# Physics

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## Abstract

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# Physics

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# DETERMINATION OF THE FLUX OF PRIMARY COSMIC PARTICLES AT LATITUDE 31°N

*(Presented by Academician D. V. Skobeltsyn, 15 I 1957)*

In determining the cross section for the inelastic interaction of cosmic-ray particles with carbon and hydrogen nuclei, we measured the intensity of the hard component in the stratosphere. These measurements made it possible to determine the flux of primary particles at the boundary of the atmosphere. The article contains a description of the instruments for measuring the inelastic-interaction cross section and the results of measurements of the intensity of the hard component (the results of the cross-section measurements will be published in subsequent articles).

The arrangement of the counters and filters in the instruments is shown in Fig. 1b. The telescope, which selected a vertical beam of cosmic particles, consisted of three rows $A$, $B$, $C$ of self-quenching counters connected in a triple-coincidence circuit, and of a row $D$ of hodoscope counters covering almost the entire solid angle of the instrument. To select the penetrating component of cosmic rays, a filter of 8 cm Pb and 0.9 cm Al was placed between rows $B$ and $C$ of the telescope counters. A filter $\Sigma$ made of the material under investigation (the contours of the graphite filter are indicated by a solid line; the contours of the paraffin filter by a dashed line), for example graphite, was mounted on a carriage and automatically, every 3 min, was moved into the space between rows $A$ and $B$ of the telescope counters or withdrawn from it, so that measurements with graphite and background measurements (as well as measurements with paraffin and graphite) alternated with one another all the time. The telescope and filters were surrounded by a large number of hodoscope counters, which served to record secondary particles arising in inelastic interactions of protons with carbon, hydrogen, and lead nuclei. In addition, all three rows $A$, $B$, $C$ of telescope counters were also connected to the hodoscope*.

The pulse controlling the operation of the instrument was the triple coincidence of discharges in the rows of counters $A$, $B$, and $C$. However, in processing the results we always took into account only those cases in which the triple coincidence was accompanied by the operation of one of the counters of row

Fig. 1

Figure 1: Fig. 1

$D$ (quadruple coincidences). For recording showers we used a circuit of a tube hodoscope with MTKh-90 thyratrons connected into the anode circuits of the tubes and serving as indicators of the operation of the given hodoscope number. All results of the instrument's operation were transmitted to the ground by radio and recorded on moving motion-picture film by means of a photoregistrator. During transmission of the hodoscope data, the Rossi tubes were blocked by a special circuit in order to avoid the superposition of pulses belonging to different control signals. The resolving capa- the telescope was $3 \cdot 10^{-6}$ sec, that of the hodoscope numbers—different for different groups of counters—was from $1 \cdot 10^{-5}$ to $2 \cdot 10^{-5}$ sec.

In 1954-1955 we raised 7 instruments into the stratosphere: two with a graphite filter ($16\ \mathrm{g} \cdot \mathrm{cm}^{-2}$) and a filter of 8 cm Pb + 0.9 cm Al; four with filters of paraffin ($18.8\ \mathrm{g} \cdot \mathrm{cm}^{-2}$) and graphite ($16.0\ \mathrm{g} \cdot \mathrm{cm}^{-2}$) and a filter of 8 cm Pb + 0.9 cm Al in the telescope; one with filters of paraffin ($18.8\ \mathrm{g} \cdot \mathrm{cm}^{-2}$) and graphite ($16.0\ \mathrm{g} \cdot \mathrm{cm}^{-2}$) without a lead filter in the telescope*.

**Fig. 1.** *a*—Dependence of the intensity of cosmic rays on altitude at geomagnetic latitude 31°N.
1—5—hard component, 6, 7—total intensity;
*b*—layout of counters and filters

To determine the flux of primary particles, it was sufficient to determine the variation with altitude of the total number of instrument triggers (after subtracting only nonlocal showers) and to extrapolate the resulting dependence to the boundary of the atmosphere. Nevertheless, since the study of the altitude variation of electron-nuclear showers from lead under conditions of good geometry was of independent interest, we processed the obtained material in the following manner:

1. **Single particle**—triggering of one counter in each of the four rows $D$, $A$, $B$, and $C$ of the telescope without shower triggering of the hodoscope counters $K$, $K_1$, $L$, $L_1$, $M$, $M_1$, $N$, $N_1$, $B$, $C$, $E$.

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* Counter dimensions: $A$, $B$, $C$: diameter 22 mm, geometrical length 200 mm, 5 counters in each row; $D$, $K$, $L$, $M$, $N$: diameter 33 mm, length 300 mm; $G$, $H$: diameter 33 mm, length 550 mm; $K_1$, $L_1$, $M_1$, $N_1$, $E$: diameter 22 mm, length 300 mm. Thickness of the glass walls of the counters 1.0-1.5 mm.

* We determined the geometrical factor of the instruments by comparing the intensity measured by the instrument at the point of launch (geomagnetic latitude 31°N, atmospheric depth 900 g/cm$^2$) with the absolute

intensity of the cosmic-ray flux at the same point, which we determined by calculation. In the calculation we used: 1) the absolute intensity of the hard component at sea level at latitude 50°N with filtration by 15 cm Pb ($0.500 \pm 0.006$ particles $\cdot$ cm$^{-2}$ min$^{-1}$ sterad$^{-1}$) (1), recalculated to 8 cm Pb (0.534 particles $\cdot$ cm$^{-2}$ min$^{-1}$ sterad$^{-1}$); 2) the latitudinal effect between 51°N and 31°N—0.95 (2); 3) the altitude variation between 1000 g $\cdot$ cm$^{-2}$ and 900 g $\cdot$ cm$^{-2}$—$1.20 \pm 0.01$ (according to data of N. L. Grigorov). From these data it follows that the absolute intensity at the point of launch is $0.534 \cdot 1.2 \cdot 0.95 = 0.609$ particles $\cdot$ cm$^{-2}$ min$^{-1}$ sterad$^{-1}$. The geometrical factor for different instruments differed by no more than ±5% from the mean value 16.5.

2. **Shower formed outside the filters** (nonlocal shower). In this category of showers we included, for example, cases in which more than one counter in row $A$ or $D$ was triggered. In addition, nonlocal showers were also registered in considerable numbers by the counters directly surrounding the graphite (paraffin) filter (counters $K$, $K_1$, $B$, $L$, $L_1$). These showers, whose number practically did not change when $\Sigma$ was placed in the telescope, were excluded in the difference effect graphite—background and paraffin—graphite.

3. **Shower in the upper part of the apparatus**—triggering of one counter in rows $D$ and $A$ by a particle producing a shower, and, in addition, triggering of not fewer than two counters from among those directly surrounding the graphite (paraffin) filter (counters $K$, $K_1$, $B$, $L$, $L_1$), independently of the triggering of the counters located near the lead. Cases of interactions in graphite (paraffin) fell into the category of showers in the upper part of the apparatus.

4. **Shower in the lower part of the apparatus** (shower from lead)—triggering of one counter in rows $D$, $A$, $B$, and $C$ and triggering of counters $M$, $M_1$, $N$, $N_1$ in the shower, or triggering of one counter in rows $D$, $A$, $B$ together with the operation of two or more counters in one of the rows $C$ or $E$. Thus, in the lower part of the apparatus we registered only those showers from lead which did not contain particles going upward. Examination of the hodoscopic patterns of these showers showed that in 96% of the cases a straight line corresponding to the path of the particle producing the shower in lead could be drawn through the counters that had been triggered within the solid angle of the apparatus. This means that the admixture of nonlocal showers in the showers from lead does not exceed 4%. To determine the total flux of particles at the boundary of the atmosphere, we used measurements with the penetrating component of cosmic rays without the graphite (paraffin) filter. A correction for $\delta$-showers and random coincidences was introduced into the measurement results. The correction for $\delta$-showers was introduced from ground-based measurement data*.

In Fig. 1a, in absolute units, the altitude dependence is given for particles that did not produce nuclear interactions in the Pb + Al filter (single particles, curve 1), and the altitude dependence of nuclear interactions registered in the lower part of the apparatus in the Pb + Al filter (curve 2).

Analysis of showers in the upper part of the apparatus in measurements with lead and without lead in the telescope showed that showers from lead with particles entering counters $K$, $K_1$, $B$, $L$, $L_1$ constitute about 30% of the number of showers registered below. Taking into account the possibility of a small miscount in our apparatus, as well as the data available in the literature on the angular distribution of shower particles in showers observed in photographic plates ($^3$), we took the magnitude of the correction for the "backward current" of showers from lead to be equal to 15% of the number of showers registered below. Curve 3 gives the number of nuclear interactions in the Pb + Al filter, corrected for showers from lead with particles going upward.

Curve 4 is the sum of curves 1 and 3, i.e., it represents the total flux of particles of the hard component (those that reacted and did not react with the material of the Pb + Al filter) at various altitudes. Extra-

* In 1949–1950 K. I. Alekseeva and S. N. Vernov carried out special experiments to observe the formation of $\delta$-electrons by the full flux of cosmic-ray particles in a graphite filter (filter area $20 \times 20$ cm$^2$, thickness 1.0 g $\cdot$ cm$^{-2}$) at various altitudes. It was found that the percentage of $\delta$-showers (mainly showers with a number of triggered counters not greater than 3) relative to the number of registered single particles at all altitudes from sea level to 20 km practically does not change. A small increase of the percentage for altitudes above 20 km was mainly caused by an admixture of electron-nuclear showers arising in the filter under study at these altitudes.

In our apparatus, $\delta$-showers registered by the counters surrounding the lead ($M$, $M_1$, $N$, $N_1$, $C$, $E$) amounted to $(6.85 \pm 0.12)$% of the number of registered single particles. The number of $\delta$-showers in the upper part of the apparatus in the absence of the filter $\Sigma$ was $(3.00 \pm 0.15)$%. Particles accompanied by $\delta$-showers were assigned by us to the category of single particles that did not produce a nuclear interaction in the filters.

extrapolation of this curve to the boundary of the atmosphere gives a value for the flux of primary particles at the boundary of the atmosphere equal to 2.0 particles $\cdot$ cm$^{-2}$ $\cdot$ min$^{-1}$ $\cdot$ sterad$^{-1}$. Foreign authors ($^4$) give, for the flux of primary particles at the boundary of the atmosphere at geomagnetic latitude 31° N, a value of 2.7—2.8 particles $\cdot$ cm$^{-2}$ $\cdot$ min$^{-1}$ $\cdot$ sterad$^{-1}$, approximately 30% higher than the value found by us (2.0 particles $\cdot$ cm$^{-2}$ $\cdot$ min$^{-1}$ $\cdot$ sterad$^{-1}$). It is possible that the larger value of the flux was obtained by them as a result of incomplete exclusion of nonlocal showers (according to our data, at high altitudes nonlocal showers constitute about 30% of the total number of instrument actuations).

**Fig. 2.** Altitude dependence of electron-nuclear showers from lead. Geomagnetic latitude 31° N: 1 —electron-nuclear showers from 8 cm Pb + 0.9 cm Al (1955, authors of the paper); 2 —8 cm Pb (1954, authors of the paper); 3 —

Figure 2

Figure 2: Figure 2

10 cm Pb (1951, S. N. Vernov and A. N. Charakhchyan); 4 –8 cm Pb (1951, S. N. Vernov and A. M. Kulikov)

In Fig. 1a there is also shown curve 5 for the altitude dependence of single particles, obtained by S. N. Vernov and A. N. Charakhchyan (5) in 1951 with a lead filter of thickness 10 cm at latitude 31° N*. Curves 6 and 7 in Fig. 1a give, respectively, the altitude dependence of single particles with a range $> 20$ g/cm$^2$ of light material (a graphite (paraffin) filter of thickness 17.4 g/cm$^2$ and counter walls $\sim 2.6$ g/cm$^2$) and the altitude dependence of the total intensity of cosmic radiation (single particles with range $> 20$ g/cm$^2$ of graphite plus electron-nuclear and electron-photon showers in 20 g/cm$^2$ of graphite), according to data from the instrument without a lead absorber.

The results of a comparison of data relating to the altitude dependence of electron-nuclear showers, obtained by us and by other authors (5) at geomagnetic latitude 31° N, are presented in Fig. 2. In this figure the abscissa axis gives the atmospheric depth $x$ in g/cm$^2$; the ordinate axis gives the natural logarithm of the number of interactions in lead. All the data presented are normalized to our 1955 data. We see that, within the statistical accuracy indicated in the graph (the statistical error is shown everywhere), the altitude dependence of electron-nuclear showers measured with a large "counting correction" (5) and without a "counting correction" (our data) coincides. From these data the absorption range of the charged particles of the shower-producing component in the stratosphere at latitude 31° N is found to be 150–170 g/cm$^2$.

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* The discrepancy between curves 5 and 1 can partly be explained by the fact that in the experiments of S. N. Vernov and A. N. Charakhchyan the absolute value for the vertical flux of the penetrating component at sea level at latitude 51° N with filtration by 10 cm Pb was taken to be 0.46 particles $\cdot$ cm$^{-2}$ min$^{-1}$ $\cdot$ sterad$^{-1}$.

*Note: Figure translations are in progress. See original paper for figures.*