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Early Cosmic Ray Research with Balloons

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Abstract

The discovery of cosmic rays by Victor Hess during a balloon flight in 1912 at an altitude of 5350 m would not have been possible without the more than one hundred years development of scientific ballooning. The discovery of hot air and hydrogen balloons and their first flights in Europe is shortly described. Scientific ballooning was mainly connected with activities of meteorologists. It was also the geologist and meteorologist Franz Linke, who probably observed first indications of a penetrating radiation whose intensity seemed to increase with the altitude. Karl Bergwitz and Albert Gockel were the first physicists studying the penetrating radiation during balloon flights. The main part of the article deals with the discovery of the extraterrestrial radiation by V. Hess and the confirmation by Werner Kolhörster.

Keywords: cosmic radiation, history, ballooning

1. First Balloon Flights

The brothers Joseph-Michel and Jacques-Etienne Montgolfier are considered as the inventors of the hot air balloon, although earlier developments were known from China, Portugal and other countries. The successful flight of their unmanned balloon on June 4, 1783 in their hometown Annonay in the south of France (see Fig. 1) was the starting point of the aeronautical era. The spherical balloon with 34 m circumference consisted of paper reinforced by linen sheets. A fire made of straw and wool produced the hot air to fill the balloon. During the ten minutes flight an altitude of about 300 m was reached. It followed an invitation of the French Academy of Sciences to repeat the flight in Versailles before the royal family. On 19 September 1783 a duck, a rooster and a wether were the first passengers flying about 3 km up to an altitude of 450 m. Only two months later, on the 21 November 1783, the first manned flight was performed with a Montgolfier hot air balloon by Jean-Francois Pilatre de Rozier together with the officer Marquis d'Arlandes. They reached an altitude of about 900 m above Paris and landed after flying a distance of 9 km.

Figure 1: First flights of unmanned balloons in France in 1783: left, the hot air Montgolfier, on the right, the hydrogen filled balloon.

It is interesting that nearly in parallel another, more powerful, technique was developed. After the discovery of hydrogen by the British scientist Henry Cavendish in 1766 first experiments were performed with the gas which was lighter than air. Also the Montgolfier brothers tested a small hydrogen filled balloon. Since the bal-

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loon envelope was not gas-tight, they continued with the hot air gas. The first unmanned hydrogen balloon was launched by the French physicist Jacques Charles and the brothers Anne-Jean and Marie-Nol Robert in August 27, 1783 in Paris (see Fig. 1). On 1 December 1783 two flights were performed. First, J. Charles and N.-L. Robert started in front of the Tuileries in Paris and reached an altitude of about 500 m. Just after landing, Charles started alone and ascended up to an altitude of 3467 m, measuring there a temperature of -8.8° C and an air pressure of 668 Pa.

For the following hundred years the professional ballooning reached in Europe and the USA a high publicity. The fascination of flying was staged in many towns as spectacular events before ten thousands of people. Beside the increasing military interest there were also few scientific campaigns. Italian balloonists were from the beginning part of this development:

- 1784 Sept. 14: Vincent Lunardi (see Fig. 2) an employee at the Italian embassy in London performed a flight with the hydrogen balloon of the French professional balloonist Jean Pierre Blachard. They landed after 24 miles near to London. On board was also a dog, a cat and a pigeon.
- 1803: Count Zambeccari from Bologna (see Fig. 2) performed a dramatic night flight and landed finally in the Adriatic Sea.
- 1806: The balloon of Carlo Broschi was destroyed after the start in Naples.
- 1842: Antonio Comaschi (Turin) performed many flights in Naples and Rome. His statement that he had reached an altitude of 9474 m was in contradiction with the measured temperature.
- 1848, March: Probably for the first time unmanned balloons were used for the distribution of political proclamations during the revolution in Milano against Austria.
- 1885: Foundation of the first military balloon company which served in Abessinia.

2. Early Scientific Balloon Flights

The first scientific flight was performed by the American physician John Jeffries (see Fig. 2) again with the hydrogen balloon of Blanchard in London in November 30, 1784 [1]. The measured data of air pressure, temperature and humidity in dependence on altitude are shown in Tab. 1. Even a pocket electrometer was on board, probably developed by the Italian physicist Tiberius Cavallo. Unfortunately, electrometer data records could not be found.

Table 1: Measurements of J. Jeffries during a flight in London on 30 November 1784.

Time	Altitude, m	Temperature, ° C	Air Pressure, Pa	relative Humidity, %
14:20	80	10.6	1015.9	0
14:45	878	4.4	914.3	-
15:03	1480	1.7	846.6	3

Although the production of hydrogen gas using iron cuttings and acid sulphur was dangerous and time-consuming, hydrogen balloons had the clear advantage to reach higher altitudes. Therefore, they were used especially for scientific flights. The French chemist and physicist Joseph Louis Gay-Lussac reached the record altitude of 7016 m in September 16, 1804. He made two important observations: (i) The oxygen fraction of air is independent on altitude. (ii) At higher altitudes the temperature decreases by 1 ° C per 174 m ascent.

Since Napoleon did not have any interest in balloon missions, for many years there were no activities in France. First scientific attempts in Germany and Italy at the beginning of the 19^{th} century failed because of balloon accidents. In England four flights have been performed by John Welsh in 1852. He recognised the influence of the solar radiation on the accuracy of temperature measurements at higher altitudes and realised a method to prevent it. The years from 1868 to 1883 were dominated by activities of French meteorologists. Albert Tessandier observed strong temperature differences inside and outside of clouds at identical altitudes. The idea to explore the atmosphere with self-registrating devices mounted on small hydrogen filled pilot balloons was also realised. The results were not very satisfac-

Figure 2: Portraits of John Jeffries, Vincent Lunardi and count Zambeccari.

tory but it was the starting point into a new era. German meteorologists started rather late but very successfully, thanks to the support of the government. Only in the years 1888 and 1889 the 'Association for the Promotion of Aeronautics' organised 65 manned balloon flights, 10 with pilot balloons and 19 with captive balloons. Highlights of the research which was continued until 1914 were: (i) The development of an automated photographic registration of temperature and air pressure (see Fig. 3). (ii) The 10800 m altitude record flight of the meteorologists Arthur Berson, Reinhard Süring and the Austrian physician Herrmann von Schrötter with the hydrogen balloon 'Preussen'. (iii) The discovery of the stratosphere by Richard Aßmann (Berlin) and Leon-Philippe Teisserenc de Boert (Paris) with pilot balloons.

This shows that meteorologists and not physicists were the driving force to develop new ballooning techniques and detectors in the second half of the 19^{th} century.

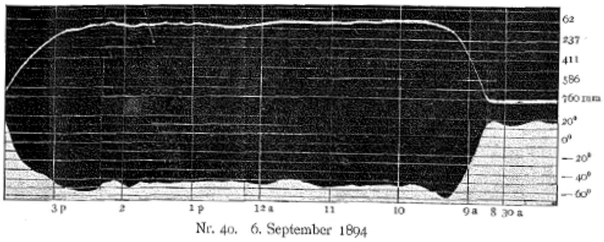

Figure 3: Automatical photographic registration of air pressure and temperature at high altitude pilot balloon flights.

3. First Indication for Cosmic Rays ?

After the discovery of natural radioactivity by Henry Becquerel in 1896, the properties of this new radiation were investigated extensively. In 1900 the Scottish physicist Charles Thomson Rees Wilson and the German physicists and high school teachers Julius Elster and Hans Geitel found out independently, why a charged conductor was loosing its charge although it was included in an isolated vessel. The reason was that natural radioactivity ionises the air around the conductor. The conductive ions then, reduce the charge. The instrument used for the measurement of charge loss was the electrometer. In the most simple construction, two gold leafs were connected to a metallic rod. The distance between the the gold leafs is a measure of the charge. With these electrometers the ionising radiation was studied in laboratories but also in the natural environment, on the Earth's surface, below the ground, in the water of lakes, rivers and oceans as well as in the atmosphere.

Probably the first who measured the ionising radiation in a balloon at high altitudes was the German geophysicist and meteorologist Franz Linke (see Fig. 4). In 1901 he received his PhD in Berlin for a work on 'Measurements of electrical potential differences with collectors in the balloon and on the Earth'. During six of twelve balloon flights between September 1900 and August 1903, he also measured the ionisaton of the atmosphere with a two-leaf electrometer provided by J. Elster and H. Geitel. The results of these investigations were published in [2].

Figure 4: The geophysicist and meteorologist Franz Linke.

It is very interesting to read his conclusion about the ionisation measurements since it looks like an anticipation of the results of Victor Hess, who discovered cosmic rays in 1912. Linke wrote (p.87):

> Would one compare the presented values with those on ground, one must say that in 1000m altitude, where the measurements in general began - the leakage (ionisation) is smaller than on ground. It is between 1 and 3 km of the same amount, and above larger than on Earth, with values increasing up to a factor of 4 (at 5500 m altitude), if the mean value at our latitude is 1.5%. The uncertainties of the observations .... only allow the conclusion that the reason of the ionisation has to be found first in the Earth.

Why Linke did not trust his results is not known. Probably, the measurements with the simple electrometer were difficult, since the leaf-electrometer was not the suitable instrument for the harsh environment in a moving balloon. It also should be remarked, that in later papers or books about the early days of research on the ionisation of the atmosphere this important work was never cited.

4. Investigation of Penetrating Radiation

Ernest Rutherford verified that the ionising radiation consists of α- and β-rays and the French physicist Paul Villard found the third component, the γ-rays. Further investigations showed that α-rays are helium nuclei, β-rays are electrons and that γ-rays have the largest penetration power of all. In 1906 A.S. Eve published the results of absorption measurements with γ-rays [3]. He deduced a power law which also allowed to estimate the absorption in air. Corresponding to this dependency, about 50 % of γ-rays should be absorbed by 157 m, and 99 % by 1000 m of air.

The German Jesuit and physicist Theodor Wulf developed with the two-string electrometer a robust instrument for outdoor measurements of penetrating radiation [4]. Fig. 5 shows the schematical view of the electrometer.

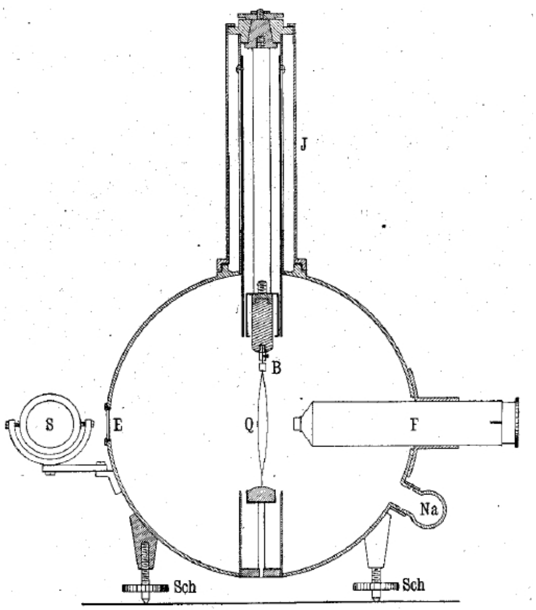

Figure 5: Schematical view of the two-string electrometer designed by Th. Wulf. Q: 2 strings, F: microscope to measure the distance between the strings, B: string fixation and electrical connection to the metallic rod housed in J, S: mirror.

In autumn 1908 the physicist Karl Bergwitz (Fig. 6) started a nine hour flight near to Braunschweig/Germany with the goal to measure the ionisation of air up to 2000 m altitude. The flight was supported by his physics teachers Elster and Geitel. Using a two-string electrometer of Wulf, he measured at 1300 m altitude still about 25% of the ionisation at ground, where according to Eve 0% was expected. Other data were not taken, since the electrometer was destroyed. After the flight an older university professor advised against it; he said that Bergwitz would lose his scientific reputation if he continues to pursue the idea of an extraterrestrial radiation. Therefore, there is only a short description of his results in his dissertation [5].

At the same time, in August and September 1908, Albert Gockel (Freiburg/Switzerland) and Th. Wulf performed the first expedition in the Alps. With two Wulf-electrometers they measured the ionisation at altitudes from 650 to 3000 m. They concluded [6]:

> An influence of the altitude on the ionisation in the closed vessels was not seen. It can be concluded that a cosmic radiation, if it exists at all, can only be a negligible part of the penetrating radiation.

It was obviously the first time that the term 'cosmic radiation' was used, 18 years before introduced by Robert Millikan.

Figure 6: Portraits of Karl Bergwitz and Albert Gockel.

Gockel (see Fig. 6) performed three balloon flights in Switzerland in the area of Zurich and Bern on 11 December 1909, 15 October 1910 and 2 April 1911. Table 2 shows the result published in [7].

Also Gockel's results were in contradiction with the expectation. He concluded:

> The results would be in agreement with the conclusion of Pacini with his observations

Table 2: Mean values of the voltage loss (ionisation) measured by A. Gockel during balloon flights in 1910 and 1911.

Date	Time	Altitude, m	Voltage Loss, V
10/15/10	07:00-09:30	0	13.3
	09:45-10:45	800-1100	10.3
	10:45-11:30	1700	8.3
	11:30-12:30	1900	8.5
	12:30-13:30	1900	9.6
	13:30-15:30	2800	10.0
	16:00	0	9.8
04/02/11	07:30-09:00	0	15.8
	09:30-11:15	1600	13.8
	11:15-12:15	1900	15.1
	12:15-13:45	2500	12.1

on the ocean and Mache in Innsbruck, that a considerable part of the penetrating is independent on the direct impact of the active (radioactive) substances contained in the upper Earth's layers. My results also agree with those of Wulf on the Eiffel tower.

5. Discovery of Cosmic Rays

As was shown in the previous chapter, there was something in the air in 1911, although the conclusions of the publications were still rather vague. In the same year Victor Franz Hess became assistant of Stefan Meyer, the director of the 1910 founded Radium Institute of the Austrian Academy of Sciences. The short biographical compilation gives an impression of the essential steps in his scientific career:

- 24.06.1883: Born in castle Waldstein near to Peggau/Austria.
- 1901-1905: Physics study at the University of Graz.
- 1906: PhD.
- 1907-1910: Assistant of Franz Exner in the Physics Institute of the University Vienna.
- 1911-1920: Assistant of S. Meyer at the 1910 founded Radium Institute of the Academy of Sciences.
- 1921-23: USA, director of the United States Radium Corporation.
- 1923: University Graz.
- 1925-1931: Professor in Graz.
- 1931-1937: Professor in Innsbruck.
- 1936: Nobel Prize for Physics.
- 1937-1938: University Graz.
- 1938: Emigration to the USA.
- 1938-1956: Professor at the Fordham University.
- 17.12.1964: died in Mt. Vernon, New York.

In the Radium Institute, Hess was close to the source, in the true sense of the word. His approach to investigate very carefully all possible influences step by step was probably the secret of success: (i) Experimental verification of the absorption coefficient of air predicted by Eve. He used the strongest radium source available in the institute [8]. (ii) First balloon flight in 28 August 1911, where he established the discovery of Bergwitz, Wulf and Gockel, that the ionisation is considerably larger than expected corresponding the absorption coefficient of air (see Table 3). (iii) Careful calibration measurements performed in early 1912 with electroscopes improved by him using radium sources [9].

Table 3: Measurement results of V. Hess' first balloon flight near to Vienna on 28 August 1911.

Time	Altitude, m	Radiation, Ions/cm^3/s
06:30-07:45	0	32.3
08:14-08:59	150-440	28.1
08:59-09:45	440-800	34.7
09:48-10:18	800-900	34.3
10:18-10:48	900-1070	35.5
11:11-12:12	0	34.9

With the support of the Austrian Academy of Sciences and the Royal Imperial Austrian Aeronautical Club in Vienna, Hess performed in 1912 six flights around Vienna (see Fig. 7). The ionisation measurements were performed with two or three electrometers in parallel. With a flight during a sun eclipse and with several flights at day and night, he could demonstrate that the sun can be excluded as the source of the penetrating radiation. The last step to prove that the penetrating radiation is of extraterrestrial origin would be a high altitude flight with increasing ionisation. In Vienna only illuminating gas was available which limited flights up to about 3000 m altitude. The German Aeroclub in Bohemia provided the balloon 'Bohemia' and hydrogen was available in a chemical company near to Aussig (now Usti nad Labem) at the border to Saxonia. Hess started the record flight together with the pilot W. Hoffrey and the meteorological observer E. Wolf in the morning of August 7, 1912. Before the maximum altitude was reached in the south of Brandenburg, Hess became shortly faint and destroyed the electrometer for the measurement of β-rays. Therefore, at 5350 m altitude there are two measurement values only. The results of all seven flights were published in [10] and summarised in Table 4. Hess wrote in the conclusion:

> The results of these observations seem to be explained by the assumption, that a radiation of high penetration power hits our atmosphere from top, which causes also in their lower layers a fraction of the observed ionisation in the closed detectors. The intensity seems to indicate variations which are visible in time intervals of one hour. Since I did not find a decrease of radiation during the night or during the eclipse, the sun can not be the reason for this hypothetical radiation, at least if one assumes a direct γ-radiation with straight-line propagation.

The discovery was not really recognised by the physics community. A striking example is the article of Erwin Schrödinger from December 1912 [11]. At the end of the article he cited the article of Hess [10] but Schrödinger did not discuss or comment the results of Hess at all. An independent confirmation of the discovery was therefore very important. The young German physicist Werner Kolhörster (see Fig. 8), assistant at the

Figure 7: Victor Hess in the balloon basket at one of the flights in 1911 or 1912.

Figure 8: Werner Kolhörster.

University Halle, performed in 1913 three flights which confirmed Hess' observations [12]. The crucial breakthrough was the flight in July 1914. Kolhörster reached with his hydrogen filled balloon an altitude of 9000 m [13]. Table 5 summarises the mean values of the measured ionisation in 1913 and of the record flight in 1914. In Fig. 9 the measured ionisation values of Hess and Kolhörster are shown for comparison.

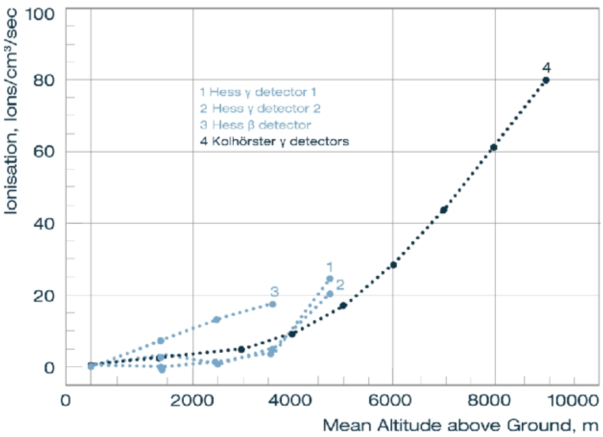

Figure 9: Comparison of the ionisation measurements of Hess and Kolhörster in dependence on the altitude.

Summarising his results, Kolhörster wrote [13]:

> One can assume that a penetrating radia-

Table 4: Seven balloon flights of V.F. Hess in 1912 [10].

Flight	Date	Time	Height above Ground, m	Ions(γ-1), cm^{-3} s^{-1}	Ions(γ-2), cm^{-3} s^{-1}	Ions(β-rays), cm^{-3} s^{-1}
1	17.4.1912	08:30-09:30	0	14.4	10.7	
		11:00-12:15	1700	13.7	11.1	
		12:15-12:50	1700-2100	27.3	14.4	
		12:50-13:30	1100		15.1	
2	26.-27.4.1912	16:00-22:30	0	17.0	11.6	20.2
		23:00-09:35	140-190	14.9	9.8	18.2
		06:35-09:35	800-1600	17.6	10.5	20.8
3	20.-21.5.1912	17:00-21:30	0	16.9	11.4	19.8
		22:30-02:30	150-340	16.9	11.1	19.2
		02:30-04:30	~ 500	14.7	9.6	17.6
4	03.-04.5.1912	17:10-20:40	0	15.8	11.7	21.3
		22:30-00:30	800-1100	15.5	11.2	21.8
5	19.6.1912	15:00-17:00	0	13.4		
		17:30-18:40	850-950	10.3		
6	28.-29.6.1912	20:10-23:10	0	15.5	12.2	
		00:40-05:40	90-360	14.9	11.4	
7	7.8.1912	06:45-07:45	1400	15.8	14.4	25.3
		07:45-08:45	2500	17.3	12.3	31.2
		08:45-09:45	3600	19.8	16.5	35.2
		09:45-10:45	4400-5350	40.7	31.8	
		10:45-11:15	4200	28.1	22.7	
		11:15-11:45	1200	9.7	11.5	
		11:45-12:10	150	11.9	10.7	
		12:25-13:12	0	15.0	11.6	

Table 5: Ionisation as difference: (Measured value) - (value at ground) for the flights in 1913 and 1914.

Altitude, m	Mean Values 1913	Flight 1914
1000	-1.5	
2000	+1.2	
3000	+4.0	+4.3
4000	+8.3	+9.3
5000	+16.5	+17.2
6000	+28.7	+28.7
7000		+44.2
8000		+61.3
9000		+80.4

tion of cosmic origin exists, which probably comes mainly from the sun. It is planned to prove this assumption with observations on the ground, above and below the water at different times, during the sun eclipse on August 21, 1914 and with further high altitude flights.

It is not clear why Kolhörster assumed that the sun is the source. His measurements did not allow this conclusion. It is even more strange, since Hess had clearly shown that the measurements during a sun eclipse and at day and night excluded the sun as a possible source. Perhaps his main motivation was to get funding for a broad cosmic ray research program. The World War stopped all these plans and only end of the 1920's the existence of cosmic rays was generally accepted. With the Noble Prize for Physics, the important pioneering work of Victor Hess was honoured in 1936.

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