertical component of the local magnetic field. Again the counter telescope did not respond to the extra radiation and in this case a comparison of good statistical accuracy can be made.

(8) From about 0300 U.T. on August 30 visual observations of aurorae were made by observers[4] at DRNL. They recorded the presence during this night of an inactive and diffused auroral surface of intensity 1 indicating no unusual activity at this time. However, on the next night (August 31) beginning at 0330 U.T. a very active auroral display was present which began in the south and later moved northward. The presence of rayed bands was also noted until 0530 U.T.

II. NATURE, ENERGY, INTENSITY, AND SPECTRAL COMPOSITION OF THE SOFT RADIATION

Considerable information about the nature of the excess radiation appearing at high altitude during the magnetic storm can be deduced using the characteristics of the three cosmic-ray detectors. The main point is that while the soft radiation caused increases above the cosmic-ray level as large as 20 to 25%, the counter telescope was not observed to have changed its rate outside of the counting rate statistics which are about 3% per hour. The total stopping power of the telescope was about 0.2 g cm^{-2} while the wall thickness of the ion chamber was 0.5 g cm^{-2}. Therefore the possibility that the enhanced counting rate is due to charged particles

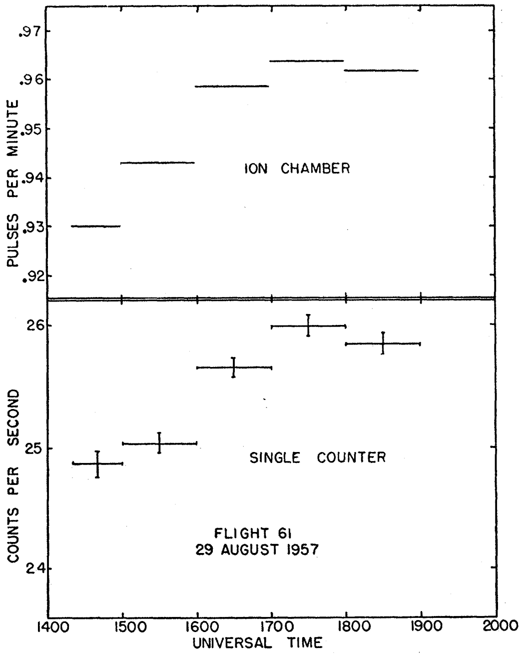

FIG. 3. The variation in the cosmic-ray intensity during the early portion of Flight 61. The steady increase is probably part of the daily variation.

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[4] H. Lutz, Defense Research Northern Laboratory, Fort Churchill, Canada (private communication).

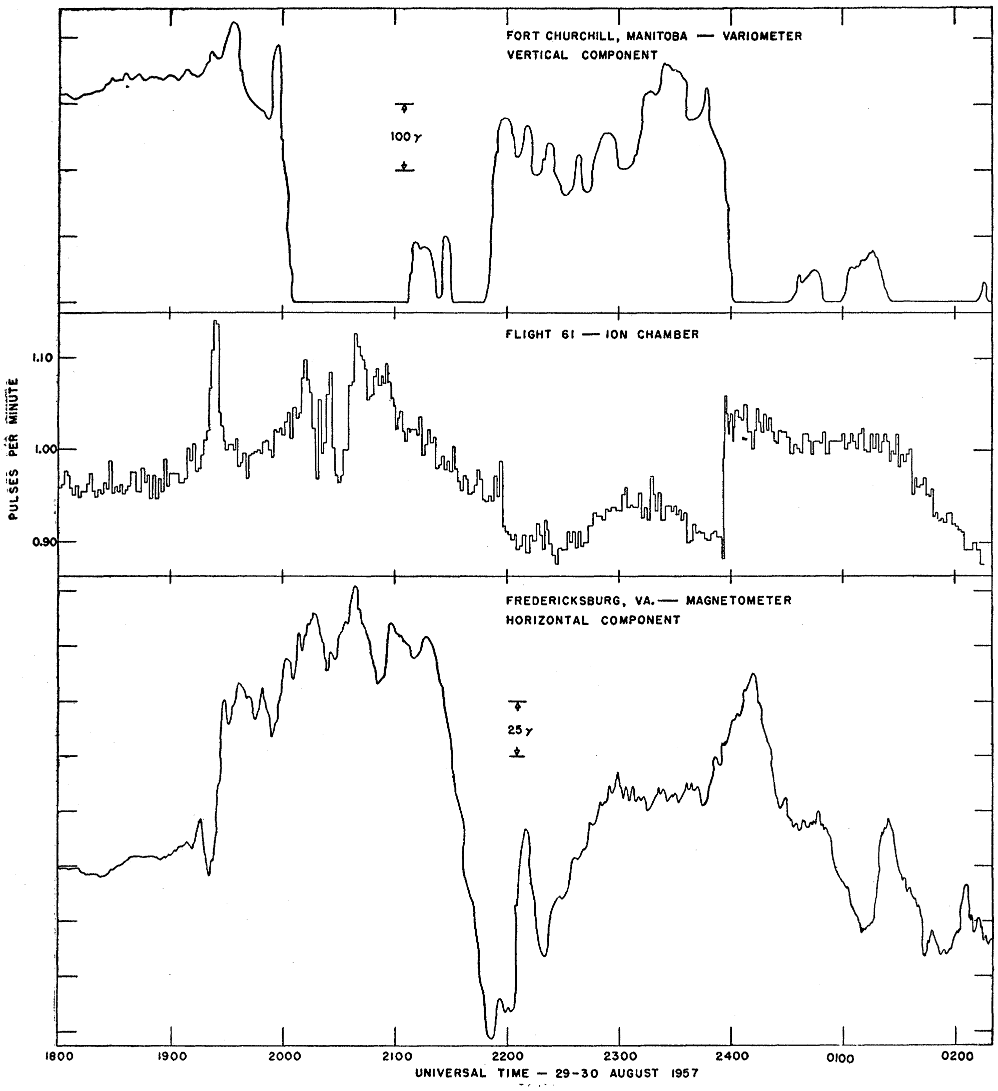

FIG. 4. Variometer and magnetometer records plotted on the same time scale as the high altitude ion chamber data. Fort Churchill is in the auroral zone while Fredericksburg, Virginia is approximately 18° in latitude removed from it.

arriving near the zenith can be ruled out. The observations could be accounted for by postulating a beam of high-energy charged particles which arrives at balloon altitude outside the solid angle of the telescope. However, it is believed that no evidence exists which would support this assumption. The observations can also be explained if the extra radiation incident on the detectors is taken to be x-rays most of which must have energy less than 700 kev since then the recoil electrons produced at the Compton edge would not have sufficient kinetic energy to penetrate the counter telescope. The γ-ray efficiency for this telescope is 0.05%.[5] There is a precedent which is at least strongly suggestive for such a view in the rocket experiments[6] of the Iowa group carried out on the soft radiation in the northern auroral zone. Further support is given to this hypothesis by carrying out simulation experiments with beams of γ rays from radioactive sources. These show that the relative response of the ion chamber and single counter that characterizes the extra radiation encountered during Flight 61 can be reproduced by γ rays of approximately 100-kev energy. There is no conclusive evidence at present that the extra radiation present at balloon altitude originally observed by Winckler[7] during an auroral display and also that present during the magnetic storm of August 29 should be identified as soft radiation as defined by the Iowa rocket experiments. However, the similarity is striking and the tentative view that they are the same will be adopted here.

The method by which the above energy estimate for the soft radiation is arrived at will now be described in some detail. The ratio of the ion chamber response to that of a single counter or other charged particle de-

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[5] J. R. Winckler and K. A. Anderson, Phys. Rev. **108**, 148 (1957).

[6] J. A. Van Allen, Proc. Natl. Acad. Sci. U. S. **43**, 57 (1957).

[7] J. R. Winckler, Phys. Rev. **108**, 903 (1957).

tector has previously been used[8] as a measure of the average specific ionization of the radiation passing through them. If in addition to this ratio the nature of the radiation is known, it then becomes possible in principle to estimate the average particle energy. In the present case the nature of the radiation is established independently by use of the counter telescope and ion chamber data, although because of statistics on the counting rates the data cannot rule out the presence of small intensities of protons and electrons.

However, for the present discussion it will be assumed that no charged particles are present in the soft radiation at balloon altitude except the small number of electrons produced by the interaction of the x-rays with the atmospheric nitrogen and oxygen atoms. Before proceeding with such calculations it is worthwhile to state in general terms the relative response of the ion chamber to the single counter for protons, electrons, and x-rays. Figure 6 shows the general features of these functions as calculated for electrons and protons. In the case of electrons no response is obtained from either detector until a kinetic energy of 80 kev is reached if one neglects secondary effects such as bremsstrahlung production in the walls. This energy is the equivalent thickness of the single counter wall. The ratio will be zero from this energy to 1 Mev when the electrons just begin to enter the active volume of the ion chamber. The ratio then rises rapidly and finally flattens out at high energies. Protons show a somewhat similar behavior except that the response curve rises much higher before flattening out to approximately the same values as for electrons at very high energies.

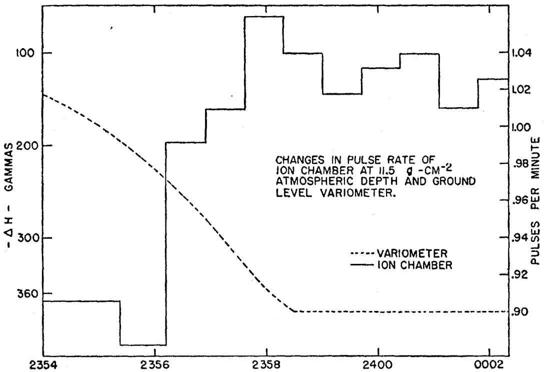

FIG. 5. The ion chamber and variometer data plotted on a greatly expanded time scale to show details of the sudden increase in the x-ray intensity and its relation to the magnetic field decrease. The variometer record is considerably smoothed but the lack of proportionality between the two curves is evident.

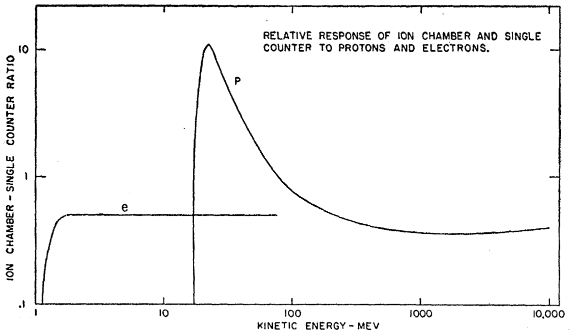

FIG. 6. Relative response of the ion chamber to the single counter as a function of electron and proton kinetic energy.

Figure 7 shows the function as determined experimentally for γ rays. In this case the beam of γ rays was normally incident to the plane containing the long axis of the single counter. In order to apply the γ ray results shown in Fig. 7 to the flight data it is first assumed that the x-rays are isotropic at the top of the atmosphere and, secondly, that there is no further production below the topmost layer. If the x-rays are supposed due to bremsstrahlung this assumption requires that the primary electrons be isotropic outside the atmosphere. The second requirement is readily met under this condition because of the short ionization range of the electrons compared with the atmospheric depth of the balloon. It is often necessary to apply a correction to the laboratory results for the x-ray relative response because of the nonspherical shape of the single counter. This correction factor which must be multiplied by the ratio as found above is a function not only of the counter geometry but of atmospheric depth and the x-ray energy as well. Furthermore a considerable fraction of the x-rays reaching the apparatus have undergone elastic and Compton scattering. This fact serves to alter the distribution of the x-rays in zenith angle from what would otherwise be

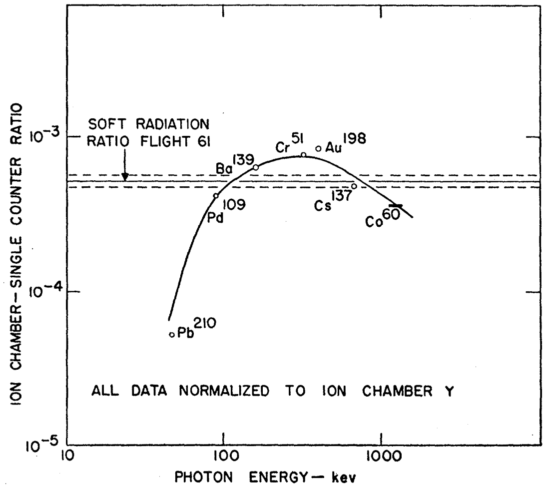

FIG. 7. Energy dependence of the ion chamber to single counter ratio for γ rays from radioactive sources.

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[8] H. V. Neher, in *Progress in Cosmic-Ray Physics*, edited by J. G. Wilson (North Holland Publishing Company, Amsterdam, 1952), p. 245.

expected in view of the energy dependent absorption of the x-rays, i.e., in the absence of scattering the x-ray beam would become increasingly harder as the zenith angle increased but with scattering the hardening is less marked. These corrections are rather small being about 15% in the case of 100-kev x-rays. They have not been included in the points presented in Fig. 7. Also plotted on this curve is the relative response of the ion chamber to the single counter for the soft radiation encountered on Flight 61. It is seen that these curves intersect at 100 kev and 800 kev. By use of the counter telescope data it should be possible to discriminate between these two possible energy choices since the telescope has a substantial γ-ray efficiency for photons above about 700 kev through the production of Compton electrons in the top counter. To estimate the expected counting rate effect in the counter telescope if the photons present have average energy of 800 kev their flux must be known. This is found from the counting rate increment in the single counter and by applying a photon detection efficiency of 0.3%. The calculation then shows that if the photons have an average energy of 800 kev the telescope counting rate should increase by about 7%. If the photons are in the 100-kev region no counting rate effect at all should be expected. The observed effect obtained by comparing the interval 2200 to 2400 U.T. (low soft radiation intensity) with the interval 2400 to 0130 U.T. is 0%±3.4%. While the choice between the two energies is not conclusively indicated by this method, the lower energy will be preferred in what follows.

A rough estimate of the actual photon intensity present at the atmospheric depth of the balloon which at this time was about 12 g cm^{-2} can be made from the absolute efficiency of the Victoreen 1B85 single counter which has been previously measured in the laboratory. Using an average figure of $\frac{1}{2}$% the photon intensity then becomes 40 photons cm^{-2} sterad^{-1} sec^{-1}. Now if one assumes for the sake of estimating the implied electron flux that these photons are produced by spatially isotropic 300-kev electrons stopping in the top layers of the atmosphere, a calculation using results given by Kasper[9] shows the electron intensity to be about 6×10^5 electrons cm^{-2} sterad^{-1} sec^{-1}, or 4×10^6 electrons cm^{-2} sec^{-1}. Choice of a lower energy for the primary electrons would, of course, lead to a higher electron flux.

It is next of interest to see if the calculated ratio of the I.C. (ion chamber) to S.C. (single counter) for the bremsstrahlung spectrum as it appears at 12 g cm^{-2} depth agrees with the flight ratio for this and other energy electrons. It will then be possible to calculate the ratio due to various primary electron spectra and thus test the reasonability of the bremsstrahlung hypothesis for the origin of these x-rays. First, the I.C. to S.C. ratio is calculated for bremsstrahlung photons taking into account their absorption but not their scattering. The following expression is used:

$$\bar{r}(E_e)=\frac{\sum_i \Delta N(E_e,E_i)\,\mathcal{E}_1(E_i,\xi)r_c(E_i)r(E_i)C(E_i)}{\sum_i \Delta N(E_e,E_i)\,\mathcal{E}_1(E_i,\xi)r_c(E_i)}.$$

$\bar{r}(E_e)$ is the calculated ratio of the I.C. to the S.C. for the bremsstrahlung photons as they appear at atmospheric depth ξ due to primary electrons of kinetic energy E_e; $\Delta N(E_e,E_i)$ is the number of photons having energy between E_i and $E_i+\Delta E_i$ produced by a primary electron of energy E_e (numerical values were taken from Kasper's[9] work); $\mathcal{E}_1(E_i,\xi)$ is the Gold integral which takes account of atmospheric absorption effects on the photons and is thus dependent on the photon energy as well as the atmospheric depth, ξ; $r_c(E_i)$ is the absolute efficiency of the single counter for photons of energy E_i, which has been determined from a relative response curve and one absolute efficiency determination; $r(E_i)$ is the ion chamber-single counter ratio as plotted in Fig. 7, including the area factor of both detectors; and $C(E_i)$ is the correction factor to allow for the nonsphericity of the single counter (a typical value for this quantity is 1.12 and it changes rather slowly with energy being largely determined by solid angle considerations). The summation over photon energies is taken from the primary electron energy, E_e, down to 20 kev. Next the scattering is taken into account in an approximate manner. It is assumed that the scattering is energy independent and that the angular distribution of the scattered x-rays is isotropic. Since all but a few percent of the photons have been scattered at least once by the time the depth of 12 g cm^{-2} has been reached, the final angular distribution of the x-rays in the atmosphere must be nearly isotropic. The absorption is taken into account simply by using the average angle (weighted by the solid angle factor) at which the photons arrive at the apparatus. The exponential factor is then calculated for the various photon energies, E_i. The results of both these calculations for several primary electron energies are shown in Fig. 8.

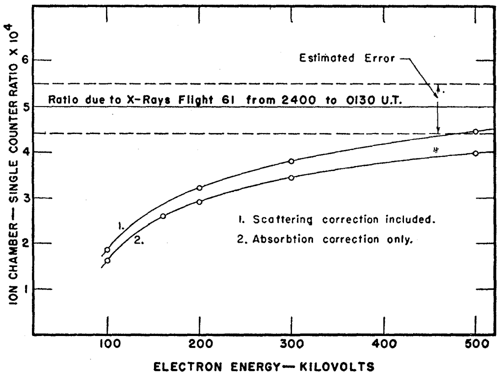

FIG. 8. Relative response of the ion chamber to the single counter for the bremsstrahlung spectrum as it appears at 12 g cm^{-2} atmospheric depth as a function of the primary electron energy.

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[9] J. E. Kasper, State University of Iowa (unpublished).

It is seen from this figure that the interpretation of the observed x-rays as being due to electron bremsstrahlung in the atmosphere is consistent with the measured ion chamber to single counter ratio. The calculations indicate, however, that most of the electrons have kinetic energy at least as great as about 500 kev. Electrons with energy less than this must have been present only with quite low intensity during the atmospheric x-ray shower of August 29–30.

III. ORIGIN OF THE SOFT RADIATION

The data obtained from Flight 61 afford considerable information on the origin of the observed x-rays. First, their close association in time with disturbances in the earth's magnetic field suggests strongly that the radiation is local in character. In fact, it is evidently connected with the arrival at the earth of a solar corpuscular stream. Explanation of the x-rays as due to direct solar emission faces the great difficulty of understanding a mechanism which emits bursts of electromagnetic radiation which arrive at the proper moment to coincide with large changes in the local magnetic field of the earth. Also, if one wishes to account for the x-rays which appeared at balloon altitudes as being due to bremsstrahlung from fast electrons possessing quite direct sun-to-earth trajectories, the same argument applies. However, for the case of the electrons an additional objection arises. This is based on the fact that soft radiation intensity rises more rapidly than the expected spread in solar transit times would allow for simple types of energy spectra. This difficulty can be shown most effectively for the time around 2356 U.T. when a very rapid increase of several fold is observed to occur in the x-ray intensity. To show that the rise time is much too sharp to be tolerated by taking into account the spread in arrival times of solar electrons for at least several types of energy spectra, calculations of the time spread have been made for a differential energy spectrum of the following form:

$$n(E)dE=(k/E^n)dE, \quad \tfrac{1}{3}m_0c^2<E<m_0c^2.$$

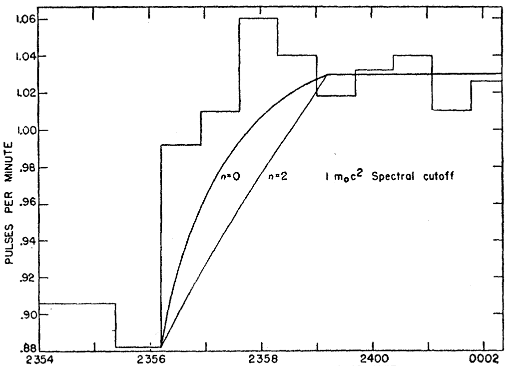

FIG. 9. Comparison of ion chamber data with expected curves if electrons leave the sun and travel to the earth in simple paths. A power-law differential energy spectrum is assumed cutoff at $\frac{1}{3}m_0c^2$ at the low end and m_0c^2 at the high end.

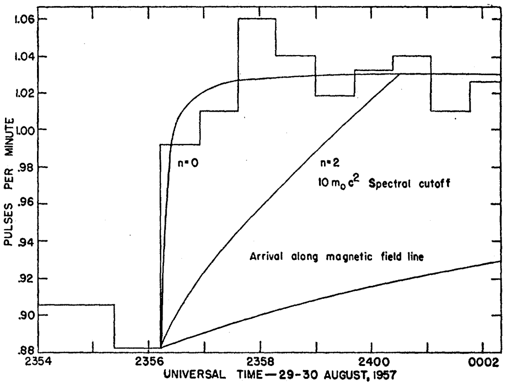

FIG. 10. Similar to Fig. 9 except the energy spectrum for the primary electrons is extended to 10 m_0c^2 for the upper limit. Also shown is the expected appearance of the rise in the x-ray intensity if electrons of 170 kev leave the sum with all possible pitch angles to a magnetic line of force connecting with the earth.

The following values of n were chosen, $n=0$, and 2 and these two resulting curves are plotted in Fig. 9 along with the behavior of the ion chamber for the time interval 2354 to 0002 U.T.

In Fig. 10 similar data are presented except in this case the spectral cutoff has been extended to 10 m_0c^2 electron energy. In both these cases it has been assumed that no magnetic or electric fields exist in the region of traversal of the electrons from the sun to the earth.

The figures show that the only one of the spectra considered which agrees with the ion chamber histogram is the flat *differential* spectrum extending up to 10 m_0c^2 kinetic energy. It should be noted that because the electrometer pulses from the ion chamber are rather infrequent (one every forty seconds), the rise time may be less than is indicated by the histogram.

In addition to the inevitable transit time effect there is another possible means by which an appreciable spread in arrival time can occur. This would be the case if a linking magnetic field existed between the earth and the sun or if the electrons are forced to diffuse outward to the earth through magnetic scattering centers even if these remove the lower energy electrons by trapping them. Since details of the magnetic field structure in interplanetary regions are not experimentally known, this argument which would eliminate the solar origin of monoenergetic and flat spectrum electrons must be regarded as weaker than the transit spread situation. However, only a weakly magnetic character of this region would be needed to produce a very large dispersion in arrival times. In Fig. 10 there is plotted a curve showing this effect for the case of linking magnetic lines between the sun and the earth based on monoenergetic electrons (170 kev) of solar origin having an isotropic distribution of pitch angles with respect to the magnetic lines. This effect is dependent on the electron energy but not the strength of the magnetic field within wide limits.

The possibility that the soft radiation arriving at least during parts of Flight 61 is supplied via the decay electrons from solar emitted neutrons is also ruled out on transit dispersion grounds. This point is raised because of an auroral theory by Petrukhov[10] which involves solar neutrons.

The evidence brought above against the possibility of x-rays or fast electrons having solar origin then making more or less direct transits to the region of the earth leaves the following choices for the origin of the soft radiation observed in connection with the magnetic storms of August 29–30.

(1) Local Acceleration

This would mean that the electrons acquire the main part of their kinetic energy within a few earth radii of the earth's surface, thus avoiding transit time and geomagnetic cutoff difficulties. The source of the electrons as well as the ultimate supplier of their kinetic energy would presumably be the solar corpuscular streams. Although the present data do not point toward or away from a particular local mechanism, the possible ways to accelerate particles will be listed here.

(a) Fluctuations in the earth's ionospheric currents.

(b) Fluctuations in the hypothesized ring current.

(c) Discharge processes in the earth's atmosphere.

(d) Induction effects from the interaction of solar magnetic clouds with the earth's magnetic field.

In connection with the first two possibilities the question of the conductivity of the surrounding regions being too great to support an electric field is generally raised. However, the possibility that the induction effects resulting from fluctuating currents give rise to plasma oscillations which under certain conditions could accelerate charged particles must be seriously considered. The phase stable plasma accelerator was suggested by Bohm and Gross[11] as a means of accelerating cosmic rays.

If the acceleration took place by means of the ionospheric currents or by discharges in the atmosphere; it might be expected that the resulting soft radiation would be spatially anisotropic. On the other hand if the radiation originates several earth radii away, say at the ring current, it is likely to be quite isotropic since the electrons could have all possible pitch angles with respect to the magnetic lines of force.

An experiment which could decide between the atmospheric origin of the soft radiation *versus* an extra-atmospheric origin would be to employ directional soft radiation detectors in a very high rocket flight (up to 300 miles).

(2) Local Release of Fast Electrons

Another means of supplying the primary soft radiation and still avoiding conflicts with the observed sharp rise times is to have fast electrons trapped in solar magnetic clouds. The electrons would then be accelerated at the sun during formation of the cloud, remain trapped during the roughly 30 hour transit and then be released as the cloud interacts with the earth's magnetic field. Following Chapman's[12] picture, if the cloud is very conductive, geomagnetic lines of force from some intermediate latitude on the earth will enter the solar magnetic cloud and consequently the electrons would spiral down to that latitude if some means of getting rid of the trapping properties of the cloud is available. Such a release of electrons as that just described would presumably occur several earth radii away from the earth in which case the electrons would arrive at the earth in reasonably isotropic fashion.

One requirement of the release model is that the solar cloud or stream must be able to store fast electrons for the order of 30 hours. Perhaps the most effective storage mechanism is that suggested by Morrison[13] in connection with cosmic-ray decreases. The cloud is taken to have small scale magnetic irregularities thus providing scattering centers which allow a diffusion of the electrons with a characteristic time on the order of the transit time or longer. Electrons of the required energy could be contained in an earth-sized cloud with scattering centers having magnetic fields on the order of 10^{-4} gauss.

A second requirement to such a local release scheme is that the electrons do not encounter sufficient matter during their transit to dissipate their original kinetic energy. For purposes of calculation, if the initial energy is taken to be a few percent higher than the energy upon arrival (a few hundred kilovolts) then the critical density for the interior of the cloud would be equivalent to about 10^7 proton-electron pairs per cubic centimeter based on a 30 hour transit time and allowing for distant collisions with free electrons.

So far arguments against the arrival of electrons from the sun based on geomagnetic theory have not been introduced. However, they may have somewhat limited usefulness to this problem. This theory predicts cutoff energies for electrons arriving in the vertical direction at $\lambda = 70°$ of about 20 Mev and about 0.5 Mev at $\lambda = 80°$. Therefore, in order to attribute the soft radiation observed in Flight 61 to individual electron orbits originating at a considerable distance from the earth, the effective errors in the latitude coordinates would have to be at least 10°. While the magnetic field of the earth as measured by cosmic-ray trajectories[14] is in conflict with present geomagnetic theory, it seems unlikely that the discrepancies are that large. However, it is true that no direct measurements of the cutoff energies have ever been made at these latitudes.

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[10] V. A. Petrukhov, *The Airglow and the Aurorae* (Pergamon Press, Inc., New York, 1955), p. 254.

[11] D. Bohm and E. P. Gross, Phys. Rev. **74**, 624 (1948).

[12] S. Chapman and J. Bartels, *Geomagnetism* (Oxford University Press, New York, 1940), p. 861.

[13] P. Morrison, Phys. Rev. **101**, 1397 (1956).

[14] Simpson, Fenton, Katzman, and Rose, Phys. Rev. **102**, 1648 (1956).

A more serious difficulty for the application of geomagnetic theory to exclude electrons of solar origin arises particularly during times of geomagnetic disturbances when there is a possibility of "breaking open" lines of force so that any electrons present can then spiral down into the earth's atmosphere. However, it should be remembered that the Iowa rocket experiments[5] show the quite usual presence of 10–100 kev x-rays above the atmosphere in the auroral zone and since it seems unreasonable that these electrons are stored at the observed altitudes between periods of geomagnetic disturbance some means of more or less continuously supplying them needs to be found. A ring current located at $\sim 7r_e$ would appear to fulfill this requirement. Magnetic lines that ran through the ring current would connect with the auroral zones so that electrons accelerated in the region of the ring current could spiral into the auroral zone without the difficulty of geomagnetic cutoff arising. Acceleration could perhaps be accomplished by small and local fluctuations in the ring system. The larger soft radiation storms could then presumably occur when the ring current is being enhanced by the corpuscular streams, a time when it would be expected that many irregularities and much turbulence would be present, thus providing magnetic induction effects which in turn might give rise to plasma acceleration.

Winckler[7] has shown the close connection between x-rays at balloon altitude and visual aurorae. The emphasis here is on the association of the soft radiation with a geomagnetic storm. The arguments against any detailed connection between the soft radiation encountered above Fort Churchill on August 29–30 and visual aurorae are the following:

(1) Visual observation of the auroral situation just following the descent of the balloon showed the presence of quiet and diffuse forms from which previous measurements made at night at balloon altitude showed no soft radiation effects should be expected. Furthermore, the brightness, activity, and number of auroral forms was considerably below the usual situation.

(2) At one time during the event of August 29–30 the soft radiation exhibited an extremely quiescent character for a period of $1\frac{1}{2}$ hours. This fact also indicates the nonassociation of the x-rays and active auroral displays in this case.

It thus appears that the acceleration of electrons in the region of the earth is a more general phenomenon and its association with visual aurorae is one of its special features. It may be, for example, that particularly for the higher energy electrons which penetrate more deeply into the atmosphere it is necessary that other conditions (such as the presence of protons) must be met in order to obtain visual effects.

In order to fully account for the soft radiation situation as it appears from considering both balloon and rocket work it may be that several separate ways of accelerating the electron may be needed. This is strongly suggested by the regular presence of soft radiation at rocket altitudes[6] apparently uncorrelated with any features of solar activity and by the infrequent appearance of soft radiation at balloon altitudes following specific solar features.

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