1. Observations of the Penetrating Radiation on Seven Balloon Flights

Viktor F. Hess

Last year I had the opportunity of making two balloon ascents to investigate the penetrating radiation: the first flight has already been reported at the scientific meeting at Karlsruhe. On both journeys no essential change was found in the radiation up to an altitude of 1100 m, compared with that observed near the ground. Gockel had similarly been unable to find the expected decrease in the radiation with height in two balloon ascents. The conclusion was thence drawn that there must be another source of the penetrating radiation in addition to the $\gamma$-radiation from the radioactive substances in the Earth’s crust.

A grant from the Kaiserlichen Akademie der Wissenschaften in Vienna has enabled me to carry out a series of seven more balloon ascents this year, from which was obtained more comprehensive observational material, extended in many ways.

Two Wulf radiation detectors of 3 mm wall thickness served for the observation of the penetrating radiation in the first place, perfectly airtight and capable of withstanding the pressure variations on all the ascents. Instrument 1 had an ionization volume of 2039 cc, the capacity being 1.597 cm; instrument 2 had volume 2970, the capacity amounting

† Physik. Zeitschr. 13, 1804–1091 (1912). (From the Section on Geophysics, Meteorology and Geomagnetism.)
‡ Vienna.
† Physik. Zeitschr. 12, 998–1001 (1911); Wien. Sitz.-Ber. 120, 1575–1585 (1911).
to 1-097 cm. Hence a loss of charge of 1 volt per hour corresponded in
instrument 1 to an ionization rate of \( q = 1-56 \) ions per cc per sec, and
in 2 to \( q = 0-7355 \) ions per cc per sec.

Both instruments had been electrolytically galvanized on the inside
to reduce the radiation from the walls of the vessel. This was suggested
by Dr. Bergwitz. After this treatment detector 1 indicated a normal
ionization of about 16 ions, detector 2 of 11 ions per cc per sec. The
firm of Günther and Tegetmeyer in Brunswick has also provided
another essential improvement to the apparatus: hitherto the sharp
setting on the fibres took place solely by moving the eyepiece, which
gave rise to a not unimportant change in the magnification, and by
repeated adjustment produced differences of up to 0-5 in the readings.
This firm has now mounted a sliding negative lens in the eyepiece tube,
which permits focusing for various positions of the fibres without a
perceptible change of magnification resulting. The accuracy of setting
is thus considerably increased.

The wall thickness of the instruments 1 and 2 was 3 mm, so that
essentially only the \( \gamma \)-rays could be effective. In order to study simulta-
neously the behaviour of \( \beta \)-rays I also used a third instrument, which
was not made air-tight, but consisted of an ordinary Wulf two-fibre
electrometer over which was inverted a cylindrical ionization vessel of
16-7 litre volume made of the thinnest commercially available zinc
(wall thickness 0-188 mm), so soft rays with the character of \( \beta \)-rays
could also play an effective part. A zinc spike 20 cm high fixed to the
fibre support of the electrometer acted as charge disperser. The capacity
was 6-57 cm.

The insulation loss in the thick-walled Wulf radiation detectors 1
and 2 was determined by the usual way with a lowered guard tube. The
hourly loss of charge amounted to 0-2 volt in instrument 1, and 0-7 volt
in no. 2. A breakdown of insulation due to damp weather is never
found.

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* Superscript letters refer to Notes at end of articles.
The last and most important point of the investigation was the measurement of the radiation at the greatest possible heights. Whilst in the six ascents undertaken from Vienna the weak lifting power of the local gas, as well as the meteorological conditions, had not permitted this, in an ascent made with hydrogen from Aussig on the Elbe I managed to carry out measurements up to 5350 m altitude.

For several hours before each flight control observations with all three detectors were made. For this the instruments were attached by means of brackets to the balloon basket, exactly as during the flight itself. The observations before the ascent were carried out at the club site of the k. k. Österreichischen Aeroklub, a level grass plot in Prater in Vienna. L. V. King has briefly conjectured that balloon observations could be disturbed by the proximity of weakly radioactive ballast sand. An increase in the radiation was never found from supplies of ballast sand.

In instruments 1 and 2 the same air density always prevails inside the ionization space as at the site of the ascent (on average 750 mm). On the other hand in the thin-walled detector 3, the pressure is always the same as in the surroundings. A reduction of the directly observed data is therefore necessary, especially in observations at great heights.

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In the following tables $q_1$, $q_2$, $q_3$ denote the penetrating radiation observed with the three instruments 1, 2, 3, in ions per cc per sec. The elementary charge is taken as $e = 4.65 \times 10^{-10}$ esu. The mean height of the balloon during a particular observation period (usually 1 hour) was deduced from the barograph trace by a graphical method. A mean value for the relative height was then calculated from the altitude above sea level of the locality directly below. The hour of day is given by the 24-hour clock in the tables.

A full account of all the balloon observations has been presented to the Kaiserlichen Akademie der Wissenschaften in Vienna, and published in the proceedings. Here I will give detailed accounts of only the two most important ascents and be content to quote average values for the others.

* Phil. Mag. 23 (6), 242 (1912).
1st Flight

This took place on the occasion of the very considerable partial eclipse of the Sun in Lower Austria on 17th April 1912. It was observed from 11 a.m. to 1 p.m. at an absolute altitude of 1900–2750 m above an almost complete layer of cumulus. No reduction in the penetrating radiation was observed during the advancing eclipse. Instrument 2 showed, e.g., an ionization of 10·7 ions before the ascent, at an average relative height of 1700 m, 11·1 ions, later at 1700 to 2100 m, during the first phase of the eclipse 14·4, and then at about 50% solar obscuration 15·1 ions. Further measurements were not possible, since the balloon was forced to descend as a result of the cooling of the gas.

An increase in the radiation was thus found at around 2000 m. As no effect of the eclipse was to be seen on the penetrating radiation, we may conclude that if a part of the radiation is of cosmic origin it can hardly come from the Sun, at least so long as one thinks of a $\gamma$-radiation propagated in straight lines. That in subsequent balloon flights I never found a distinct difference in the radiation between day and night confirms this view.

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The following 7th flight was undertaken as a really high ascent.

7th Flight (7th August 1912)

We took off at 6.12 a.m. from Aussig on the Elbe. We flew over the Saxony border by Peterswalde, Struppen near Pirna, Bischofswerda and Kottbus. The height of 5350 m was reached in the region of Schwielochsee. At 12.15 p.m. we landed near Pieskow, 50 km east of Berlin. Unfortunately no observations could be made at the site of the ascent before the journey, but measurements were made after landing under the still filled balloon, in order to see immediately after descending from 5000 m whether the balloon had become covered with radioactive induction and so emitted a radiation itself. As may be seen from the table (Obs. no. 11), no sign of an increase in radiation was observed
under the balloon after landing. The weather was not perfectly clear on this journey: a barometric depression approaching from the west made itself apparent as clouding set in. It should nevertheless be expressly state that we were never in a cloud nor even in the vicinity of one; as at the time that the cumulus clouds appeared as isolated balls scattered all around the horizon, we were already above 4000 m in height. Above us as we approached the maximum height was a thin cloud sheet much higher still, whose base was probably at 6000 m at least, and through which the Sun shone only weakly.

We first consider the results with the thick-walled instruments I and 2. At 1500 to 2500 m mean altitude the radiation was just about as strong as was normally found on the ground. Then begins a clearly perceptible rise in the radiation with increasing height, seen by both instruments—at 3600 above the ground both values are already about 4–5 ions higher than on the ground.
In both γ-ray detectors the values at the greatest altitude are about 20 to 24 ions higher than at the ground. The very high values \( q_1 = 28.1 \) and \( q_2 = 22.7 \) were found also on the descent at 4400 m. These greatly exceed the normal values of 12 and 11 ions. In the ensuing very rapid descent (2 m per sec) the very low value of 9.7 was measured in instrument 1 at a mean height of 1200 m, while instrument 2 registered the normal value 11.5. I think it possible that in instrument 1, which was provided with very thick fibres, a certain stiffness of the filament sometimes produced a noticeable irregularity.

The results obtained from both detectors under the still-inflated balloon after landing were, as remarked above, quite normal.

To gain a picture of the variation of the penetrating radiation with altitude, on the average, I have combined all the 88 radiation values I have observed in balloons at suitable intervals of height in the following table. For each height, averages are formed from several individual values which were obtained under different conditions and which could be influenced by the previously mentioned transient variations, so one should not expect to obtain as yet a wholly exact picture of the development of the radiation with increasing altitude. The numbers in

<table>
<thead>
<tr>
<th>Mean height above ground m</th>
<th>Observed radiation in ions per cc per sec</th>
<th>Inst. 1</th>
<th>Inst. 2</th>
<th>Inst. 3</th>
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</thead>
<tbody>
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<td>( q_1 )</td>
<td>( q_2 )</td>
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<tr>
<td>0</td>
<td></td>
<td>16.3 (18)</td>
<td>11.8 (20)</td>
<td>19.6 (9)</td>
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<td>up to 200</td>
<td></td>
<td>15.4 (13)</td>
<td>11.1 (12)</td>
<td>19.1 (8)</td>
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<tr>
<td>200–500</td>
<td></td>
<td>15.5 (6)</td>
<td>10.4 (6)</td>
<td>18.8 (5)</td>
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<tr>
<td>500–1000</td>
<td></td>
<td>15.6 (3)</td>
<td>10.3 (4)</td>
<td>20.8 (2)</td>
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<tr>
<td>1000–2000</td>
<td></td>
<td>15.9 (7)</td>
<td>12.1 (8)</td>
<td>22.2 (4)</td>
</tr>
<tr>
<td>2000–3000</td>
<td></td>
<td>17.3 (1)</td>
<td>13.3 (1)</td>
<td>31.2 (1)</td>
</tr>
<tr>
<td>3000–4000</td>
<td></td>
<td>19.8 (1)</td>
<td>16.5 (1)</td>
<td>35.2 (1)</td>
</tr>
<tr>
<td>4000–5200</td>
<td></td>
<td>34.4 (2)</td>
<td>27.2 (2)</td>
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</tbody>
</table>
brackets indicate the numbers of actual observations from which the means were derived.

We learn from this table that directly above the earth the radiation falls off a little. On the average this decrease amounts to 0.8 to 1.4 ions. Since, however, a decrease of up to 3 ions has been found on some ascents, and over 2 ions in very many measurements, we shall quote about 3 ions as the maximum value of the decrease. This decrease extends up to 1000 m from the ground. It clearly results, as mentioned earlier, from the absorption of γ-rays emitted from the earth’s surface. Hence we conclude that the γ-radiation from the earth’s surface and the uppermost layers of the ground gives an ionization of about 3 ions per cc per sec in zinc vessels.

At altitudes up to 2000 m the radiation again begins to increase perceptibly. By 3000 to 4000 m the increase amounts to 4 ions, and at 4000 to 5200 m fully 16 to 18 ions, in both detectors. With the thin-walled detector, when the values are reduced to normal pressure, the decrease is reversed sooner and more strongly.

What is the cause of this increase of the penetrating radiation with altitude, now observed many times and simultaneously with three detectors?

If one adopts the view that only the known radioactive substances in the earth’s crust and atmosphere emit a radiation with the character of γ-radiation and produce ionization in closed vessels, serious difficulties defy explanation:

According to the direct determinations of the absorption coefficient of γ-rays in air by myself⁴ and Chadwick,⁵ the absorption of the radiation from the earth’s surface must be rapid, so that 500 m above the ground scarcely 10% of the radiation can remain. As has been mentioned, I have been able to demonstrate this experimentally in the balloon; but at the same time it appears that the radioactive substances in the ground do not play such a preponderant role in the total radiation as many authors believe. Its share was determined as 3 ions per cc per sec.

⁴ *Wien. Sitz.-Ber.* 120, 1205–1212 (1911).
⁵ *Le Radium*, 9, 200–202 (1912).
There still remain the decay products of emanations, for producing ionization through $\gamma$-radiation at high altitudes. Because of their short lifetimes, thorium and actinium emanations and their decay products will not be able to reach great heights. Only radium-emanation, with a half-life of nearly 4 days, can be drawn up to great altitudes in rising air currents. In general, however, the concentration of emanation, and therefore also the RaC content of the air, will soon decrease with height. An increase in the radiation with height could only arise through an accidental accumulation of RaC of purely local character: it is for instance imaginable that such accumulations might occur in stable layers at a temperature inversion, or in cumulus clouds or in mist, as it is known that RaC atoms frequently act as condensation nuclei. However, a uniform increase of the penetrating radiation with altitude, as found in my observations, cannot be explained in this way. Also, in flights 2 and 6, in which the balloon travelled close to the ground for hours in such a stable layer at an inversion, I observed no increase in the radiation, although the RaC content of the air must be larger near the ground. At a height of 5000 m the RaC content will certainly not suffice to cause so great an increase in the radiation as I found.

The fluctuations in the radiation often found by Pacini$^6$ and Gockel$^7$ on the sea and on land, and by myself in the balloon, also raise great difficulties for an explanation of the penetrating radiation based only on the radioactive theory. I have repeatedly observed such variations in the middle of the night, in a perfectly calm atmosphere. In the absence of any meteorological change, there are no grounds for tracing them back to changes in the distribution of radioactive substances in the atmosphere.

The results of the present observations seem to be most readily explained by the assumption that a radiation of very high penetrating power enters our atmosphere from above, and still produces in the lowest layers a part of the ionization observed in closed vessels. The intensity of this radiation appears to be subject to transient variations, recognizable in hourly readings. Since I found a reduction in the radiation at the bal-

$^6$ Le Radium, 8, 307–312 (1911).
loon neither by night nor at a solar eclipse, one can hardly consider the Sun as the origin of this hypothetical radiation, at least so long as one thinks only of a direct $\gamma$-radiation with rectilinear propagation.

It is not so very surprising that the increase in the radiation first becomes really noticeable beyond 3000 m: the decrease in the $\gamma$-radiation from the ground prevails in the first 1000 m, and after that comes the decrease in the induction strength, which makes itself felt until over 3000 m. The absorption of the radiation coming from above in any case follows an exponential curve; the increase in radiation as one goes up will hence become steeper at greater heights.

Note

* Hess was concerned amongst other things with the apparent fluctuations in the radiation, but we omit this material.