ACKNOWLEDGMENTS

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Primary Cosmic-Ray Proton and Alpha-Particle Intensities and Their Variation with Time*

PETER MEYER
The Enrico Fermi Institute for Nuclear Studies and Department of Physics, The University of Chicago, Chicago, Illinois
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A series of high-altitude balloon flights was carried out in 1957 and 1958 to study the flux of primary cosmic-ray protons and α particles during variations in the total cosmic-ray intensity. The following results are obtained for α particles with energies exceeding 530 Mev/nucleon under 13.5 g/cm^2 of air: (a) During a large Forbush-type decrease the α-particle and proton intensities were closely correlated. This demonstrates that a modulation mechanism is operating on both components. (b) At certain times variations in the α-particle intensity were observed within a few hours which were not accompanied by corresponding changes in the proton flux. This is tentatively ascribed to an anisotropy in the α-particle flux that reaches the earth. (c) While there existed an intensity decrease in the proton flux between 1957 and 1958 which is also observed in the neutron monitor station data, no such variation occurred in the α-particle flux. A division of the α particles into two energy groups (450 Mev/nucleon $\leqslant E_1 \leqslant$ 960 Mev/nucleon and $E_2 \geqslant$ 960 Mev/nucleon) shows (a) that the Forbush decrease is of the same magnitude in both energy groups, (b) that the hourly flux increase observed in some flights is about the same in both energy groups, and (c) that from 1957 to 1958 the flux in the low-energy group increased, while it decreased in the high-energy interval, contrary to the well-known behavior of the proton flux. These independent α-particle flux variations cannot be explained by any of the modulation mechanisms so far proposed. We suggest that occasional solar production of α particles may be responsible for our results.

The absolute flux of α particles with energies exceeding 560 Mev/nucleon at the top of the atmosphere was measured on five different days.

I. INTRODUCTION

VARIATIONS in the total primary cosmic-ray intensity have been observed and studied for a number of years. The main tools for these investigations are permanently installed cosmic-ray monitors that are able to record the intensity over long periods of time. More recently, this work was complemented using aircraft and balloon-borne instruments.

It was possible to show that most variations occur in the primary flux of cosmic-ray particles and are not due to local influences such as geomagnetic or meteorological effects, and it could be demonstrated that the mechanisms that give rise to such variations are solar controlled and must operate within or near the solar system. Extensive work has been carried out to find some model that may account for the observed phenomena, but no unique explanation is as yet available.

Most investigations that were carried out so far on the intensity variations of the primary cosmic radiation are concerned with the total flux of incoming particles. We know, however, that approximately 86% of the primary flux are protons, about 13% consist of alpha particles, while the remaining 1% are still heavier nuclei. The information on intensity variations of the different components of the primary radiation is still very limited. A more detailed knowledge of their flux and of their energy spectrum as a function of time can be used to test the models that were proposed to explain the changes observed in the total cosmic-ray flux. The emphasis of the present experiment is to move a step in this direction through an investigation of some of the time variations of the primary proton and alpha-particle fluxes and a study of the correlation between the two components. If, for example, the total flux of the low-energy primary cosmic radiation is of galactic origin and the intensity modulation takes place in the solar system due to disordered magnetic fields, one would expect very similar changes for each rigidity interval in the proton and α-particle component. Should, on the other hand, solar production of particles with cosmic-ray energies play a more important role than is generally assumed, variations in the ratio of α-particle flux and proton flux are likely to occur. For two reasons, it is advantageous to choose the cosmic-ray alpha particles as the prototype of the heavy primaries.

1. They are, next to the protons, the most abundant component, contributing more than 10% to the primary flux of particles.

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2. They can readily be studied with electronic detectors with an excellent discrimination against protons and the still heavier components.

Work on the changes in intensity and energy spectrum of the primary cosmic-ray alpha particles in correlation with the total cosmic-ray intensity changes and the 11-year activity cycle of the sun was carried out in recent years using photographic emulsions and electronic detectors. A rather close correlation between the changes in α-particle and proton fluxes was found and it was concluded that the same mechanism is responsible for the intensity modulation of both components.[1]

The question we wished to ask in the present investigation concerns primarily the relationship between the short-term variations of primary protons and alpha particles. In this group would fall the 27-day variation, the sudden and sharp Forbush-type intensity decreases, and possibly 24-hour variations. We, therefore, had to select properly the times for which measurements were to be made to obtain data at periods of highest and lowest total cosmic-ray intensity. The cosmic-ray neutron monitor at Chicago[2] was used for the purpose of choosing the appropriate times of measurement.

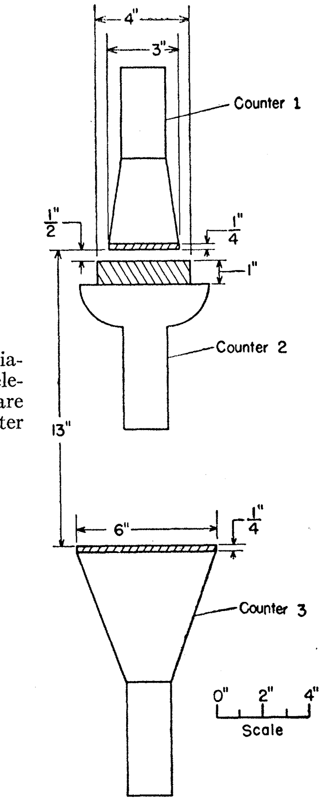

FIG. 1. Schematic diagram of the counter telescope. Counters 1 and 3 are plastic scintillators; Counter 2 is a Čerenkov counter.

II. INSTRUMENTATION

An electronic detector capable of measuring alpha-particle fluxes over an appreciable range of energy has been described by McDonald.[3] His technique of using a combined scintillation counter and Čerenkov counter for discrimination between alpha particles and protons has, with slight modifications, been used in the present experiment, and we refer to the paper by McDonald for a detailed discussion of the capabilities of this detector. Figure 1 shows a schematic cross section through the apparatus used in the present experiment. Counter 1 and Counter 3 are cylindrical plastic scintillators $\frac{1}{4}$ inch thick with diameters of three inches and six inches, respectively. Each is viewed by a two-inch Dumont photomultiplier through a conical air light pipe with reflecting walls. Counter 2 is a Čerenkov counter consisting of a cylindrical Lucite radiator, one inch thick and four inches in diameter, mounted in optical contact with a five-inch Dumont photomultiplier. The top of the Lucite was painted black in order to obtain minimum light output from upward moving particles. A geometry factor of 8.3 ± 0.4 sterad$\times$cm^2 is obtained by requiring a coincidence between Counter 1 and Counter 3. This geometry factor varies slightly between different sets of equipment, the error being unchanged. For each coincidence, the light output of Counter 1 and Counter 2 are independently measured by displaying the electronic pulses on two separate cathode ray tubes and photographing them. Each particle passing through the counter telescope is, therefore, characterized by two numbers, one giving its energy loss in the scintillation counter and one giving its output of Čerenkov light. The plastic scintillator material was chosen because of its small density and because it does not require any protective windows. The proportionality between light output and energy loss of the passing particles is satisfactory within the range of energy loss covered in the experiment.[4] Using Lucite with an index of refraction 1.5 as the material for the Čerenkov radiator, alpha particles with energies down to 450 Mev/nucleon are well discriminated against low-energy protons. The telescope is easily calibrated with relativistic cosmic-ray mu mesons at sea level. In this case, the scintillation detector shows a pulse-height distribution with a half-width of about 30% of the average pulse height produced by the mesons, and the Čerenkov detector has a half-width of around 40%.

During the balloon flights the entire apparatus was placed in an aluminum cylinder and kept at atmospheric pressure.

III. THE EXPERIMENTS

Two series of measurements at high geomagnetic latitude were carried out to investigate the proton and

[1] Freier, Ney, and Fowler, Nature **181**, 1319 (1958); Freier, Ney, and Waddington, Bull. Am. Phys. Soc. Ser. II, **3**, 221 (1958); F. B. McDonald, Phys. Rev. **107**, 1386 (1957); Bull. Am. Phys. Soc. Ser. II, **3**, 220 (1958).
[2] Simpson, Fonger, and Treiman, Phys. Rev. **90**, 934 (1953).
[3] F. B. McDonald, Phys. Rev. **104**, 1723 (1956).
[4] C. N. Chou, Phys. Rev. **87**, 903 (1952).

TABLE I. The proton flux, α-particle flux, and Climax neutron monitor intensity during five balloon flights.

Date	Climax neutron monitor intensity	Average pressure during flight (mm Hg)	Total number of protons counted in flight	Proton flux corrected for 13.5 g/cm² (m⁻² sec⁻¹ sterad⁻¹)	Total number of α-particles counted in flight ($E>530$ Mev/nucleon)	α-particle flux corrected for 13.5 g/cm² and background ($E>530$ Mev/nucleon) (m⁻² sec⁻¹ sterad⁻¹)	α-particle flux at the top of the atmosphere ($E>560$ Mev/nucleon) (m⁻² sec⁻¹ sterad⁻¹)
August 16, 1957	2841±1%	11.3	41 940	1910±2%	2275	103.0±4%	136.4±9%
August 30, 1957	2480±1%	10.2	48 546	1662±2%	2265	94.0±4%	124.4±9%
September 16, 1957	2780±1%	10.2	51 424	1921±2%	3224	115.1±4%	153.9±9%
July 12, 1958	2709±1%	9.4	75 828	1627±2%	5094	103.7±3%	138.0±8%
July 22, 1958	2694±1%	9.0	80 701	1588±2%	5836	105.2±3%	140.1±8%

α-particle flux We chose Prince Albert, Saskatchewan (53° 13′ N, 105° 41′ W) as the balloon launching site in 1957 and Neepawa, Manitoba (50° 16′ N, 99° 27′ W) in 1958. The geomagnetic cutoff rigidities are 0.6 Bv and 0.7 Bv, respectively, according to Quenby and Webber.[5] They are well below the low-rigidity cutoff of the primary spectrum during the years of this experiment, and we can expect that small changes in latitude during a flight will not noticeably influence the flux measurement. The actual change in latitude never exceeded 1°. For all balloon flights the altitude was chosen to be approximately 100 000 feet, corresponding to a residual layer of 13 g/cm² of atmosphere above the equipment. Allowing for the additional amount of matter to be traversed in order to reach Counter 3, one finds that particles with energies exceeding 150 Mev/nucleon are capable of triggering the counter telescope. While in 1957 the balloons remained at constant altitudes for about eight hours, this time was extended to 20 hours in 1958. The pressure was monitored throughout the flight with a Wallace-Tiernan gauge type *FA* 160 which, together with a clock, was photographed at regular intervals on the data recording film.

Twelve days were selected for balloon flights using the neutron monitor data from Chicago. Seven of those flights were satisfactory in both balloon and equipment performances and five of them are included in the present analysis. They took place on August 16, 1957, August 30, 1957, September 16, 1957, July 12, 1958, and July 22, 1958. In Figs. 2 and 3, the total cosmic-ray intensity as measured by the Climax neutron monitor is plotted as a function of time for the two periods of balloon measurements. The arrows indicate the days on which balloon flights were made. The period in 1957 showed about the largest intensity changes for the entire year. Especially around September 1, 1957, solar activity was at a very high level.

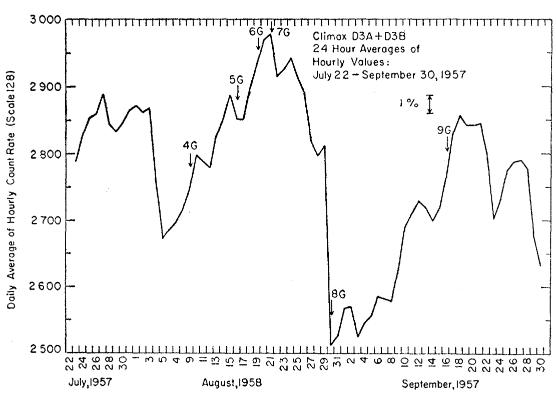

FIG. 2. The total cosmic-ray intensity as a function of time measured by the Climax neutron monitor during the period of the 1957 balloon expedition. The days of balloon flights are indicated by arrows.

[5] J. J. Quenby and W. R. Webber, Phil. Mag. 4, 90 (1959).

IV. THE RESULTS

In Table I we give the values of the total cosmic-ray intensity as measured with the Climax neutron station, the proton flux and the α-particle flux for the five selected balloon flights. These are averaged over the periods in which the measurements were carried out. The following corrections were taken into account. The flux values were corrected for altitude changes of the balloon during each flight. These amounted to less than 1 mm Hg in the flights that were selected except for one occasion where the pressure increased by about 2 mm Hg for four hours (August 16, 1957) and another increase by 5 mm Hg during the last hour of the flight on July 12, 1958.

In the case of the α particles we normalized all data

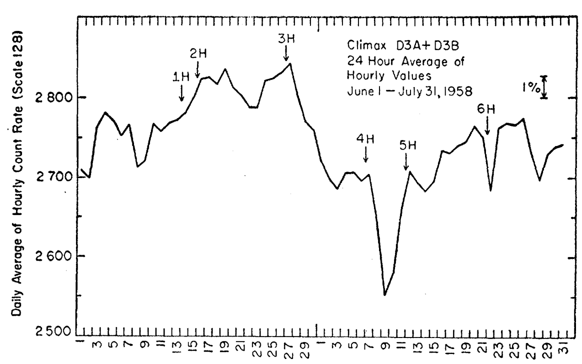

FIG. 3. The total cosmic-ray intensity as a function of time measured by the Climax neutron monitor during the period of the 1958 balloon expedition. The days of balloon flights are indicated by arrows.

TABLE II. The relative changes in proton flux, α-particle flux, and the neutron monitor intensity at three stations with respect to the values of August 16, 1957.

	Balloon data		Neutron monitor station data		
Date	Proton flux % change	α-particle flux % change $E>530$ Mev/nucleon	Sulphur Mountain $R=0.98$ Bv	Climax $R=2.71$ Bv	Sac Peak $R=4.7$ Bv
August 16, 1957	0	0	0%	0%	0%
August 30, 1957	-13.0 ± 2	-9 ± 4	-12.4%	-12.7%	-7.9%
September 16, 1957	$+0.6\pm2$	$+12\pm4$	-4.1%	-2.1%	...
July 12, 1958	-14.8 ± 2	$+1\pm4$	-7.3%	-4.8%	-1.6%
July 22, 1958	-16.8 ± 2	$+2\pm4$	-6.6%	-5.2%	-2.8%

to an altitude corresponding to 13.5 g/cm^2 of air above the detector using an absorption mean free path[3] of 45 g/cm^2 for α particles in air and we corrected for a general background in the α-particle region (see Sec. D).

A similar procedure was followed to obtain corrected proton flux values. We again normalized to 13.5 g/cm^2 of air overhead using the altitude dependence of the proton flux which was measured during the ascents of all flights. All singly charged particles able to penetrate the scintillation counter telescope were included in the proton group. The lowest energy accepted is, therefore, determined by the low-rigidity cutoff in the primary spectrum at the time of the measurement.

A. The Changes in α-Particle and Proton Flux during the Forbush Decrease of August 30, 1957

The largest intensity changes between days of measurements occurred during the 1957 balloon flight series. Alpha-particle flux measurements were carried out before, during, and after the large Forbush type decrease of August 30, 1957. Some preliminary results that we observed in connection with this phenomenon have been reported earlier.[6] The main question we wish to investigate is the relative change of the proton flux and the alpha-particle flux during this interesting period of large total intensity change.

We begin by comparing the changes in total intensity, proton intensity, and intensity of α-particles with energies exceeding 530 Mev/nucleon at the altitude of observation.

Using the values that were obtained on August 16, 1957, before the Forbush decrease occurred, as a reference, we observe the changes given in Table II. It should be noted that the lowest rigidity of protons or α particles admitted in this measurement is not determined by the geomagnetic cutoff at the location of the balloon flights. In the case of protons, it is given by the low-rigidity cutoff in the primary cosmic-ray spectrum in the years of the experiment. It should, therefore, be at about 1.8 Bv. The lowest α-particle rigidity included in the figures of Table II is 2.3 Bv and is determined by our selection of the pulse-height region.

Within the accuracy of our experiment, from August 16, 1957 to August 30, 1957, the same relative changes occurred in the averaged proton and α-particle intensities. Within two weeks after the decrease, both components returned to a high intensity value, the α-particle increase being considerably larger than the corresponding change in the proton component. We suspect that this high α-particle flux value is connected with the large intensity increase that was observed in the α-particle component during the measurement on September 16, 1957. This will be discussed in Sec. C.

If one compares the relative intensity changes of various neutron monitor stations[7] (Table II) between the days of balloon measurements, one notices that up to 4 Bv there exists very little rigidity dependence for this particular event. Within the limits imposed by the velocity sensitive range of the Čerenkov counter one can investigate the rigidity dependence of this variation for the α particles. We have, therefore, subdivided our α-particle fluxes into two intervals, the first including α particles with energies between 450 and 960 Mev/nucleon and the second for energies exceeding 960 Mev/nucleon. These data are included in Table III. The Forbush decrease is observed in both energy intervals with about equal amplitude. Within the error of the experiment there is no evidence for a strong energy or rigidity dependence. We conclude that within the energy interval covered by this experiment, a common modulation mechanism operated on both primary particle components during the large Forbush-type decrease of August 30, 1957.

The rigidity dependence observed in this particular Forbush-type decrease is strikingly different from the rigidity dependence of the 11-year cycle variation (see Sec. B) and our result adds to the increasing evidence that the mechanisms responsible for the two

TABLE III. The α-particle flux in two energy intervals during the five balloon flights.

Date	α-particle flux 450–960 Mev/nucleon corrected for 13.5 g/cm^2 (m^{-2} sec^{-1} sterad^{-1})	α-particle flux >960 Mev/nucleon corrected for 13.5 g/cm^2 (m^{-2} sec^{-1} sterad^{-1})
August 16, 1957	33 ± 6%	85 ± 5%
August 30, 1957	31 ± 6%	72 ± 5%
September 16, 1957	38 ± 6%	87 ± 5%
July 12, 1958	37.6 ± 5%	77.5 ± 4%
July 22, 1958	35.1 ± 5%	81.8 ± 4%

[6] Peter Meyer, Bull. Am. Phys. Soc. Ser. II, 3, 221 (1958).

[7] We wish to thank Dr. D. C. Rose for his permission to use the data from his cosmic-ray monitor network.

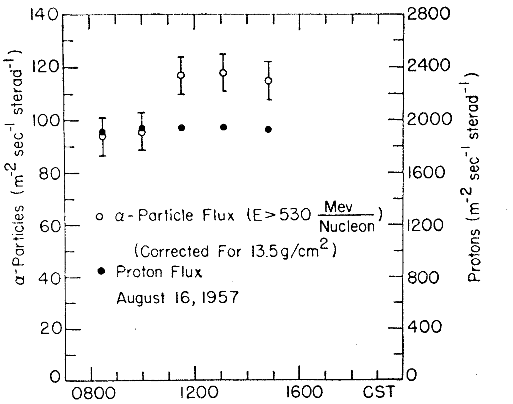

FIG. 4. The flux of α particles and protons under 13.5 g/cm² residual atmosphere as a function of local time during the balloon flight of August 16, 1957. (These data are not corrected for background in the α-particle region.)

types of intensity variations are not closely related. The rigidity independence of the Forbush decrease in the low-energy region can be explained on the basis of modulation by disordered magnetic fields. It turns out that the scale of the disordering is equal to the Larmor radius at the energy below which the independence occurs (Parker[8]). The measurements at aircraft altitude made by Simpson[9] before, during, and after the Forbush decrease of August 18, 1951, also showed this rigidity independence in the same rigidity interval. We may point out here that our experiment is not capable of discriminating between an energy dependence and a rigidity dependence of these variations.

B. Changes in the Primary Particle Intensity and Spectrum between 1957 and 1958

During the period between the two balloon flight expeditions, noticeable changes occurred in the primary cosmic-ray intensity and energy spectrum as exhibited by the monthly averaged intensities recorded by neutron monitor stations at various latitudes.[10] Furthermore, measurements using aircraft established[11] that the low-rigidity cutoff of the primary cosmic-ray spectrum changed to higher rigidities between the summer of 1956 and the beginning of 1958. These changes follow the pattern now known as the 11-year cycle of cosmic-ray intensity and spectrum and one expects the largest intensity changes to occur in the low-energy end of the spectrum.[12,13] This is indeed observed if one compares the relative changes in intensity as measured by neutron stations (Table II) on the days of balloon flights and the changes in proton intensity at balloon altitude. A strong rigidity dependence is present in contrast to the observations of the Forbush decrease discussed in the previous section. A decrease in intensity, comparable to the one observed in the proton component, was also observed at high altitude and latitude, using balloon-borne neutron equipment.[14]

We did, however, not find a comparable decrease in the flux of primary α particles with energies exceeding 530 Mev/nucleon, which remained almost unchanged. Therefore, the ratio of the proton flux at 13.5 g/cm² over the α-particle flux at 13.5 g/cm², which had an average of 17.6 in the 1957 flights, became 15.4 in 1958. The division of the α-particle flux into two energy intervals (Table III) seems to indicate that a decrease in intensity does take place in the high-energy group, while the low-energy flux increases, although the errors are rather large. This behavior is exactly the opposite of what one would expect on the basis of the proton flux data.

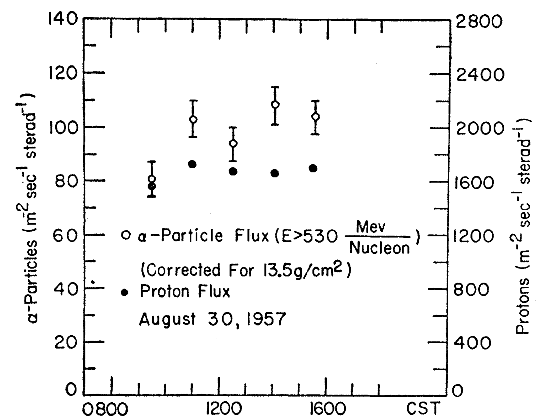

FIG. 5. The flux of α particles and protons under 13.5 g/cm² residual atmosphere as a function of local time during the balloon flight of August 30, 1957. (These data are not corrected for background in the α-particle region.)

C. Rapid Variations in the Primary α-Particle Flux

An outstanding advantage of an electronic counting device for the measurement of the primary cosmic-ray flux is the possibility of studying in detail the intensity as a function of time during the periods the equipment stays at altitude. We have divided the flight periods into equal intervals, each lasting for approximately 90 minutes. The results so obtained for the α-particle flux and for the proton flux as a function of time are presented in Figs. 4 through 8. During all of the measurements carried out in 1957 we noticed an increase in the α-particle flux as a function of time which was not accompanied by a similar change in the proton intensity.

[8] E. N. Parker, Phys. Rev. **103**, 1518 (1956); **110**, 1445 (1958).
[9] J. A. Simpson, Phys. Rev. **94**, 426 (1954).
[10] J. A. Simpson (unpublished results).
[11] P. Meyer and J. A. Simpson (unpublished).
[12] Peter Meyer and J. A. Simpson, Phys. Rev. **99**, 1517 (1955); **106**, 568 (1957).
[13] H. V. Neher and H. Anderson, Phys. Rev. **109**, 608 (1958).
[14] K. B. Fenton (private communication).

This effect was most remarkable in the measurement of September 16, 1957. All flights in the 1957 group of experiments were launched in the early morning hours and therefore cover about the same period of local time. The total cosmic-ray intensity was measured independently with a vertical Geiger counter telescope during those flights[15] and shows the same time dependence as the proton flux. The α-particle increase is not only observed at energies exceeding 530 Mev/nucleon, but occurs with comparable amplitude in the two energy intervals of 450–960 Mev/nucleon and >960 Mev/nucleon.

This observation raises the question whether a 24-hour variation or anisotropy in the α-particle flux may occasionally be present.[6] It should be noted that a similar effect has previously been observed by McDonald in his α-particle measurement of March 13, 1956. Ours as well as McDonald's observations were carried out at a time of enhanced solar activity as exhibited by the

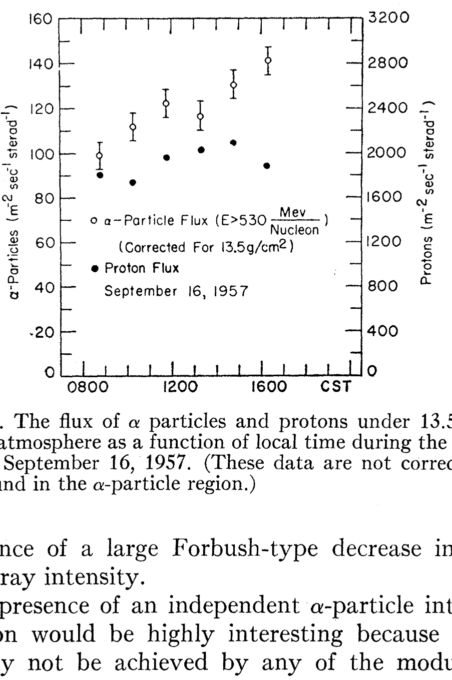

FIG. 6. The flux of α particles and protons under 13.5 g/cm^2 residual atmosphere as a function of local time during the balloon flight of September 16, 1957. (These data are not corrected for background in the α-particle region.)

occurrence of a large Forbush-type decrease in total cosmic-ray intensity.

The presence of an independent α-particle intensity variation would be highly interesting because it can certainly not be achieved by any of the modulating mechanisms that have so far been considered. In spite of the large number of α particles counted in this experiment, the evidence for the independent α-particle intensity variation is subject to a substantial error. For example, the probability that the measurement of September 16, 1957 is consistent with identical α-particle and proton variation amounts to about $\frac{1}{10}$.

In order to study this variation in more detail, the 1958 flights were designed to remain at altitude for about 20 hours, but no similar independent α-particle intensity change could be observed, as seen from Figs. 7

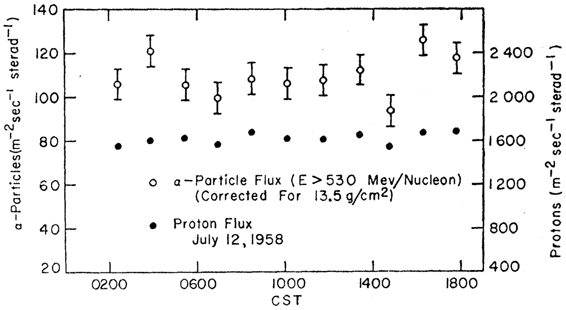

FIG. 7. The flux of α particles and protons under 13.5 g/cm^2 residual atmosphere as a function of local time during the balloon flight of July 12, 1958. (These data are not corrected for background in the α-particle region.)

and 8. We plan to carry out some further experiments to study this phenomenon.

D. The Absolute Flux of Primary α Particles with Energies in Excess of 560 Mev/Nucleon

The total number of α particles measured during each flight of the present experiment is substantially higher than in any previous investigation, due to the large geometry factor and the length of time of each measurement. It, therefore, seems worthwhile to use the data for a determination of the absolute flux of primary α particles. If one wishes to obtain an absolute measurement and to extrapolate the α-particle fluxes to the top of the atmosphere, the following quantities have to be known:

1. the absorption length of α particles in air;
2. the average path length in air traveled by a primary particle before reaching the detector;
3. the contribution of α-particle fragments from heavier nuclei colliding above the apparatus;
4. the contribution by α particles originally not passing through the entire telescope but producing a fast knock-on electron capable of triggering Counter 3;
5. the general background due to showers, nuclear interactions, etc. in the pulse-height region in which the α particles fall.

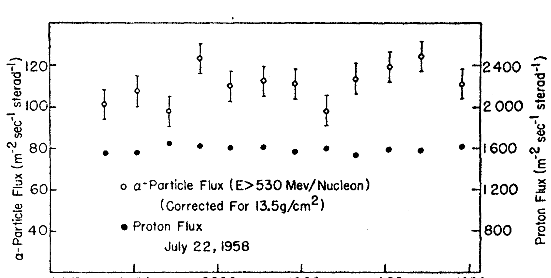

FIG. 8. The flux of α particles and protons under 13.5 g/cm^2 residual atmosphere as a function of local time during the balloon flight of July 22, 1958. (These data are not corrected for background in the α-particle region.)

[15] This equipment was built and is used in a different research program by Mr. F. Jones and Mr. K. Yates. I wish to thank them for participation on my flights and for providing me with the data.

The absorption mean free path of α particles has been determined by McDonald[3] and we used his value of (45 ± 4) g/cm^2. The average layer of air traversed by the primary particles turns out to be 2% higher than the vertical path for our geometry. The number of α-particle fragments from heavier primaries contributing to the measured α-particle flux at the altitude of the equipment was estimated using the equations given by Noon and Kaplon[16] and extending the solution of these equations to the α-particle flux. In order to obtain a numerical result we modified the heavy primary flux values of Danton, Fowler, and Kent,[17] so as to account for the changing primary intensity with the solar activity cycle.[18] We used the fragmentation probabilities of Rajopadhye and Waddington[19] and the interaction mean free paths published by Püschel.[20]

An estimate of the fraction of α particles which do not fall into the angle of acceptance of the telescope but are counted after producing a knock-on electron which triggers Counter 3 can be obtained using the results of Webber[21] with μ mesons on a very similar telescope which had guard counters installed. Webber estimates a correction of about -2%. The fact that the energy a knock-on electron has to exceed in order to trigger the bottom counter in our telescope is more than twice as high as in Webber's arrangement, leads us to a correction of less than -1%. We, therefore, did not correct for this effect.

Two factors contribute to a background in the α-particle region. First, a tail due to the pulse-height distribution of singly charged particles may extend into this region and, second, there will be a general background due to showers and nuclear interactions. The first effect can be eliminated by observation of the pulse-height distribution of sea-level μ mesons. A measurement of this kind yielded a negligible contribution in the pulse-height region occupied by α particles with energies exceeding 530 Mev/nucleon. In order to obtain an estimate of the general background underlying the α-particle region, we extrapolated the background in the two-dimensional pulse-height matrix into this region. This procedure leads us to a correction of about -5% with an accuracy of not better than 30%.

After including the above-mentioned corrections and all errors, we arrive at the absolute primary α-particle fluxes at the top of the atmosphere that are presented in the last column of Table I. Taking into account an energy loss of 30 Mev/nucleon during the traversal of the residual atmosphere and the equipment, these flux values contain all primary α particles with energies exceeding 560 Mev/nucleon.

[16] J. H. Noon and M. F. Kaplon, Phys. Rev. **97**, 769 (1955).

[17] Danton, Fowler, and Kent, Phil. Mag. **43**, 729 (1952).

[18] Freier, Ney, and Waddington, Phys. Rev. **114**, 365 (1959); Aizu, Fujimoto, Hasegawa, Koshiba, Mito, Nishimura, Yokoi, and Schein (to be published). I wish to thank these authors for providing me with their results prior to publication.

[19] V. Y. Rajopadhye and C. J. Waddington, Phil. Mag. **3**, 19 (1958).

[20] W. Püschel, Z. Naturforsch. **13a**, 801 (1958).

[21] W. R. Webber, Nuovo cimento **4**, 1285 (1956).

SUMMARY AND CONCLUSIONS

From a series of cosmic-ray α-particle and proton flux measurements carried out during the years 1957 and 1958, the absolute α-particle flux at the top of the atmosphere was obtained for five different days. On August 30, 1957 a large Forbush-type intensity decrease occurred and flux measurements could be made before, during and after this event. The following results were obtained:

1. The primary proton and α-particle intensity show the same relative change during the Forbush decrease. This demonstrates that the mechanism responsible for this intensity change is operating in the same way on both components and is a modulation mechanism. No energy dependence could be found.
2. The relative change in proton intensity at altitude is of the same amount as that observed at the Climax and the Sulphur Mountain neutron monitors. This means that there is no noticeable rigidity dependence in this Forbush decrease up to a rigidity of 3 Bv.

The measurements in 1958 took place at a period with no large cosmic-ray intensity changes. We can compare the proton and α-particle fluxes on the days of balloon flights in 1957 and 1958 and we are led to the following results:

1. The proton intensity at balloon altitude and high latitude decreased by about 15% between the days of flights from 1957 to 1958. We compare this number with the changes in intensity observed by neutron monitor stations on the days of balloon flights and find a decrease of 7% for Sulphur Mountain and 5% for Climax. This indicates a noticeable change in the low-energy portion of the primary proton spectrum between flight days in the two years which undoubtedly is connected with the solar cycle variation of the primary cosmic radiation.
2. No decrease, comparable to the change in proton intensity, could be observed in the α-particle component. The flux of α particles with energies exceeding 530 Mev/nucleon remained unchanged between the flights of 1957 and 1958. A subdivision of the α-particle flux into two energy groups (450 Mev/nucleon $\leqslant E_1 \leqslant$ 960 Mev/nucleon and $E_2 \geqslant$ 960 Mev/nucleon) leads, with less statistical accuracy, to the conclusion that an intensity decrease is present in the high-energy interval, while the low-energy flux increases from 1957 to 1958. The resulting change in spectrum is opposite to the observations made with protons.

During several flights in 1957, while solar activity was at a very high level, we observed an increase in α-particle flux within a few hours which was not correlated to a change in proton flux. In each case this increase occurred during the daylight hours. We tentatively ascribe this observation to a 24-hour variation in α-particle intensity, but further experiments are necessary to substantiate this effect.

Both the observation of an independent hourly α-particle intensity variation as well as the change in the ratio of α particle to proton flux between the balloon flights in 1957 and 1958 cannot be explained by the action of a modulation mechanism only, which operates on both primary components. One is led to suspect the possibility of occasional production of primary α particles by the sun. The experimental evidence is scarce and it cannot be justified to draw a more detailed conclusion at the present time, but further experiments should be directed towards answering this question.

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Analytic Properties of Transition Amplitudes in Perturbation Theory*

STANLEY MANDELSTAM
Department of Physics, University of California, Berkeley, California
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The analytic properties of two-particle transition amplitudes as functions of both energy and momentum transfer are examined in perturbation theory. The modified Nambu representation previously proposed by the author for expressing these properties is discussed in a little more detail. It is shown that, as long as the masses do not satisfy certain inequalities connected with the existence of anomalous thresholds, the fourth-order terms, calculated in the usual manner, satisfy the representation. The spectral functions are calculated explicitly for spinless particles. The proof can be extended to the sixth order, but is not worked out here. The modifications necessary when there exist anomalous thresholds are mentioned.

1. INTRODUCTION

IN a previous paper,[1] a representation was proposed for two-particle transition amplitudes when both the energy and the momentum transfer become complex. This representation exhibits analytic properties of the transition amplitude which are generalizations of the analytic properties expressed by the usual dispersion relations, in which one of the variables is kept fixed. The representation is similar in appearance to one proposed earlier by Nambu[2] for Green's functions; however, it differs in detail and its validity is postulated in a much more restrictive form.

Double dispersion representations of this type have not thus far been proved from the general principles of quantum field theory. The usual dispersion relations can be proved by examining the restrictions imposed by causality on the four-point Green's function, provided that the momentum transfer is sufficiently small.[3-5] It is unlikely that a corresponding proof can be carried out in our case, or indeed that the representation follows from these requirements alone. The general principles of field theory contain much more information, since the causality condition enables one to deduce analytic properties of all the Green's functions, which are related to one another by the unitarity conditions. It is therefore very possible that the representation is a consequence of the general principles of field theory, but it

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