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Čerenkov Counter Flux Measurement of Cosmic-Ray Alphas at 41°*

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A Čerenkov counter inside a Geiger counter telescope was flown by balloon to a residual atmospheric depth of 16 g/cm². The purpose of the experiment was to measure the flux of cosmic-ray alpha particles and to investigate the usefulness of a Čerenkov counter for flux measurements on the more heavily charged cosmic-ray components. A Čerenkov counter was used because of its inherent discrimination against slow secondary particles. The pulse height distribution obtained showed a partially resolved peak at approximately 4 h_0, where h_0 is the mean pulse height corresponding to a fast proton. This is experimental confirmation of the Z^2 dependence for Čerenkov radiation. There were 3024 events which gave pulse heights corresponding to alphas. There is evidence that 451 were due to side showers, 651 were due to nuclear interactions, an additional 478 were due to either side showers or interactions, and 1444 were due to primary alphas. This leads to the value 99±16 particles/m²-steradian-second, as the extrapolated flux at the top of the atmosphere. There is also an indication of peaks corresponding to carbon and oxygen. There is evidence that the geometry factor of the telescope was appreciably increased for the heavy components due to the action of delta rays.

PURPOSE AND MOTIVATION

THIS paper reports an experiment whose primary goal was to determine the flux of cosmic-ray alpha particles at geomagnetic latitude 41°. A secondary goal was to learn something of the usefulness of a Čerenkov counter for flux measurements on cosmic-ray components with charge $3 \leq Z \leq 9$.

It is now generally accepted that cosmic rays are simply very high-energy atomic nuclei. Multiply-charged particles in cosmic rays were discovered in 1948 by Freier *et al.*[1] who sent photographic emulsions and cloud chambers to the top of the atmosphere by balloon. Ultimately we would like to know the flux and energy spectrum of each charge component, as this kind of information should be very helpful in solving the fundamental problem of the origin and history of cosmic rays.

PAST MEASUREMENTS OF THE ALPHA FLUX

Table I summarizes some past measurements[2–9] of the alpha flux. Consider how well these flux values determine an energy spectrum. Over the latitude-sensitive region, the integral energy spectrum for the total flux is approximated quite closely by:

$$I(E_t) = K/E_t^{\gamma}, \quad (1)$$

where E_t is the total energy of the particle, $I(E_t)$ is the flux of particles with energy greater than E_t, and γ has the value 1.0. Since most cosmic rays are protons, it is generally assumed that the proton component has an inverse power-law energy spectrum with exponent equal to 1.0 also. This assumption is probably correct unless, as was pointed out by Kaplon *et al.*,[10] the total

TABLE I. Summary of some past measurements of the alpha flux.

Geomagnetic latitude	Cutoff energy (total in Bev/nuc.)	Method	Experimenter	Flux (particles per m²-steradian-sec)
0	7.6	inefficient Geiger counter	Singer[a,b]	14±20
30	4.9	emulsion	Goldfarb[c] *et al.*	60±10
41	2.75	proportional counter	Perlow[d] *et al.*	110±20
41	2.75	inefficient Geiger counter	Singer[e,b]	140±60
	1.68	cloud chamber	Linsley[f]	135±20
51	1.54	emulsion	Goldfarb[c] *et al.*	340±120
55	1.30	scintillation counter	Ney[g] *et al.*	340
55	1.30	proportional counter	Davis[h] *et al.*	310±30
55	1.30	cloud chamber	McDonald[i]	230±60

[a] See reference 2.
[b] These flux values were calculated from Singer's data on the assumption that his equipment looked only at fast protons and fast alphas. If slow protons were also present, this method will give an alpha flux which is too high.
[c] See reference 3.
[d] See reference 4.
[e] See reference 5.
[f] See reference 6.
[g] See reference 7.
[h] See reference 8.
[i] See reference 9.

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1 Freier, Lofgren, Ney, Oppenheimer, Bradt, and Peters, Phys Rev. **74**, 213 (1948).

2 S. F. Singer, Phys. Rev. **80**, 47 (1950).

3 Goldfarb, Bradt, and Peters, Phys. Rev. **77**, 751 (1950); see also *Progress of Cosmic Ray Physics*, edited by J. G. Wilson (North Holland Publishing Company, Amsterdam, 1952), p. 221.

4 Perlow, Davis, Kissinger, and Shipman, Phys. Rev. **88**, 321 (1952).

5 S. F. Singer, Phys. Rev. **76**, 701 (1949).

6 J. Linsley, Phys. Rev. **93** (1954). (Corrected flux value given in a private communication.)

7 E. P. Ney and D. M. Thon, Phys. Rev. **81**, 1069 (1951).

8 Davis, Caulk, and Johnson, Phys. Rev. **91**, 431 (1953). (Corrected flux value was given to Professor E. P. Ney in a private communication.)

9 F. B. McDonald (private communication to Professor E. P. Ney, 1953).

10 Kaplon, Peters, Reynolds, and Ritson, Phys. Rev. **85**, 295 (1952).

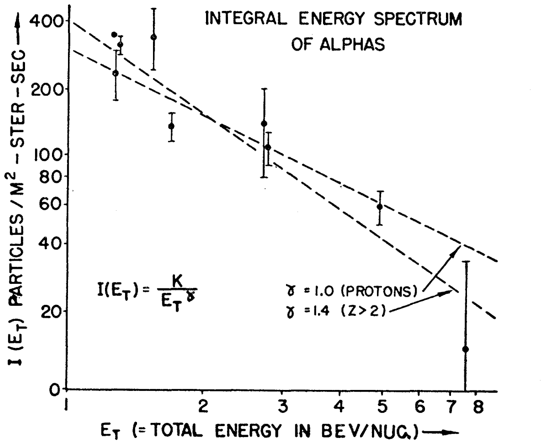

FIG. 1. The points represent flux values measured at various geomagnetic latitudes. The values of E_t are the cut-off energies at the corresponding latitudes. The dotted lines have slopes corresponding to $\gamma=1.0$ and 1.4 in the spectrum $I(E_t)=K/E_t^\gamma$.

flux measurements included a large amount of albedo (the higher energy protons would make relatively more albedo and this would tend to flatten the total flux spectrum). In any case, the value 1.0 is a lower limit for the exponent in the proton energy spectrum.

Similar attempts to fit the C,N,O, and $Z\geq 10$ components indicate a value of about 1.4 for the exponent in their energy spectra.[10] One would probably expect alphas to have an integral energy spectrum with exponent between the values 1.0 and 1.4. Figure 1 is a graph of the results listed in Table I. The dotted lines are not attempts at best fits to the data but rather show the slopes corresponding to the values 1.0 and 1.4. As can be seen, the data are not sufficiently self-consistent to decide between what we expect are the two limiting values. Equipment which can give more precise results should therefore be developed and should be used in a series of flux measurements at different latitudes.

APPLICATION OF A ČERENKOV COUNTER TO ALPHA FLUX MEASUREMENTS

In past counter experiments one usually identified primary alphas by measuring ionization loss. In principle, one should obtain a pulse-height distribution showing resolved peaks due to the cosmic rays with charge 1, 2, etc. The results have not been precise, however, because of the presence of background due to: (1) slow secondary protons originating in the residual atmosphere above the equipment, (2) proton induced nuclear interactions occurring in the detector, (3) showers of fast singly-charged particles originating in the air surrounding the equipment.

There is some evidence that the most serious problem is slow secondaries. A number of experiments which did not attempt to discriminate against slow particles also did not obtain any alpha peak. On the other hand, the Naval Research Laboratory group which flew proportional counters[4,8] included absorbers in their telescopes to eliminate slow particles and did succeed in partially resolving the alpha peak. In addition, the experiment which will be described in this paper and a recent experiment by Bohl[11] had provision to eliminate slow particles, and both succeeded in partially resolving the alpha peak.

An alternative to including an absorber in the equipment is to use a Čerenkov counter because it, in effect, has the absorber "built in." As is well known, a slow proton gives less Čerenkov light than a fast one. Therefore the pulse from such a particle will not cause background in the region of pulse heights expected for alphas.

The Čerenkov counter seems like an inviting tool for counter measurements on the very heavy components also. Here background usually was due to nuclear interactions in which a few evaporation particles lost a great deal of energy and gave very large pulses. However, in order to give as much Čerenkov light as a fast oxygen nucleus, the interaction would have to produce essentially 64 fast mesons.

Čerenkov counters had been used for balloon flight experiments during the past few years by Winckler and Anderson[12] in their studies of the albedo problem. They were recently adapted to flux measurements of multiply charged cosmic rays by Linsley.[6] Several years ago Ney[7] developed the first scintillation counter equipment suitable for balloon flight flux measurements of heavies. The present experiment is an outgrowth of that work, but it is built around a Čerenkov counter.

DESCRIPTION OF THE EQUIPMENT

In essence, the equipment consists of a Geiger counter telescope to define a solid angle in space from which particles will be accepted, a Čerenkov counter to determine their charge, some devices to identify background events, and apparatus to record the information obtained.

Trays A, B, and C, which are shown in solid black in Fig. 2, form the Geiger counter telescope. The equipment records only those events which cause a coincidence between these three trays. Thin-wall (30-mg/cm^2) counters were used in tray A to reduce the number of nuclear interactions occurring just above the radiator.

If f_v is the number of particles per m^2 per second per steradian coming from the vertical, and N is the observed counting rate of the telescope, then

$$N=Gf_v, \quad (2)$$

where G is a constant determined by the geometry of the telescope and the angular distribution of the incident radiation. The geometry factor for this

[11] L. Bohl (to be published).

[12] J. R. Winckler and K. Anderson, Phys. Rev. **93**, 596 (1954).

telescope for an isotropic flux was 9.5 ± 1 cm²-steradian.

Between trays A and B (Fig. 2) is the Čerenkov counter. The radiator is a cylindrical slab of Lucite 4 in. in diameter and 1 in. thick. The Lucite is optically coupled by a film of Canada balsam to the cathode of a Dumont K1198 photomultiplier (an end-window photomultiplier with a 5-in. diameter photocathode). This tube was operated with the cathode at ground potential and the collecting anode at plus 1220 volts. A positive output signal was taken from the tenth dynode, amplified, and displayed on a cathode ray tube (CRT). It is assumed that the deflection on the CRT is proportional to the voltage output of the photomultiplier which in turn is proportional to the amount of Čerenkov light made in the Lucite. This means the pulses from the photomultiplier must be free of saturation effects. The Dumont tubes are presumably free of saturation for signals in which the instantaneous currents are less than 12 ma.[13]

Let i be the instantaneous tube current, C be the output capacity of the tube, V_0 be the output voltage signals, and t be the duration of the pulse in the photomultiplier. Then if the current pulse is approximated by a square wave,

$$i=CV_0/t. \tag{3}$$

Taking C equal 10 $\mu\mu$f, and assuming spread in transit time makes $t\geqslant 5\times10^{-9}$ second, we see from Eq. (3) that the instantaneous current will be less than 12 ma if the output signals are less than 6 volts. The amplifiers were designed so that the maximum signal required (i.e., full scope deflection) was 5 volts.

If a proton interacts in the Lucite, making four fast mesons, the detector will indicate that an alpha came through. The same thing would happen if a narrow shower of fast particles originating in the air above the apparatus passed through the detector. In order to identify these events as background, an attempt was made to make the detector indicate whenever more than one particle passed through the telescope. This was done by placing the Geiger counters in tray B

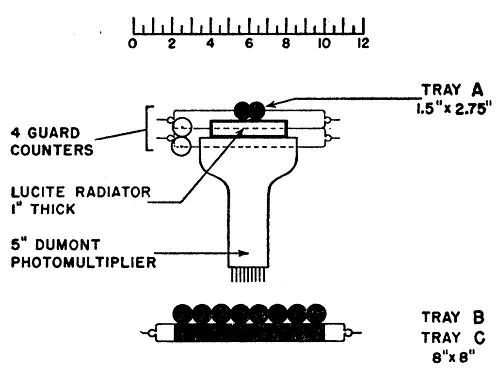

FIG. 2. Čerenkov counter telescope.

[13] B. R. Linden, Nucleonics **11**, 31 (1953).

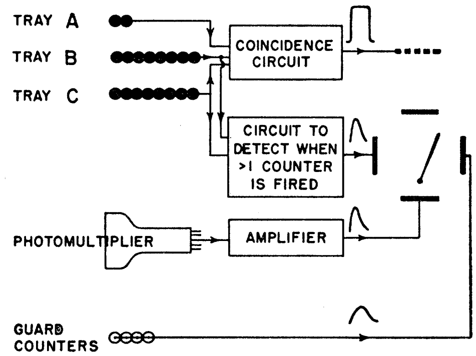

FIG. 3. Method of recording events.

perpendicular to those in tray C and having an electronic circuit which would indicate whenever more than one Geiger counter was tripped simultaneously in either tray. There were 8 Geiger counters in each tray so the bottom 64 square inches was effectively divided into 64 separate units, and the detector could tell whenever particles passed through more than one of these units simultaneously. In a further attempt to determine which events were really due to alphas and which to background, four guard counters were placed alongside the Lucite radiator to detect side showers.

Figure 3 illustrates the method of recording. The pulses from the photomultiplier are amplified and then fed to the vertical deflection plates of a cathode-ray tube. The CRT, however, is normally cut off. A coincidence between trays A, B, and C produces an enabling gate which is applied to the grid of the CRT and turns it on. A camera takes continuous pictures of the CRT. Thus if a single fast particle passes through the telescope, a vertical line, whose height is proportional to the square of the charge of the particle, will be recorded on the film.

The outputs of both tray B and tray C are also fed to a circuit which detects those cases in which more than one Geiger counter in a tray is fired simultaneously. When this happens a signal is fed to one of the horizontal deflection plates. When a guard counter is triggered, a signal is fed to the other horizontal deflection plate. Thus if a nuclear interaction takes place, the pulse on the film will appear tipped to one side, and if a side shower takes place, it will be tipped to the other side.

It was desired to record pulses ranging in size from 0 to $80h_0$, where h_0 is the mean pulse height corresponding to a fast proton. In order to do this, two cathode-ray tubes were used (like two scales on a voltmeter). One tube covered the range 0 to $9h_0$ and the other covered the range 0 to $80h_0$.

A watch with a second hand, a thermometer, and a Wallace and Tiernan pressure gauge were mounted on an instrument panel which was photographed by the same camera which photographed the cathode-ray tubes. The camera lens was always open so a light would flash on the instrument panel (but not on the cathode-ray tubes) once every minute.

All the equipment was mounted in a spherical gondola whose diameter was 30 in. and whose wall thickness was 0.03 in. The gondola was pressure tight, and thus the equipment remained in one atmosphere of pressure during the flight. (This was to prevent corona discharge.) The Wallace and Tiernan gauge was connected by a hose to a lead-through fitting in the wall of the gondola.

The equipment was flown by balloon[14] from San Angelo, Texas, on Februrary 2, 1954. It reached an altitude of 16 g/cm² at 9:30 A.M. c.s.t. and remained within 1 g/cm² of this altitude until 3:28 P.M. C.S.T. At 3:28 P.M. the equipment, suspended from a parachute, was released from the balloon and floated to earth. The equipment was recovered in good condition, and its operating characteristics appeared to be the same as before the flight.

RESULTS

When the apparatus is operated at sea level it is responding primarily to fast μ mesons. The pulse height distribution obtained is shown in Fig. 4. The dotted curve represents a Poisson distribution of mean 30. The good fit implies that on the average, a fast meson causes 30 photoelectrons to be collected at the first dynode. It will be useful to have an idea of the

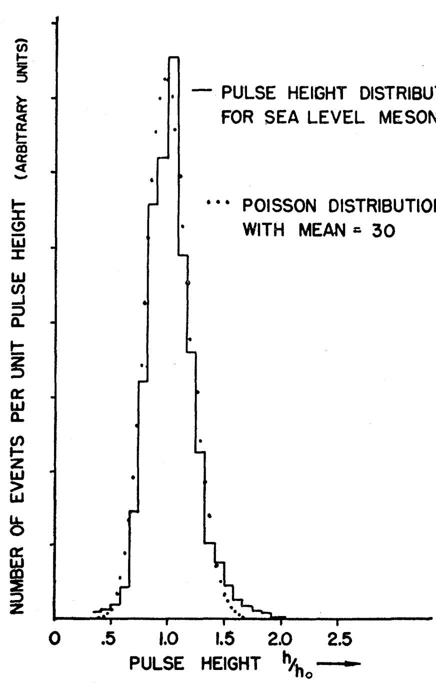

FIG. 4. The pulse height distribution for sea level mesons can be fitted quite closely by a Poisson distribution with mean 30. (The disagreement at the peak is probably due to the effects of personal bias in measuring the pulse heights.)

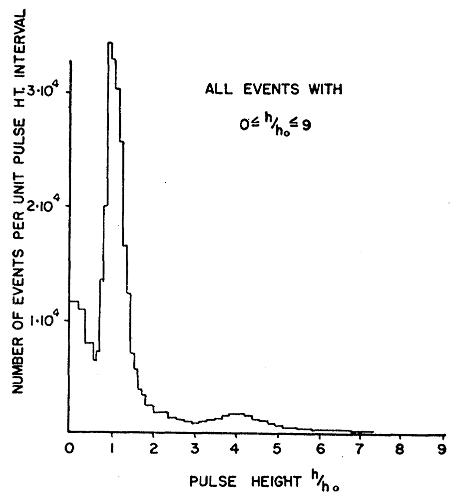

FIG. 5. Pulse height distribution for all events. This distribution includes events in which the guard counters were triggered and events in which more than one particle passed through the detector.

region of pulse heights in which alphas are expected to lie. If "photoelectron statistics" were the only source of fluctuations, we would expect the alpha peak to follow a Poisson distribution with mean 120. The alpha peak is broadened, however, due to variations in the energy of the incident alphas. At 41° the cut-off kinetic energy is 1.75 Bev/nuc. A particle with this energy gives 87 percent of the saturation amount of Čerenkov light. Thus at 41° the alpha particles will give amounts of Čerenkov light varying between 87 and 100 percent of the saturation value. Furthermore, a few percent of the alphas will give large pulses because they produce knock-on electrons in the Lucite which also give Čerenkov light. Combining these effects leads to the prediction that essentially no alphas will give pulses less than $2.7h_0$ and only a few percent will give pulses greater than $5.4h_0$.

Figure 5 shows the pulse height distribution obtained at high altitude for all events with pulse heights in the range 0 to $9h_0$. This distribution includes all events in which a guard counter was discharged and all events in which more than one particle passed through the telescope.

It seems fairly clear that there is a group of pulses due to fast particles of charge 1, a group due to fast particles of charge 2, and a group representing background. The Z equals 1 peak is very large compared to the Z equals 2 peak, which simply points up the difficulty in measuring the alpha flux, if there is any tendency for proton events to produce pulses in the alpha region.

Figure 6 shows an enlarged view of the pulse height distribution in the alpha region. Since all events are included in this pulse height distribution, the only discrimination involved is the inherent discrimination of a Čerenkov counter against slow particles. It is of

[14] The balloon flight was made by Office of Naval Research Project Skyhook.

interest to note that this, in itself, is enough to bring out a partially resolved alpha peak. The solid arrow was drawn under the proton peak, and the dotted arrow was drawn at four times the pulse height corresponding to the proton peak. The fact that the alpha peak falls essentially at the dotted arrow is an experimental verification of the Z^2 dependence of Čerenkov radiation. The shaded lines are drawn at h equals $2.7h_0$ and $5.4h_0$. As was mentioned above, all but a small percentage of alphas are expected to lie within these limits. The area under the curve between the two lines corresponds to 3024 events. Of course, many of these pulses are to be classed as background and the next job is to try to determine which events are the true alphas.

It seems reasonable to say that all events in which the guard counters are triggered are not single alphas that passed vertically downward through the telescope. Therefore, these events are not what we are interested in and are to be classed as background (it was for this reason that the guard counters were included in the equipment). There is a check on this assumption. If indeed the guard counter events are not associated in any way with alphas, then their pulse height distribution should not show any structure in the alpha region. Figure 7 shows the pulse height distribution for the guard counter events only. Again the shaded lines define the region in which alphas are to be expected. Outside the lines there are no alphas, so all these pulses must be background. The distribution inside the shaded lines follows an interpolation of the curve outside. This is what we would expect if these events were all background as is being assumed. There are 451 guard counter events in the alpha region (i.e., between the shaded lines).

Next consider the events in which more than one counter in trays B or C were triggered. As has been mentioned, it was hoped that this device would identify background due to proton-induced nuclear interactions taking place in the Lucite radiator. However, it is also possible for an alpha to cause more than one Geiger

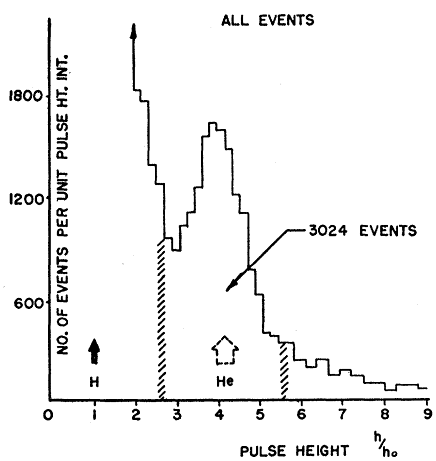

FIG. 6. An enlarged view of the alpha region shown in Fig. 5.

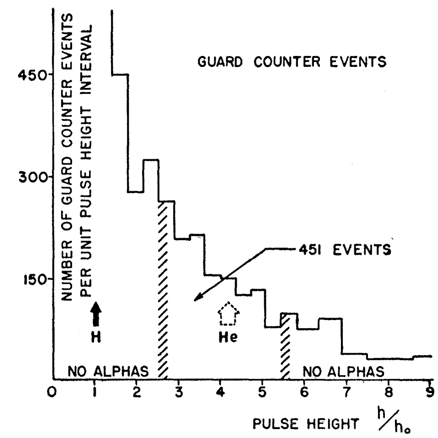

FIG. 7. The pulse height distribution for events in which a guard counter was discharged. There is no "structure" in the alpha region, which is consistent with the assumption that all these events are background due to side showers.

counter to be triggered simultaneously. This can come about in 3 ways. First there is about 7 ± 3 g/cm^2 of matter between the Lucite and tray C. An alpha can go through the radiator, give a Čerenkov pulse of the right size, then interact in this matter and the resultant shower can trip more than one Geiger counter. Second, it is possible that a delta ray made by the alpha will trigger an additional Geiger counter, and third, a small number of alphas traveling at large angles will be able to pass obliquely through two adjacent counters. If true alphas do occasionally cause more than one Geiger counter to be fired, than the pulse height distribution for the multiple counter events should show an alpha peak superimposed on the background due to proton interactions in the Lucite. Qualitatively this is what was found. Figure 8 shows the pulse height distribution for these multiple counter events. Again the shaded lines indicate the region in which alphas are expected. Note that a small peak does appear and it does lie roughly within the shaded lines. Outside the lines there should be few alphas. To get the background in the alpha region, an interpolation was made and is indicated by the dotted line. The area under the peak but above the dotted line represents true alphas and amounts to 247 events. This is 17 percent of the total number of events which were finally believed to be alphas. The area under the dotted line represents background and amounts to 651 events.

The pulse height distribution for what remained after using these two devices to identify background events is shown in Figure 9. These are the pulses which appeared straight on the film. The dotted curve is the pulse height distribution obtained from sea level mesons, and it is therefore what one would expect to get at altitude if there were nothing but fast protons. There is not appreciable broadening in the main proton peak but there is an extra group of small pulses presumably due to single slow secondaries.

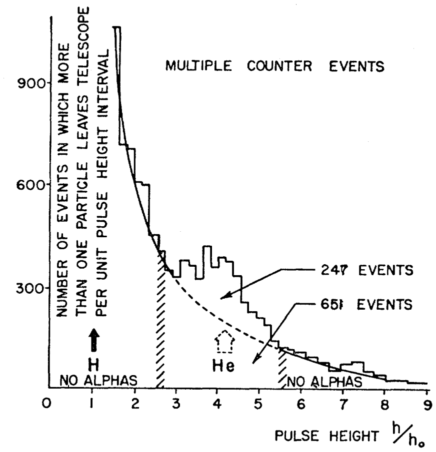

FIG. 8. The pulse height distribution for events in which two or more counters in tray *B* or *C* are triggered simultaneously. Here there *is* "structure" in the alpha region. 247 events are due to alphas and 651 are due to proton-induced interactions.

This group does not blot out the alpha region because the pulses are small, but had this been a device which measured ionization loss, those particles would have given pulses on the other side of the proton peak. This, of course, is the principle advantage of the Čerenkov counter.

Figure 10 shows an enlarged view of the alpha region. Now that the guard counter and multiple counter events have been subtracted out, the alpha peak is more clearly resolved, but since the valley doesn't drop to zero, there must still be background. This means that the other devices were not 100 percent efficient in detecting nonalpha events. There are two kinds of background here. One is caused by the tail of the proton peak. These pulses do not actually extend into the alpha region but do contribute to the curve to the left of the alpha peak. The other background is probably caused by nuclear interactions which failed to trip two

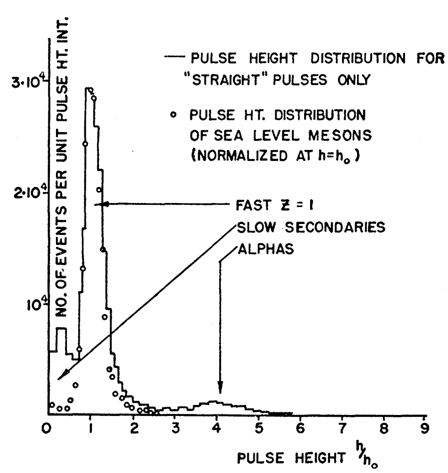

FIG. 9. The pulse height distribution for "straight" pulses only. Events in which guard counters or multiple counters in trays *B* or *C* were triggered are *not* included.

Geiger counters, and these events would give pulses of all heights. To estimate the magnitude of this background in the alpha region, we would like to make an interpolation as was done before, but before interpolating it is necessary to subtract out the proton tail. This can be done because it has the same shape as the known meson tail. After the protons are subtracted out, it is assumed that the remaining pulses outside the alpha region are all nuclear interactions. These are shown in solid black in Fig. 11. It is this solid black curve which is used to interpolate the background into the alpha region. This interpolation is indicated by the heavy dotted line.

An alternative method of estimating the background is to use data obtained while the balloon is ascending. Here one takes the data obtained at an altitude sufficiently high that there are appreciable numbers of protons which can produce interactions, but sufficiently low so that there are no alphas. Then all large pulses

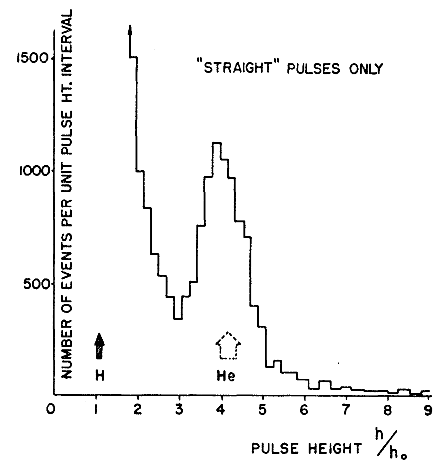

FIG. 10. An enlarged view of the alpha region shown in Fig. 9.

must be background. Of course since we are dealing with protons which have been degraded in energy, this may only give a lower limit for the background at altitude. The background estimated in this way is shown by the lower dotted line. This method has been used by various people in the past. Note that the two methods, at least in the case of a Čerenkov counter, give significantly different results.

The value obtained using the upper curve was taken as the estimated remaining background. This correction amounts to 478 particles, which is 33 percent of the total number of true alphas. This is a large correction and means there is the possibility of a significant error in the result. This points up the fact that in a counter experiment one must get a well resolved peak if one hopes to get a precise value for the flux.

After making this correction, there are 1197 "straight" pulse events remaining, and it is assumed they are all alphas. In addition there were the 247 multiple counter events which are believed to be alphas.

The time during which this total of 1444 events occurred is 355.5±1 minutes. A mean free path of 50 g/cm^2 for the absorption of alphas in the 16 g/cm^2 of air above the equipment and in the first cm of Lucite in the radiator was used to extrapolate the counting rate to the top of the atmosphere. We finally obtain as the result of this experiment the value [see Eq. (2)]:

$$f_v = \frac{(1444)}{e^{-17/50}\,(355.5)(60)(9.5\times10^{-4})}$$
$$= 99 \text{ particles/m}^2\text{-steradian-second,}$$

for the flux of alpha particles at the top of the atmosphere at a geomagnetic latitude of 41 degrees.

Since the value of the flux is based on 1444 events, the statistical uncertainty is less than 3 percent. More

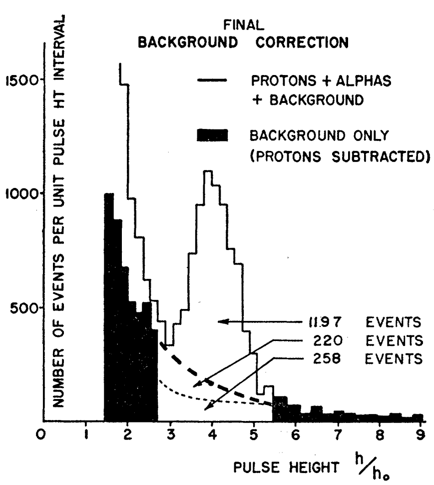

FIG. 11. The final background correction. The upper curve is a repetition of Fig. 10. The solid black curve is what one obtains after subtracting out the proton tail. The heavy dotted line is the estimated background in the alpha region based on an interpolation of the solid black curve. The light dotted line is the estimated background based on data taken while the balloon was ascending.

important possible sources of error, however, are the value of the geometry factor, and the magnitude of the background corrections. It is estimated that the flux value is correct to within ±16 percent.

Figure 12 shows the summary of alpha flux values that was given in Fig. 1 with three additions. The dot with the arrow next to it represents the result of this experiment. The two dots just below it represent the results of Bohl's[11] double scintillation counter and Linsley's[15] Čerenkov counter triggered cloud chamber. All three experiments were flown from Texas last February. As can be seen, the three points are reasonably consistent and lie somewhat below the previous values. It would be very interesting now to have these experiments repeated at other latitudes in order to get

[15] J. Linsley, Phys. Rev. **96**, 829(A) (1954).

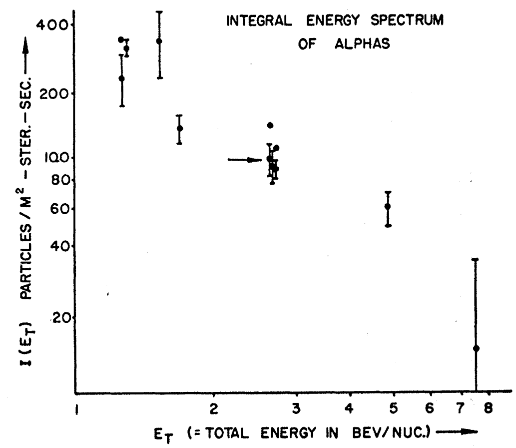

FIG. 12. This is a repetition of Fig. 1 except that three new points have been added at $E_t = 2.75$ Bev/nuc. The point with the arrow is the result of this experiment. The two points just below it are due to Bohl and Linsley.

a better idea of the integral energy spectrum of primary alphas.

The behavior of the Čerenkov counter in the $3 \leqslant Z \leqslant 9$ region is shown in Figs. 13 and 14. Figure 13 gives the pulse height distribution in the range $9h_0$ to $80h_0$ for those events which gave "straight" pulses (i.e., events which triggered a guard counter or more than one counter in trays B or C are not included). The regions of pulse heights which one expects to correspond to the various elements are indicated along the abscissa. These regions have been determined by using (1) the Z^2 dependence for Čerenkov light, (2) the amplifier calibration curve, and (3) the fact that the peaks are smeared downward by 13 percent due to variations

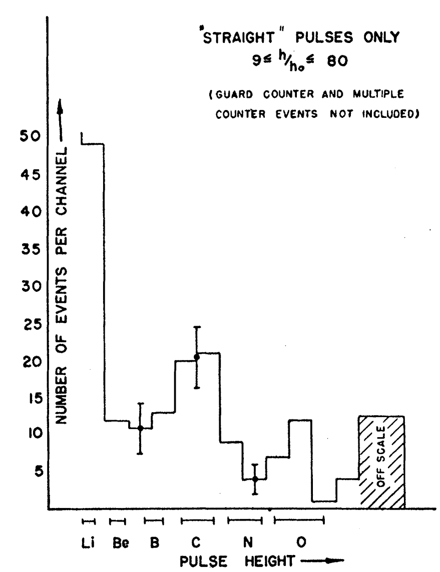

FIG. 13. Pulse height distribution in the range $9h_0$ to $80h_0$ for those events which gave "straight" pulses only (i.e., events which triggered a guard counter or more than one counter in trays B or C are not included).

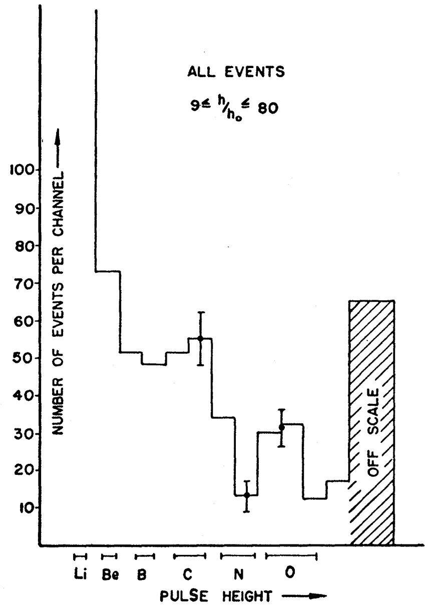

FIG. 14. Pulse height distribution for all events in the range $9h_0$ to $80h_0$.

in the energy of the primaries and then smeared out symmetrically an additional few percent due to other fluctuations.

There are no resolved peaks in the Li, Be, B region; however, there is some indication of partially resolved carbon and oxygen peaks. In judging the usefulness of a Čerenkov counter for measurements on the more heavily charged components on the basis of Fig. 13, one should remember that (1) the distribution involves rather few events (69 in the C,N,O region), and this makes resolution difficult; and (2) the effect of variations in energy spreads out the peaks to a serious extent (one would be better off in this respect if the experiment were done at the equator).

Figure 14 is the pulse height distribution for all events. There were a total of 209 events which gave pulses in the C,N,O region. Of these 25 triggered a guard counter, 115 triggered multiple counters in trays B and C and the remaining 69 gave "straight" pulses. If one believes that proton-induced nuclear interactions will not give pulses in the C,N,O region when one uses a Čerenkov counter, then all 209 events must be associated with true C,N,O's. (This is possible since C,N,O's have a large probability of making delta rays which could trigger a guard counter or a second Geiger counter.) Extrapolating the total counting rate to the top of the atmosphere using a mean free path of 35 g/cm^2, one obtains a C,N,O flux of 17 particles/m^2-steradian-second. This is to be compared with the value 6 particles/m^2-steradian-second obtained with emulsions.[10] Thus, either there are background events that are not associated with C,N,O's, or the geometry factor is 2 or 3 times bigger for C,N,O's than for protons. Linsley has obtained results with his Čerenkov-triggered cloud chamber which indicate the geometry factor is increased for the heavy components. This happens because some heavies which pass through the Lucite radiator but miss one of the trays of the telescope get recorded anyway because a delta ray triggers the missed tray. Figure 14 shows that when multiple counter events are included, there is considerable fill-in to the left of the carbon peak. This would imply that the number of nuclear interactions which give Čerenkov pulses in the neighborhood of $25h_0$ to $35h_0$ is of the same order as the number of boron and carbon nuclei.

The data obtained in this experiment is consistent with the picture that all pulses from a Čerenkov counter corresponding to $Z>6$ are indeed associated with a heavy nucleus, but for $Z<6$ the event may be a nuclear interaction. The large C,N,O flux along with Linsley's results indicate that in a counter experiment in the C,N,O region one must realize that acceptable paths cannot be defined by Geiger counters alone. The C,N,O's have an extension in space due to the action of their delta rays. Thus, one must use either Geiger counter trays of large area or some counter which can differentiate between a heavy nucleus and a delta ray it may produce.

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