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28. April 1969.

FINAL SCIENTIFIC REPORT.

Heavy Particles in Primary Cosmic Radiation

1 July 1966 - 30 April 1969.

University of Lund, Department of Physics

Lund, Sweden.

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Air Force Office of Scientific Research OAR,
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United States Air Force under Grant AF-EOAR 66-35.

The research program under Grant AF EOAR 66-35 has included studies of the composition and the energy spectrum of the primary cosmic radiation and studies of nucleus-nucleus interactions at medium and high energies.

The investigations have been performed with nuclear emulsions which have been exposed to the primary radiation in high altitude balloon flights or in sounding rocket flights.

The investigations of the primary radiation have mainly been concentrated on studies of the composition of the flux of heavy primaries. One of the main purpose of our research has been to investigate the composition of the radiation in different energy intervals. We have also performed an investigation of the isotopic composition of the carbon in the primary flux. We can further report improvements in the track photometers and in the track photometer techniques which we use in most of our identifications of the heavy primary particles.

The studies of the nucleus-nucleus collisions have been concentrated on such interactions in which the primary particles either have had an energy larger than 2 GeV/nucleon or have had an energy in the interval 100 - 400 MeV/nucleon. Comparisons between nucleus-nucleus interactions and proton-nucleus interactions have been performed in both energy intervals.

The research program under Grant AF EOAR 66-35 has included the following studies.

1. The composition and the energy spectrum of low-energetic cosmic ray nuclei with $Z \leq 9$.
2. The composition of low-energetic primaries with $Z \geq 9$ in the cosmic radiation.
3. The charge spectrum of relativistic primaries with $Z \geq 10$ in the cosmic radiation.
4. The charge distribution of the energetic heavy nuclei with $Z \geq 16$ in the primary cosmic radiation.
5. The relative frequency of the carbon isotopes ^{12}C and ^{13}C in the primary cosmic radiation.
6. A study of the mass resolution in investigations of the isotopic abundances of elements in the primary cosmic radiation.
7. A study of a method to separate the carbon isotopes by means of short δ-rays.
8. An energy spectrum of primary cosmic ray helium nuclei determined by means of nuclear emulsions exposed in sounding rocket flights.
9. A photometer device for the identification of multiply charged particles stopping in nuclear emulsions.
10. Charge identifications of heavy primary cosmic ray particles by means of less sensitive nuclear emulsions.
11. A study of the possibilities to use δ-ray photometry for the identification of very heavy nuclei in primary radiation.
12. Identification of fast heavy primaries from measurements of mean track width and of change of mean track width.
13. Datahandling system for track photometers.

14. A new very fast nuclear track photometer.
15. Multiply charged fragments in nucleus-nucleus collisions.
16. Cascade and evaporation processes in relativistic nucleus--nucleus and proton-nucleus interactions.
17. A study of nucleus-nucleus collisions in the hundreds of MeV region. A comparison of proton-nucleus and nucleus--nucleus collisions and an analysis on the α-particle production in nucleus-nucleus interactions.
18. A study of nucleus-nucleus collisions in the hundreds of MeV region. - A comparison of non-relativistic and relativistic nucleus-nucleus collisions and an analysis of the disintegration of the target nucleon.

The following papers have been published in the period of Grant AF EOAR 66-35.

I. L. Malmqvist,
Low energy heavy primary particles in cosmic radiation,
Arkiv Fysik 34, 33 (1966).

II. K. Kristiansson, A. Ladd and L. Malmqvist,
A photometric device for the identification of multiply charged particles stopping in nuclear emulsions,
Arkiv Fysik 34, 139 (1966).

III. O. Mathiesen, C.E. Long, P.S. Freier and C.J. Waddington,
The charge distribution of the energetic very heavy nuclei in the primary cosmic radiation,
Canadian Journal of Physics 46, S538 (1968).

IV. P.-I. Olsson and K. Kristiansson,
An energy spectrum of primary cosmic ray helium nuclei determined by means of nuclear emulsions exposed in sounding rocket flights,
Arkiv Fysik 38, 383 (1968).

V. I. Otterlund and B. Andersson,
Multiply-charged fragments in relativistic nucleus--nucleus collisions,
Arkiv Fysik 35, 133 (1967).

VI. I. Otterlund,
Cascade and evaporation processes in relativistic nucleus-nucleus and proton-nucleus interactions,
Arkiv Fysik 38, 467 (1968).

VII. I. Otterlund and R. Resman,
A study of nucleus-nucleus collisions in the hundreds of MeV region,
Arkiv Fysik 39, 265 (1969).

The following preliminary reports were given at The Conference of the Swedish National Committee for Physics, Kiruna, 1967:

I. G. Jönsson,
A study of a method to separate the carbon isotopes by means of short δ-rays.

II. G. Jönsson, K. Kristiansson and L. Malmqvist,
Relative abundances of the carbon isotopes ^{12}C and ^{13}C in the primary cosmic radiation.

III. P.-I. Olsson,
An energy spectrum of primary cosmic ray α-particles.

IV. [illegible]. Otterlund,
Cascade and evaporation processes in relativistic nucleus--nucleus and proton-nucleus collisions.

Dissertation:

I. Otterlund,
Studies of High-energy nucleus-nucleus interactions
(Lund, 1969).

Papers to be published in the near future:

G. Jönsson, K. Kristiansson and L. Malmqvist,
The relative abundance of the carbon isotopes ^{12}C and ^{13}C in primary cosmic radiation.

U. Dellien and K. Söderström,
The composition of low-energetic primaries with $Z \geq 9$ in the primary cosmic radiation.

On the following pages summaries are given of the investigations which have been in progress under the period of Grant AF EOAR 66-35.

1. <u>The composition and the energy spectrum of low-energetic cosmic ray nuclei with $Z \leq 9$</u>.

Published in Arkiv Fysik 34, 33 (1967).

Charge and energy spectra of the low energy primary particles in cosmic radiation have been studied in a nuclear emulsion stack which was exposed at 2.7 g/cm^2 of residual atmosphere, at Fort Churchill, on July 28, 1963. The investigation has been concentrated to the charge interval $3 \leq Z \leq 9$. In this region photometer identification measurements have been made on 84 tracks of stopping heavy primary particles giving a complete resolution between consecutive charge groups.

In the energy interval 150 - 250 MeV/nucleon the L/M-ratio was found to be 0.38 ± 0.13, which is in agreement with other investigations. Placed together these results indicate that the L/M-ratio most probably passes through a maximum at an energy of a few hundred MeV/nucleon. The differential flux values observed are also in agreement with those found in other investigations made in the summer of 1963.

2. <u>The composition of low-energetic primaries with $Z \geq 9$ in the cosmic radiation</u>.

This investigation is a continuation of the study described in the previous paragraph, and is also carried out in the emulsion stack exposed at Fort Churchill in the summer of 1963. In all, 81 tracks of stopping primary particles heavier than oxygen have been identified.

A photometric technique has been utilized for the identification. Each particle has been measured with a track photo-

meter from the end point at least 10 mm backwards along the track. As a parameter for the charge identification the total track area between 0.5 and 10 mm of residual range has been chosen. The standard deviation in the charge determination is 0.2 units of charge at $Z = 12$ and 0.4 units of charge at $Z = 26$. This means that the resolution between consecutive charge groups is sufficient to make it possible to study the elemental abundances in the low energetic cosmic radiation in the charge interval $9 \leq Z \leq 26$.

The resulting charge spectrum shows many features in common with the spectra of relativistic particles previously published. The elements of even nuclear charge are more abundant than elements of odd nuclear charge. Iron is the most frequent element in the interval $Z \geq 20$, and particles heavier than iron are rare. None have been found in this investigation. If one assumes that all the particles in the region $20 \leq Z \leq 25$ are the products of spallation reactions between primary iron nuclei and the interstellar hydrogen, the maximum amount of matter passed by the iron nuclei has been calculated to 1.5 g/cm^2. This figure is not significantly different from the result of the same calculation made on relativistic particles, but it is certainly different from the figure ~ 4 g/cm^2 obtained from the abundances of low-energetic Li-, Be and B-nuclei.

The relative abundances of the elements in the charge interval $8 \leq Z \leq 14$ has been calculated. The comparison has been limited to the energy interval $250 \leq E \leq 400$ Mev/nucleon.

element	O	F	Ne	Na	Mg	Al	Si	P-K
relative abundance	7	<0.1	0.5	0.4	1.8	~0	1	0.3

The study is finished and the results are to be published in Arkiv Fysik in the near future.

3. <u>The charge spectrum of relativistic primaries with $Z \geq 10$ in the cosmic radiation</u>.

Earlier work on the charge spectrum of relativistic heavy primaries has shown that it is possible to discriminate different charges at least up to $Z \simeq 30$ by using the conventional photometric technique. To improve the statistics in the interval $Z > 10$, we are going th measure the charge of primary particles found in a stack of 186 Ilford G5 emulsions with dimensions 20x10x0.06 cm^3 each, flown in July 1966 from Palestine, Texas, in cooperation with University of Minnesota. So far 1/6 of the stack has been scanned for particles with $Z \geq 10$. In 1/10 of the scanned area 100 tracks have been found. These have been traced through the stack.

A photometer has been set up and connected to the data aquisition system of type Solartron OP 3417. The interface between this and the photometer has been modified to include in the data an automatical reading of the depth coordinate of the track.

4. <u>The charge distribution of the energetic very heavy nuclei in the primary cosmic radiation</u>.

Published in Canadian Journal of Physics 46, S538 (1968).

During the period Sept. 1, 1965 to Dec. 31, 1966 one member of our group, docent Olev Mathiesen, has been at the University of Minnesota, Minneapolis, Minn., as an ESRO Fellow and set up a track photometer of the same type as currently in use at our laboratory. The new feature of the instrument is that the output is fully digitized, and thus suitable for subsequent analysis on a digital computer.

A group at the University of Minnesota including docent

Mathiesen has used the instrument for a study of the detailed charge composition of primary cosmic ray nuclei having $Z \geq 20$ which were detected in a stack of nuclear emulsions flown in 1965 from Hayderabad, India, under approximately 4 g/cm^2 of residual atmosphere.

5. The relative frequency of the carbon isotopes ^{12}C and ^{13}C in the primary cosmic radiation.

The investigation of the isotopic composition of the carbon nuclei in the primary cosmic radiation has been almost finished. The choice of the carbon nuclei for a study of the isotopic composition is partly motivated by the fact that the quotient $^{12}C/^{13}C$ is a sensitive probe on which processes these nuclei have passed through before they were accelerated, and partly because a number of suitable carbon tracks were available in the emulsion stack exposed at Fort Churchill in 1963.

The principle of the mass determination is founded on the fact that all particles with the same nuclear charge in a nuclear emulsion give rise to tracks of the same width provided that the residual range of the tracks has been normalized by a factor which is inversely proportional to the mass of the particle. This normalization factor can be found experimentally and is consequently a measure of the mass of the particle.

A comparison between unnormalized tracks of ^{12}C- and ^{13}C--nuclei shows that there is a difference in width which falls in two residual range regions. In the interval $R \lesssim 1$ mm the ^{13}C-track will have an area which is about 2 % smaller than the area of a ^{12}C-track. In the interval $1 \leq R \leq 14$ mm just the reverse situation obtains. Both intervals have been utilized for an analysis of the isotopic composition of carbon.

The analysis of the mass based on width measurements in the residual range interval $0 \leq R \leq 1$ mm.

For this part of the study there are 37 stopping tracks of carbon nuclei available in the emulsion stack. The measurements of the width in this range interval have been carried out with a photometer constructed for measurements with high precision on short tracks. The normalization factor previously mentioned has been calculated for each track giving a relative mass value of each track.

The standard deviation of the experimentally determined mass values amounts to 0.72 ± 0.09 units of mass. This result is in good agreement with the suggestion that one isotop dominates among the cosmic ray carbon nuclei. This part of the investigation has been finished.

The analysis of the mass based on width measurements in the residual range interval $1 < R < 14$ mm.

For this part of the study there are about 42 tracks of carbon nuclei available in the emulsion stack. The analysis is based on photometer measurements of the area of the track. The measurements have been performed with a track photometer constructed for measurements of long track sections. A normalization factor will be calculated in each track in the same way as mentioned above. Any definite results can not yet be mentioned but a preliminary analysis indicates a resolution somewhat better than the resolution in the interval $0 < R < 1$ mm.

6. A study of the mass resolution in investigations of the isotopic abundances of elements in the primary cosmic radiation.

The study of the elemental abundances in the primary cos-

mic radiation has given valuable information about the origin, acceleration and transport of the cosmic ray particles. An improvement of the precision in the experimental technique, such that the isotopic composition of the charge groups could be studied should increase the possibilities considerably to draw conclusions about the history of the radiation.

We have started an investigation of the possibilities to measure the mass of a stopping primary particle in the charge interval $4 \leq Z \leq 14$. The analysis of the mass of the particle will be based on photometric measurements in the tracks. The relation between the mean track width and the residual range in the interval $0 \leq R \leq 1$ mm has been determined for some representative elemental groups in the interval $4 \leq Z \leq 14$. An extension to the range interval $1 \leq R \leq 14$ mm is also being planned. From the shape of these relations and from the statistical errors in the photometric measurements a theoretical resolution between different isotopes of the same element can be calculated.

7. A study of a method to separate the carbon isotopes by means of short δ-rays.

Alvial (1) has found it possible to identify and separate the carbon isotopes ^{12}C and ^{13}C in nuclear emulsions by means of the position of a maximum in track width at 36 and 42 μ residual range respectively. This maximum is ascribed to the appearance of one grain δ-rays.

In this investigation measurements on the last 100 μ of 14 carbon tracks parallel to the surface of the emulsions has been carried out by a nuclear track photometer. No maximum in the track width similar to that reported by Alvial was found. Also, it was found impossible to determine the mass of a carbon

nucleus from such photometric track measurements of the last 100 μ of the track due to the statistical fluctuation in the track width.

8. An energy spectrum of primary cosmic ray helium nuclei determined by means of nuclear emulsions exposed in sounding rocket flights.

The energy spectrum of primary cosmic ray helium nuclei has been studied in two nuclear emulsion stacks, which were exposed in August 1962 in two sounding rocket flights from Kronogård in northern Sweden. The energies of 134 helium nuclei are determined by Coulomb multiple scattering measurements. Their differential energy spectrum has a maximum at about 250 MeV/nucleon. The energy spectrum and the total flux of helium nuclei are found to be in agreement with the results of two investigations made by other groups in 1962.

The experiment shows that the energy spectrum of galactic helium nuclei can be studied by means of nuclear emulsions exposed in sounding rocket flights with an exposure time of a few minutes.

9. A photometric device for the identification of multiply charged particles in nuclear emulsions.

Published in Arkiv Fysik 34, 139 (1967).

A track photometer suitable for the identification of multiply charged particles stopping in nuclear emulsions has been studied. The apparatus consists of a microscope whose eye-piece has been replaced by a slit system and a photomultiplier connected to a pen recorder. The image of the track moves across the narrow slit, placed in front of the photomultiplier, and absorption profiles are obtained and registered by the recorder.

The particle charge is obtained from the mean widths of the profiles. The standard error of the charge determinations amounts to about 0.2 units of charge in the interval $3 < Z < 10$, when a residual range of 800 μ is measured. Emulsion distorsion effects seem to increase the errors in the charge determination of particles heavier than oxygen.

10. Charge identification of heavy primary cosmic ray particles by means of less sensitive nuclear emulsions.

When electron sensitive nuclear emulsions are exposed during long space experiments one gets a large background of tracks of singly charged particles. One way to reduce this undesired background is to use less sensitive emulsions, which do not register such particles. A study of the possibilities to use less sensitive nuclear emulsions in the investigation of the charge spectrum of heavy primaries has therefore started.

In order to find out if the non-electron sensitive Ilford K2 emulsion is useful in this respect an emulsion stack was exposed which consisted of 65 pellicles of Ilford K2 and 65 pellicles of Ilford G5 emulsion. The stack was exposed in a balloon flight at Fort Churchill, Canada, in July 1967. Photometric mean track width measurements have been performed on tracks of a number of relativistic cosmic ray particles, which have passed both the G5 and the K2 emulsions. For this purpose a new track photometer has been built. This photometer is connected to a digital datahandling system of type Solartron OP 3417. The ratio between the mean track widths for the same track in G5 and K2 emulsions was very nearly constant and quite independent of the charge of the particle within a large charge interval. Furthermore the statistical deviation of the mean track width measurements in K2 is less than in G5 emulsions.

This preliminary results indicates that Ilford K2 emulsions can be useful in the study of the relativistic spectrum.

An investigation of the charge resolution of low energy heavy primary cosmic ray particles in K2 emulsions is also going on. Photometric measurements have been made on about 220 tracks from heavy particles stopping in the emulsion. The analysis and the computer processing of the photometer data is in progress.

11. <u>A study of the possibilities to use δ-ray photometry for the identification of very heavy nuclei in primary cosmic radiation</u>.

Relativistic heavy nuclei in the primary cosmic radiation can be identified in nuclear emulsions by a determination of the δ-ray density in the tracks. If the δ-ray density is low it can be determined by a direct counting of the number of such δ-rays which fulfil certain counting conditions. If on the other hand the δ-ray density is high the direct counting is difficult and systematic errors may arise. One way to get around this difficulty may be to register the δ-ray density by measuring their light absorption by means of a microphotometer. The main purpose of the investigation is to study the possibilities to identify nuclei in the radiation which are much heavier than iron and much less abundant by means of such microphotometric measurements. A nuclear track photometer which will be used for the investigation of the light absorption profiles of these tracks of very heavy particles is now under construction.

12. Identification of fast heavy primaries from measurements of mean track width and rate of change of mean track width.

The composition of the cosmic radiation has been studied in several investigations at high ahd low energies. In many of these studies the photometric method for charge identification has been used and very accurate results have been obtained. However, these accurate results are limited to relativistic nuclei and to nuclei which stop in the emulsion. In the intermediate energy interval no photometric method for charge-determination has been reported. The purpose of this investigation is to find out to what degree it is possible to identify also nuclei in this energy interval $100 \leq E \leq 2000$ MeV/nucleon. If such a method is available it will not only be useful in studies of the charge spectrum of the cosmic radiation but also in the analysis of nucleus-nucleus interactions.

A new track photometer is under construction. The analysis will start with photometric measurements on tracks of nuclei which interact with emulsion nuclei. From these interactions which all have been studied earlier, it is possible to obtain some information about the energy and charge of the incident nucleus.

13. Datahandling system for track photometers.

The datahandling system, which was being built at the time of our Progress Report No 1, has been completed. It has been used in some of the experiments which are described in the present report. The system was designed to accomodate three photometers on a time-sharing basis, utilizing a Solartron System OP 3417 with external logical circuits. The output is on punched paper tape. At each measuring station a printer allows the experimenter to follow the measurements continously.

14. A new very fast nuclear track photometer.

One of the most time consuming operations in the studies of charge and mass spectra of cosmic ray particles by means of the photometric technique, is the determination of the back ground level and the elimination of errors due to crossing tracks and other disturbances in the emulsion. In order both to speed up the measurements and to correct for or eliminate disturbances automatically a new photometer is being built. It utilizes a TV-camera mounted on the microscope. By means of appropriate electronic circuits the output from the Vidicon allows a direct measurement of the projected area of the track, with automatic correction for variations of the transparency of the emulsion and certain other disturbing effects. The new instrument will eliminate any remaining subjective influences on the measurements by the observer.

15. Multiply charged fragments in relativistic nucleus-nucleus collisions.

Published in Arkiv Fysik 35, 133 (1967).

Multiply charged fragments emitted from the projectile nuclei in eighty-eight nucleus-nucleus collisions produced in nuclear emulsions by heavy cosmic ray primaries have been studied. The charge of the projectile nuclei falls in the interval $3 \leq Z \leq 26$ and the threshold kinetic energy is about 1.7 GeV/nucleon. The emulsions used were exposed to the primary cosmic radiation in a balloon flight at St. Angelo, Texas, in January 1955. This analysis is an extension of the study of relativistic nucleus-nucleus collisions measured in an earlier investigation (1).

The angles between the direction of the projectile nucleus and the fragments have been measured. In order to get accurate

results in these measurements the following procedure was adapted. Careful measurements of coordinates of points in the tracks of the fragment and the primary nuclei were performed. Using the coordinates we then calculate curves which describe the tracks with good approximation. The angles between the calculated curves of the primary particles and of the secondary particles were determined at the point of interaction. This very complicated way to determine angles between tracks was chosen in order to eliminate emulsion distorsion as much as possible.

The angular distribution of α-particles emitted from the projectile nuclei has been studied and compared with the distribution to be expected if the α-particles are produced in an evaporation process from the excited fragments of the projectile nuclei. From this analysis it has been found that the distribution of most of the α-particles is consistent with the evaporation theory. A small percentage of them is split, however, from the incident nuclei with such large angles in the laboratory system that it is unreasonable to believe that they have been produced in an evaporation process.

Furthermore it has been found that the mean angle of the evaporation α-particles in the shower does not depend very much on the number of nucleons involved in the interaction.

From the azimuthal distribution of the α-particles and from the angular distribution of the heavy fragments it has been concluded that the fragments have a recoil component in the transverse direction to the incident nucleus.

16. <u>Cascade and evaporation processes in relativistic nucleus-nucleus and proton-nucleus interactions</u>.

Published in Arkiv Fysik 38, 667 (1968).

In this paper further investigations of the relativistic nucleus-nucleus interactions measured in ref. 1 have been performed. The charges of the primaries fall in the interval $3 \leq Z \leq 26$ and the threshold kinetic energy was about 1.7 GeV/nucleon at the top of the atmosphere. The energy spectrum of the cosmic ray particles is so steep that more than 80 % of the projectile nuclei will have their kinetic energy in the interval $2 \leq E \leq 15$ GeV/nucleon. It is shown that the heavy prong distribution in proton-nucleus collisions at an arbitrary energy in this interval is representative for this type of interactions in the whole energy interval and therefore suitable for comparison with the nucleus-nucleus collisions.

In the investigation the cascade and evaporation processes have been studied and compared to the corresponding processes in proton-nucleus collisions at 6.2 GeV and 22.5 GeV obtained by Winzeler (3). The following results can be mentioned.

In collisions with heavy target nuclei, it has been found that on the average more particles are emitted from the target nucleus in a nucleus-nucleus collisions than in a proton-nucleus collision.

The comparison between the proton-nucleus and the nucleus-nucleus collisions shows that a cascade nucleon transfers on an average more excitation energy to the target nucleus in a proton-nucleus collision than in a nucleus-nucleus collision. Futhermore it is shown that approximately the same number of black track-producing particles are emitted in nucleus-nucleus and proton-nucleus collisions despite the large difference in the cascade particles produced in the two different kinds of

interaction. The number of black track-producing particles seems also to be independent of the number of pions produced in the interaction. It is suggested that this may partly be explained by the production of excited nucleons in high-energy interactions. All the results show that the second stage of the interaction process is essentially independent of the nature of the incident particle.

17. <u>A study of nucleus-nucleus collisions in the hundreds of MeV region. - A comparison of proton-nucleus and nucleus-nucleus collisions and an analysis of the α-particle production in nucleus-nucleus interactions</u>.

Published in Arkiv Fysik 39, 265 (1969).

Eighty-one nucleus-nucleus collisions produced in nuclear emulsions by heavy cosmic ray primaries have been studied for kinetic energies of primaries in the interval $100 \lesssim E \lesssim 500$ MeV/nucleon. The emulsion stack used in this investigation was exposed to the primary cosmic radiation in a balloon flight at Fort Churchill, Canada, in July 1963.

The angular distribution and the energy of all particles leaving the point of interaction have been measured and the particles have in most cases been identified.

From the analysis of the experimental material the following results can be mentioned.

It is shown that the nucleon-nucleon cascade developed in a nucleus-nucleus interaction in the hundreds of MeV region is rather well described simply as a superposition of cascades similar to those developed in nucleon-nucleus interactions.

The angular distribution of the black track producing particles is anisotropic with a large number of particles in the forward direction. This must be the result of a large admixture

of cascade particles. A large velocity component in the forward direction for the excited fragments of the target nuclei can also contribute to this anisotropy.

The angular distribution of the α-particles emitted from the target nuclei is anisotropic and the energy distribution has a long tail in the high energy region.

The angular and energy distribution of the alpha-particles emitted from the projectile nuclei show that a small percentage of them cannot possibly be explained by an evaporation process.

It is concluded that in nucleus-nucleus collisions alpha--particles are emitted partly from excited fragments and partly in direct interactions between nucleons and clusters of nucleons.

It was found that there is a large spread in angles and energies of the alpha-particles produced in nucleus-nucleus interactions. To investigate if the knock-on process can account for this large spread we have calculated the maximum energy of an alpha-particle knocked-out with a given angle relative to the incident particle. It is found that the large spread in angles and energies can be understood if we choose reasonable values of the momenta of nucleons and clusters of nucleons inside the interacting nuclei.

From the analysis it is found that nucleus-nucleus collisions are suitable for studies of the mechanisms responsible for alpha-particle production in high-energy interactions. Depending on the intranuclear momenta of the nucleons and clusters of nucleons a large number of knock-on alpha-particles are emitted with high energy and large angle and then can be separated therefore from the alpha particles produced in other processes.

18. <u>A study of nucleus-nucleus collisions in the hundreds of MeV region. - A comparison of non-relativistic and relativistic nucleus-nucleus collisions and an analysis of the disintegration of the target nucleus</u>.

This work is a further analysis of the nucleus-nucleus collisions in the energy region $100 \leq E \leq 500$ MeV/nucleon. In this investigation, particles emitted from the target nuclei have been studied. The results obtained have been compared to corresponding results in relativistic nucleus-nucleus collisions in an earlier investigation.

Energy-, momentum- and angular distribution of protons and α-particles emitted from the target nuclei have been studied and compared with distributions expected from the evaporation theory. It has been found that many of the protons and α-particles emitted with energies < 30 MeV/nucleon can be explained by this theory. However, there are too many particles with energies < 5 MeV/nucleon in the experimental distributions.

The existence of this excess is difficult to explain by an evaporation model. Furthermore there are also particles which originate in the cascade process. This fact complicates the analysis of the distributions of particles with energies less than 30 MeV/nucleon.

In the interactions studied fragments with $Z \geq 3$ have also been identified. Energies and emission angles for some of these fragments indicate that they have been produced in a direct process.

References.

1. Alvial, G., Proc. 9th Int. Conf. Cosmic Rays, London 1965.

2. Andersson, B., Otterlund, I. and Kristiansson, K., Arkiv Fysik 31, 527 (1966).

3. Winzeler, H., Nuclear Physics 69, 661 (1965).

Inventions.

No inventions were conceived or made during the period covered by the report.

Personnel.

The list below gives the names of the scientists and technicians which have taken part in the research work under Grant AF EOAR 66-35.

Fil.mag. R. Andersson,
Fil.mag. U. Dellien,
Professor S. von Friesen,
Fil.kand. M. Jensen,
Fil.mag. G. Jönsson,
Docent K. Kristiansson,
Fil.mag. L. Larsson,
Res.engineer B. Lindkvist,
Docent O. Mathiesen,
Fil.lic. P.-I. Olsson,
Fil.lic. I. Otterlund,
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13. ABSTRACT

The research program under Grant AF EOAR 66-35 has included studies of the composition and the energy spectrum of the primary cosmic radiation and studies of nucleus-nucleus interactions at medium and high energies.

The investigations have been performed with nuclear emulsions which have been exposed to the primary radiation in high altitude balloon flights or in sounding rocket flights.

The investigations of the primary radiation have mainly been concentrated on studies of the composition of the flux of heavy primaries. One of the main purposes of our research has been to investigate the composition of the radiation in different energy intervals. We have also performed an investigation of the isotopic composition of the carbon in the primary flux. We can further report improvements in the track photometers and in the track photometer techniques which we use in most of our identifications of heavy primary particles.

The studies of the nucleus-nucleus collisions have been concentrated on such interactions in which the primary particles either have had an energy larger than 2 GeV/nucleon or have had an energy in the interval 100 - 400 MeV/nucleon. Comparisons between nucleus--nucleus interactions have been performed in both energy intervals.

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