NEW RESULTS OF COSMIC-RAY RESEARCH

By V. F. Hess

Continuous registrations of the cosmic-ray ionization by Steinke's standard apparatus at elevations above sea-level of 2300 and 600 meters (Hafelekar and Innsbruck) kept at constant temperature from 1931 to 1934 and in 1936 have brought interesting results. Among these, for instance, the existence of a regular, small diurnal variation according to solar time has been established.1

Recently one of my collaborators, W. Illing,2 tested the existence of diurnal variation according to sidereal time as postulated by A. H. Compton's theory of the extra-galactic origin of the cosmic radiation. The curve derived from 21,000 hourly observations in three years showed a certain resemblance to Compton's theoretical curve, which however disappeared when all observations were reduced to the same outdoor temperature.

(I) The external temperature-effect—Several authors (Steinke, Hess, and Steinmaurer) have shown that the cosmic-ray ionization after reduction to a constant barometric pressure still shows a certain correlation to the temperature outside. On the Hafelekar (2300 meters above sea-level) with the apparatus screened by lead (10 cm thick) on all sides the ionization decreases by about 0.9 per mille when the temperature outside rises by one degree. It seemed important to investigate this "external temperature-effect" thoroughly.

It may be realized that an effect of this kind can be due only to the change of density of the air in the neighborhood of the station, perhaps within a few hundred meters, caused by temperature-variations outside; a rise of temperature results in a diminution of scattered radiation from the vicinity of the apparatus. Therefore it seems plausible that every change in the mass-distribution within the air—even at constant barometric pressure—should be accompanied by a slight variation of the observed cosmic-ray intensity.

In order to study this "external temperature-effect" more closely it was necessary to work out quantitatively the correlation between outdoor temperature and barometric pressure and then—on account of this—by the method of multiple correlation (1) the correlation between cosmic-ray ionization and atmospheric pressure and (2) the correlation between cosmic-ray ionization and outside temperature.

This analysis of our observations of 1931-34 has been carried out by J. A. Priebsch and W. Baldauf. The whole material was divided in 25 sections (comprising one to two months each) and the correlation- and regression-coefficients were individually calculated for each section, using daily mean values of the cosmic-ray ionization (J), temperature (T), and barometric pressure (B).

2Terr. Mag., 41, 185-191 (1936).

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FIG. 1—ANNUAL VARIATION OF THE TEMPERATURE-COEFFICIENT, 1932-1934

FIG. 2—IONIZATION, OBSERVED AND REDUCED TO CONSTANT TEMPERATURE, NOVEMBER 1ST, 1934

FIG. 3—DAILY MEAN VALUES OF COSMIC-RAY IONIZATION AND OF NUMBER OF COUNTER-COINCIDENCES (VERTICAL-RAYS), JUNE 14 TO 30, 1934
It was found that the effect due to outside temperature is not constant but shows seasonal variations (see Fig. 1). On the Hafelekar (mean intensity of cosmic radiation filtered by 10 cm of lead, $2.7 J = 2700 \text{ mJ}$) the temperature-coefficient from the average of three years amounts to about $-2.8 \text{ mJ per degree in winter and } -1.0$ to $-1.5 \text{ mJ per degree in summer. Thus it would be incorrect to reduce the observations by using an average temperature-coefficient for all seasons.}

The practical use of the method of multiple correlation was much simplified by J. A. Priebsch and can be applied readily without undue loss of time when daily average values of $J, B$, and $T$ are used. Instead of the outside temperature $T$ the density of the air can be introduced by a simple transformation.

The variation of the cosmic-ray ionization with the barometric pressure is usually expressed by plotting values of $J$ against those of $B$; G. Hoffmann and E. G. Steinke have drawn this diagram in such a way that the corresponding values of $J$ and $B$ for successive days were connected by straight lines. Priebsch and Baldauf showed that these graphs as in Figure 2 are much more regular when the values of $J$ are reduced to a constant outside temperature. It was also proved conclusively that reduction to a constant density of outside air has the same effect as the reduction to constant temperature. In the first case, however, the correlation between cosmic-ray ionization and barometric pressure is a better one. [A full account of these studies appears in SitzBer. Wien. Ak. Wiss. for October 1936.]

The seasonal variation of the temperature-coefficient of the cosmic-ray ionization is most probably due to the different vertical mass-distribution of the air in different seasons.

(II) *Cosmic rays and solar activity*—From all that we know at present it is generally considered as not very probable that even a small percentage of cosmic rays is primarily emitted by the Sun. Nevertheless it seemed interesting to investigate if certain processes on the Sun are accompanied by variations of the cosmic-ray intensity. This analysis was carried out by H. Th. Graziadei in my Institute (report now in press SitzBer. IIa, 145).

First the correlation with the number of flocculi was investigated. During 1931 to 1934 it was found that the intensity of the cosmic-ray ionization at the Hafelekar shows a slight decrease with increasing number of flocculi. The correlation-coefficient was $-0.48 \pm 0.08$.

The entire observational material was then divided according to the cycles of the Sun's rotation. Different periods of rotation (from 25 to 29 days) were tried out and it was found graphically that a rather regular variation of the cosmic-ray intensity (expressed by the daily mean values) does result within the rotation-period when this is taken as 27 days. The amplitude of this variation amounts to $\pm 7 \text{ mJ}$. It seems therefore that according to the position of the surface of the Sun relative to our planet the intensity of the cosmic radiation shows a slight but distinct variation. Now since our observations cover as yet not much more than one-third of a whole sunspot-cycle of eleven years, it would be premature to draw far-reaching conclusions at present. Nevertheless a

\footnote{Wien. SitzBer. Ak. Wiss., Ila, 145, 101-144 (1936).}
certain relation between cosmic-ray ionization and solar activity seems to be established.

(III) Irregular fluctuations of cosmic-ray ionization—Aside from the statistical variations the existence of irregular fluctuations of the cosmic-ray ionization (designated variations of the second kind by A. Corlin) has been found by several authors. Our observations show that these fluctuations of the daily mean values, sometimes amounting to as much as two per cent, do occur even after reduction to normal barometric pressure and to a constant outside temperature.

The existence of these fluctuations was proved more directly and conclusively within the last few months by independent registrations of the cosmic-ray intensity at two distant stations and also by simultaneous registration of counter-coincidences. The two stations were six kilometers apart—at the Hafelekar (2300 meters above sea-level) and in Innsbruck (under the roof of the University Building, 600 meters above sea-level). The ionization was registered by two Steinke apparatus screened by 10 cm of lead on all sides (plus 7 cm of iron at the Hafelekar). A double-coincidence counting-set was placed also at the Hafelekar with the tubes parallel and with their axes vertically above each other. The daily mean values of the ionization and of the number of coincidences were reduced to normal pressure and then plotted against time as abscissa. This graph (Fig. 3) shows beautifully that the variations of ionization and of the number of coincidences occur simultaneously at both stations and therefore cannot be due to instrumental deficiencies. The graph shows a general decrease of intensity from May 27 to June 2 and a very sharp increase beginning on June 20, reaching a maximum on June 25. This increase amounts to 50mJ on the Hafelekar and 34mJ in Innsbruck, that is, two per cent of the total intensity and the counting tubes showed at the same time an increase of the number of double coincidences of eight per cent (vertical radiation). A triple-coincidence counting-set, registering the number of showers (tubes in triangle-arrangement) also showed a similar increase. From all this we must conclude that between June 20 and 25 a real increase of the cosmic radiation was registered by our instruments. The appearance of a new star (Nova Cephei)—visually discovered in the night of June 18-19—might be a mere coincidence; it will be remembered that no effect of the last Nova (Nova Herculis) on the cosmic-ray ionization could be detected with certainty. Nevertheless it will be very interesting to compare our results with the observations in other countries.

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The Editor has kindly sent us the following remarks by S. E. Forbush referring to the foregoing paper:

"(1) It may be said if a change in mass-distribution (even at constant pressure) does appreciably alter the cosmic-ray intensity, then it would appear necessary to show whether this accounts for all of the apparent diurnal variation.

"(2) Regarding the 'outdoor temperature-effect' a study of selected records for 160 days at Cheltenham gives values five times smaller than the smallest of those given by Dr. Hess (see p. 345). So far as the Cheltenham cosmic-ray records are concerned, the 'apparent' temperature-coefficients have been found to vary greatly so that no great reliance may be placed on them. The question of this apparent outdoor temperature-effect is so important that the addition of information regarding the detail of its calculation would be a valuable addition to this section so that others might know the procedure followed.

"(3) With reference to Part II, would it not be preferable to give more of the evidence upon which the conclusion at the end of the paragraph is based?

"(4) Regarding the effect referred to in Part III, one may well inquire if the simultaneous changes are actual changes in the intensity of cosmic rays or the result of inevitable uncertainties in the corrections which are applied."

We comment on these as follows:

(1) Es ist wohl nicht möglich, die im Laufe eines Tages sich zeigenden regelmässigen Schwankungen der Ionisation (täglicher Gang") allein durch Aenderungen der Massenverteilung (selbst bei konstantem Luftdruck) innerhalb der Atmosphäre zu erklären. Denn wenn man die auf konstanten Luftdruck reduzierten Werte der Ionisation noch dazu auf gleiche Aussentemperatur reduziert, verschwindet der tägliche Gang in keinem Falle, auch wenn man die zur Reduktion verwendeten Koeffizienten innerhalb weiter Grenzen variiert.


(3) Ebenso muss bezüglich Einzelheiten über Beziehungen zwischen Strahlungsintensität und Sonnentätigkeit auf die ausführliche Abhandlung von H. Graziadei verwiesen werden, die gleichfalls alsbald im Druck erscheinen wird (Wien, SitzBer., Sitzung vom 25. Juni). In dieser Arbeit
wird eine Kurve gegeben, welche den mittleren Verlauf der Intensität der Ultrastrahlung während der Sonnenrotation darstellt.

(4) Die Ähnlichkeit im Verlaufe von Strahlungsintensität in Innsbruck und am Hafelekar, sowie überdies der Häufigkeit der Vertikalkoinzidenzen an letzterem Orte von Tag zu Tag kann nicht eine scheinbare, durch Reduktionsfehler vorgetäuschte sein. Denn vor allem sind die in Rede stehenden Schwankungen erheblich (um eine Zehnerpotenz) größer, als solche, die durch Luftdruck- oder Temperaturschwankungen hervorgerufen werden und somit auch allenfalls durch fehlerhafte Reduktion entstehen können. Durch die vorliegenden Untersuchungen scheint uns erstmalig die Existenz von Strahlungsschwankungen experimentell sicher nachgewiesen zu sein, die nicht erst in den unteren Schichten der Atmosphäre der Strahlung aufgeprägt werden, sondern entweder durch Veränderungen in den höchsten atmosphärischen Schichten hervorgerufen sind oder wirkliche Änderungen der primären Strahlungsintensität darstellen.