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Early Cosmic-Ray Work Published in German

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Abstract. The article gives an overview on early cosmic-ray work, published in German in the period from around 1910 to about 1940.

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INTRODUCTION

The electric conductivity of air was intensely studied in the first decade of the twentieth century [1]. This led eventually to the discovery of cosmic rays in 1912. Traditionally, in this period many scientists published in German language in journals like "Physikalische Zeitschrift", "Zeitschrift für Physik", or "Naturwissenschaften". In the following we will review early cosmic-ray work published in German from around 1910, when the field of cosmic-ray research started, to about 1940, when publications in German vanished due to the general political development. The idea of this article is to make some of the early works available to readers, who do not have access to German articles. In the early German literature, several names are used to describe "cosmic rays": "Höhenstrahlung" (high-altitude radiation), "Hesssche Strahlung" (Hess rays), and "Ultrastrahlung" (ultra rays). For further studies we recommend the books by V.F. Hess [2], H. Geiger [3], and W. Heisenberg [4].

THE BEGINNINGS

In the early twentieth century the electrometer was the standard instrument to study radioactivity and the related conductivity of air. It was known that radioactivity ionizes air (or gases in general) and an electrometer in the vicinity of a radioactive source will be discharged. One of the best electrometer builders of this time was the Jesuit monk Theodor Wulf. In 1909 he publishes on "A new Electrometer for static charges" [5]. A schematic view of his apparatus is given in Fig. 1 (*left*). Heart of the device is a pair of quartz fibers. They are attached at the bottom to a further, bend quartz fiber, which acts as a spring. By adjusting the tension on this spring, the sensitivity of the electrometer can be adjusted. The distance of the two fibers is measured through a microscope, which is attached at the circumference of the device. Series production of the devices was provided through the company Günther & Tegetmeyer, Braunschweig.

Wulf used his apparatus e.g. to measure small capacities [6]. Main application however, was a survey to find the origin of the radioactivity in the air. In his article "On the

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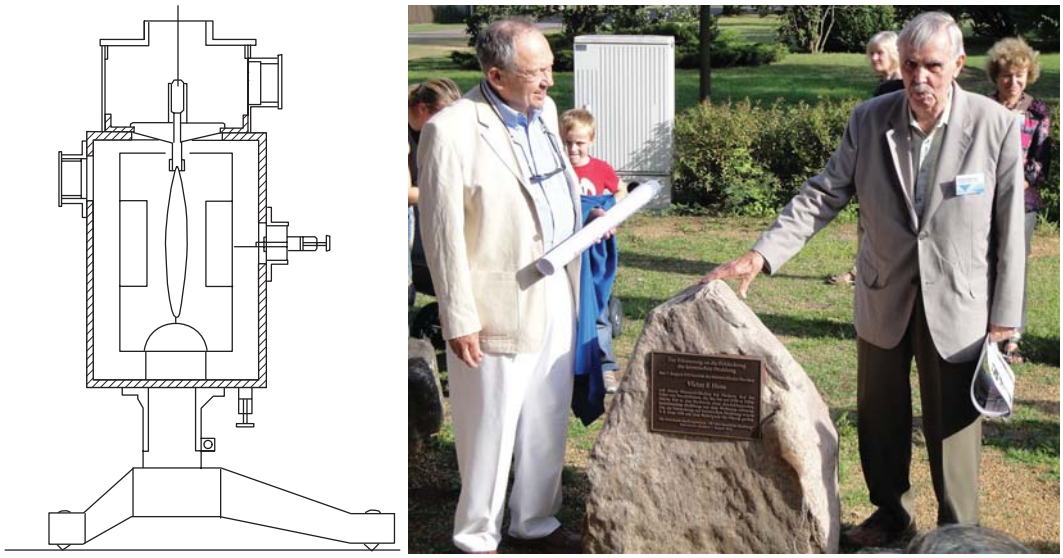

FIGURE 1. *Left*: Electrometer after Th. Wulf [5]. *Right*: Two grandsons of V.F. Hess revealing a plaque to commemorate the discovery of cosmic rays on August 7th, 2012, close to the presumed landing site of V.F. Hess in Pieskow close to Berlin. It reads: "To commemorate the discovery of cosmic rays. On 7 August 1912 landed the Austrian physicist Victor F. Hess with a hydrogen balloon close to Pieskow. On the journey from Lower-Bohemia he reached an altitude of 5300 m and he proved the existence of a penetrating, ionizing radiation from outer space. For the discovery of cosmic rays V.F. Hess has been awarded the Nobel Prize in Physics in 1936. The participants of the symposium '100 years cosmic rays', Bad Saarow-Pieskow, 7 August 2012".

origin of the gamma radiation in the atmosphere" [7] he describes a survey, conducted in Germany, the Netherlands, and Belgium, where he measured the intensity of the radiation in various places. He finds an anti-correlation between the radiation intensity and the ambient air pressure. His explanation sounds today rather exotic: one observes less radiation at higher pressure, since the radioactive air is pressed back into the soil/ground.[1] He summarizes his article [7]: "The contents of this article is best summarized as follows. We report on experiments, which prove that the penetrating radiation is caused by radioactive substances, which are located in the upper layers of soil up to a depth of about 1 m. If a fraction of the radiation originates in the atmosphere, it has to be so small, that it can not be detected with the present apparatus."

To prove this theory, Wulf carried an electrometer to the top of the Eiffel tower in Paris ("Observations on the radiation of high penetration power on the Eiffel tower") [8]. However, his measurements were not conclusive. At 300 m above ground he observed less radiation, but the radiation level did not vanish completely, as expected for a purely terrestrial origin.

[1] From a present point of view, in which the pressure effect is explained due to a variation of the absorber column density in the atmosphere, one may wonder that observing a pressure dependency has not led to the conclusion that the radiation penetrates the atmosphere from above.

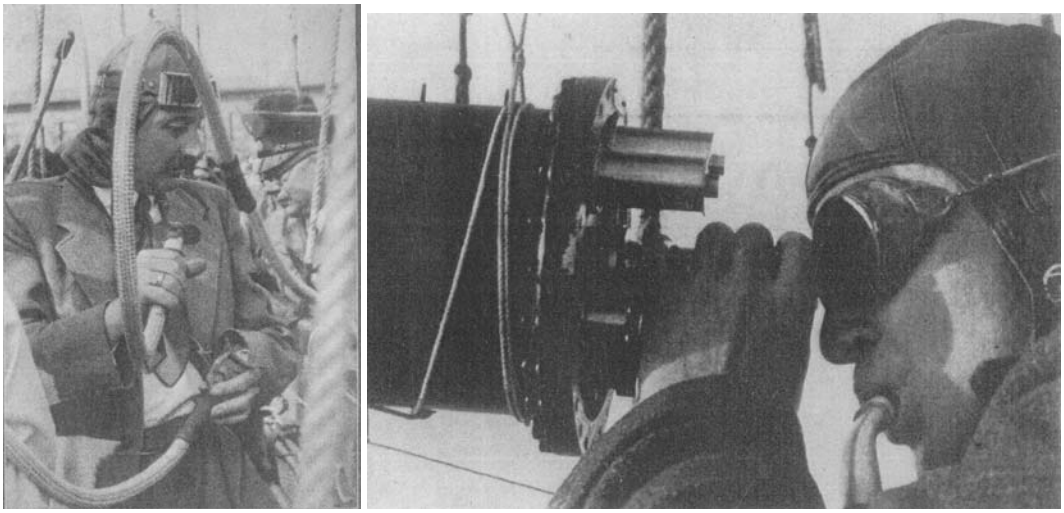

FIGURE 2. Dr. M. Schrenk (*left*) with a breathing apparatus in the balloon gondola and V. Masuch, reading an electrometer (*right*), preparing for their balloon launch on May 13th, 1934 [10].

BALLOON INSTRUMENTS

The next step was to carry electrometers to higher altitudes to obtain results beyond doubt. Among the first scientists to conduct such measurements was A. Gockel, reporting on "Measurements of the penetrating radiation during balloon campaigns" [9]. However, his results were not conclusive.

The break-through has been achieved by V.F. Hess in 1912. He used sealed, pressure tight electrometers. Thus, the particle number density inside the apparatus was kept constant, despite of the varying ambient temperature and air pressure during a balloon ascent. In his article "On the observation of the penetrating radiation in seven free balloon campaigns" [11] Hess reports on balloon ascends between April and July 1912. The decisive launch was conducted on August 7th, 1912 from Aussig an der Elbe (Austrian Empire). At 6:12 AM the balloon "Bohemia", filled with 1680 m^3 hydrogen was launched, carrying the pilot, Captain (of the K&K Austrian army) W. Hoffory, the "meteorological observer" E. Wolf, and the "air electrical observer" V.F. Hess to an altitude of 5300 m a.s.l. The balloon floated in northern direction, towards Berlin and landed at 12:15 PM, close to the village Pieskow (Prussia), 50 km east of Berlin. On August 7th, 2012, a plaque has been erected close to the assumed landing site to commemorate the discovery of cosmic rays, see Fig. 1 (*right*).

Hess conducted measurements with three independent electrometers during the flight. The radiation intensity recorded by Hess as a function of altitude exhibits first a decrease (as expected for a terrestrial origin) but then a strong increase above 1400 m. Thus, the terrestrial origin has been disproved. Hess summarizes his findings: "The results of the present observations can be most likely explained through a radiation of very high penetrating power, impinging onto the atmosphere from above, and being capable to cause the observed ionization in closed vessels even in the lowest layers of the atmosphere. The intensity of the radiation exhibits timely variations on hourly timescales. Since I did not find a reduction of the radiation intensity during night or during a solar eclipse, the

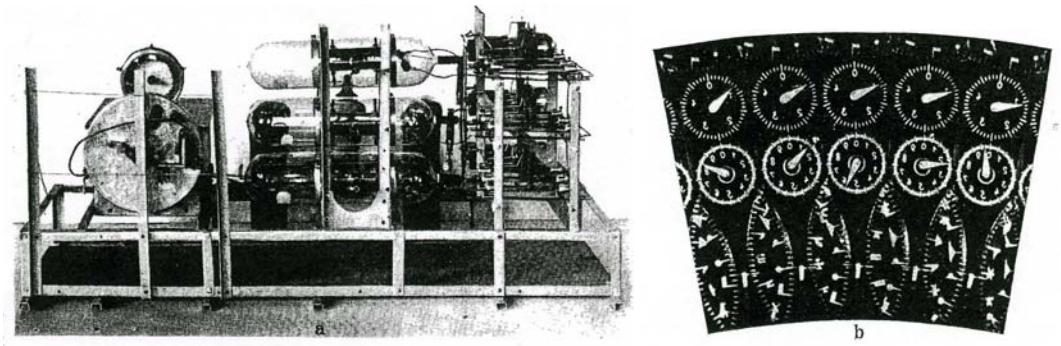

FIGURE 3. Recording instrument used by Pfotzer [14]. *Left*: the apparatus consists of (from left to right) a photographic recording unit, the electron vacuum tubes for the coincidence circuit, and a particle hodoscope, comprising of 3×3 Geiger-Müller tubes. *Right*: a photographic plate with the instrument readings, recorded automatically during the flight.

Sun can be excluded as the origin of this hypothetical radiation." Hess has been awarded the Nobel Prize in 1936 for his revolutionary findings.

The measurements were extended by W. Kolhörster to higher altitudes. He conducted "Measurements of the penetrating radiation in a free balloon at high altitudes" [12] to altitudes exceeding 9 km above sea level. These observations clearly demonstrated an increase of the intensity as a function of altitude, thus, clearly confirming an extra-terrestrial origin. Kolhörster has constructed his own electrometers ("A new thread electrometer") [13].

On May 13th, 1934 a balloon campaign was conducted under the leadership of W. Kolhörster to measure cosmic radiation up to altitudes of 12 000 m [10]. The balloon shell was comprised of two layers of cotton fabric, with a rubber layer in between. It had a diameter of 26.3 m and was filled with 10 000 m^3 hydrogen. It carried a wicker basket gondola with the dimensions 2.3 m $\times$ 1.8 m. To be able to breath at high altitudes, the crew used a breathing apparatus as shown in Fig. 2. It is comprised of an oxygen pressure bottle, a pressure reducing valve, and a mouth piece. They carried an oxygen supply for four hours. The balloon was launched on May 13th, 1934 at 8:32 AM in Bitterfeld (Prussia). During the balloon flight a tragic accident happened and the two collaborators of Kolhörster died in the balloon gondola: Dr. M. Schrenk and V. Masuch. The dead bodies and the balloon were found close to Sebesh (Russia) close to midnight, about 1400 km from the launch point.

As a next step in the historical development the electroscopes were replaced by a new type of detector: the Geiger-Müller tubes [15]. An essential step towards unmanned balloons with an automatic read-out of the measurement devices was the invention of the coincidence technique, reported by W. Bothe and W. Kolhörster in "The nature of the high-altitude radiation" in 1929 [16]. Two Geiger-Müller tubes have been operated in coincidence with a metal absorber between the two tubes. The intensity of the penetrating radiation has been measured as function of the thickness of the absorber material. For the discovery of the coincidence technique, W. Bothe has been awarded the Nobel Prize in 1954.

G. Pfotzer constructed a particle hodoscope, comprising of a matrix of 3×3 Geiger-Müller tubes, operated in coincidence [14], see Fig. 3 (*left*). The coincidences were

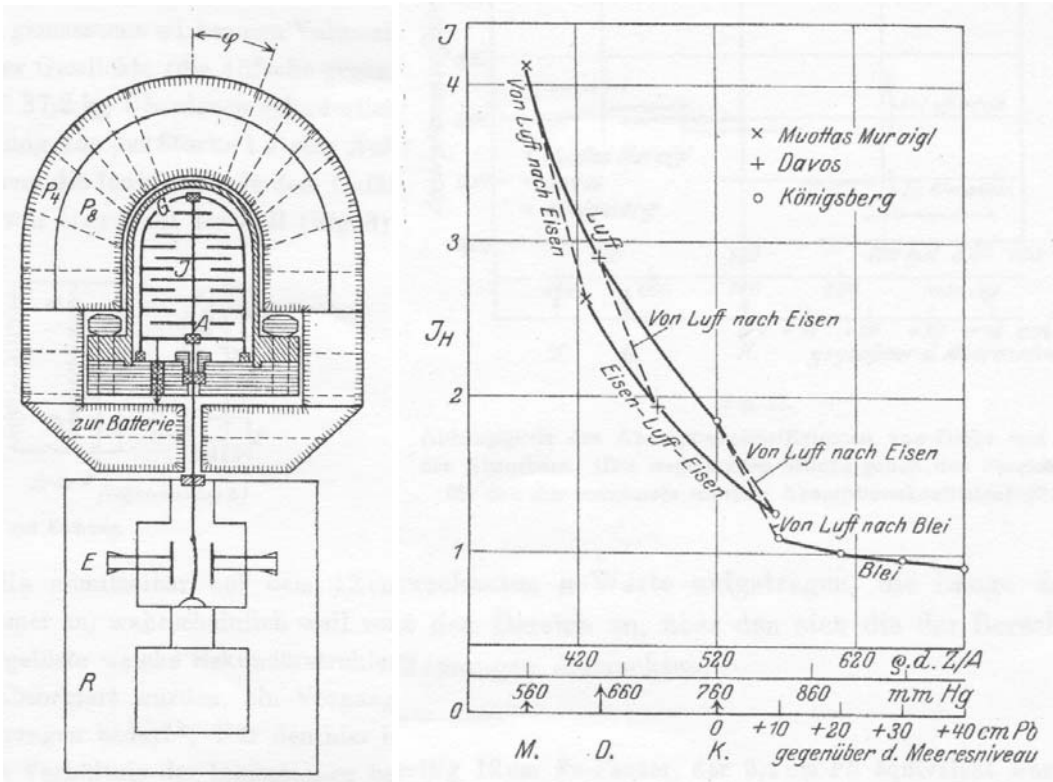

FIGURE 4. *Left*: Ionization chamber with electrometer read-out, used by Steinke to measure the radiation intensity. *Right*: Measured intensity of the penetrating radiation as a function of the atmospheric overburden [17].

recorded with an electric circuit, build with electron vacuum tubes. The readings of the instruments (particle rate, ambient air pressure and temperature) were photographed with an automatic camera, taking pictures in a predefined time interval. After each picture, the photographic plate was rotated. After the flight, the photographic plate had to be recovered and it was analyzed under a microscope, see Fig. 3 (*right*). Pfotzer measured the particle rate as function of pressure/altitude up to a height of 29 km.

He reports about "Three-fold coincidences of the ultra rays from vertical direction in the stratosphere" [14]. The measured intensity exhibits a strong increase as a function of the altitude, reaching a maximum at a height of about 15 km, where the particle rate is more than 20 times higher, as compared to sea level.The maximum is today referred to as "Pfotzer maximum" after its discoverer.

ABSORPTION OF COSMIC RADIATION

E. Steinke conducted "New investigations of the penetrating Hess rays" [17] and he studied the absorption of the radiation in the atmosphere in 1928. He used an ionization chamber, read out by a Wulf one-string electrometer. The ionization chamber was shielded by a segmented 12 cm iron absorber. The set-up is shown in Fig. 4 (*left*).

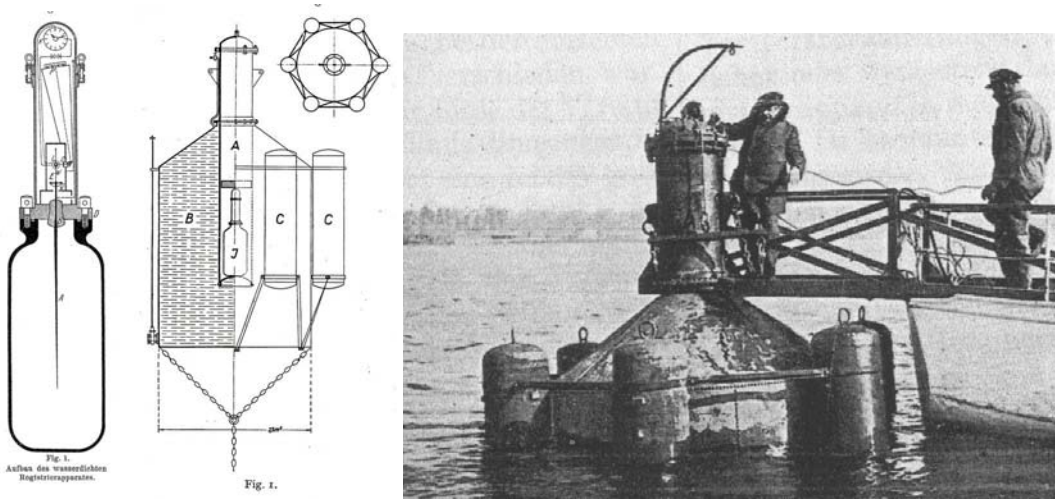

FIGURE 5. An ionization chamber with automatic read-out, used by Regener to measure the absorption of the radiation in Lake Constance [18].

Individual segments of the shield could be removed, thus, the apparatus was sensitive to radiation from a certain zenith angle interval. He measured the radiation intensity as a function of the zenith angle at different altitudes above sea level, starting from Königsberg (Prussia) 0 m a.s.l., via Davos (Switzerland) 1600 m a.s.l., to Muottas Muraigl 2500 m a.s.l. The results are depicted in Fig. 4 (*right*). It should be noted that he already put on the abscissa $d \cdot \rho Z/A$, i.e. $\Delta E = d \cdot dE/dx$, the energy loss in the atmosphere, measured from the top.[2]

Steinke points out that "the direction and absorption measurements allow a flawless separation of the Hess rays from the ambient radiation. The angular distribution of the Hess rays, corresponds to values, which are compatible with the assumption of an isotropic radiation from outer space, taking into account the absorption along the different pathlengths through the atmosphere." He points out that the absorption coefficient depends on the absorber material, and not only on the column density, see Fig. 4 (*right*) and he suggests to describe the radiation with two components: a "hard" and a "soft" component.[3]

Steinke conducted systematic studies of the intensity variations. He reports "On variations and the barometric effect of cosmic ultra rays at sea level" [21] and describes periodic and non-periodic variations, such as an anti-correlation between the ambient pressure and the radiation intensity (barometric effect), as well as an annual modulation and a sidereal modulation of the cosmic-ray intensity.

To study the absorption of the ultra rays in water E. Regener constructed an ionization chamber with electrometer read-out. The apparatus was attached to a buoy, as sketched

[2] H. Bethe published his "Theory of the passage of fast corpuscular radiation through matter" in 1930 [19]. The Bethe-Bloch equation to describe the energy loss of a particle traversing matter gives the proportionality $dE/dx \propto \rho Z/A$.

[3] Similar measurements were conducted later by B. Rossi and colleagues at Mt. Evans in Colorado and Rossi realized that the differences in the absorption curves are caused by the decay of muons [20], p. 118.

FIGURE 6. Three pioneers of cosmic-ray research: Regener (right) demonstrates his balloon electrometer to Hess (left) and Steinke (center). Immenstaad/Lake Constance, August 1932.

in Fig. 5, and could be lowered into the water to record the radiation intensity. The apparatus recorded automatically the intensity every hour for up to eight days. Regener conducted measurements in Lake Constance up to a depth of 250 m. He reports on "The absorption curve of the ultra radiation and its interpretation" [18] and discusses the attenuation of the ultra rays, measured in meter water equivalent, counted from the top of the atmosphere. He states that cosmic rays are with high probability undulatory radiation and he strictly denies a corpuscular nature of cosmic rays. As a nice anecdote it may be remarked that Regener named the boat, which was used to conduct the measurements, "Undula", indicating his believe about the nature of the radiation. During the measurements at Lake Constance the photograph shown in Fig. 6 has been taken.

It was also Regener, who pointed out in his article on "The energy flux of the ultra rays" [22] in 1933 that the energy flux of cosmic rays corresponds roughly to the energy flux of starlight. For the cosmic-ray intensity at the top of the atmosphere he gives a value of $3.53 \cdot 10^{-3}$ erg cm^{-2} s^{-1} and he notices that this value corresponds to a flux of a couple of hundred α-particles per cm^2 and s, impinging onto the atmosphere of the Earth. He also conducts an interesting calculation: a celestial body, which is exposed to cosmic rays will be heated through the absorption of cosmic rays. The body reaches a temperature of about 2.8 K.

EXTENSIVE AIR SHOWERS AND NUCLEAR INTERACTIONS

The coincidence technique also brought the next step forward in the observation of cosmic particles at ground level. W. Kolhörster placed two Geiger-Müller counters next to each other and operated them in coincidence. He recorded the number of coincidences as a function of the distance between the two counters, as illustrated in Fig. 7 (*left*). Objective of these investigations was to determine the random coincidence rate between the two counters. However, the measurements clearly indicated an excess of coincidences, which led to the discovery of extensive air showers. In 1938 he reports about "Coupled high-altitude rays" [23]. He explains that the observed particles are secondary particles from cosmic rays, i.e. air showers. The secondary particles in the showers are produced at high altitudes above the ground and they are distributed over a large area on

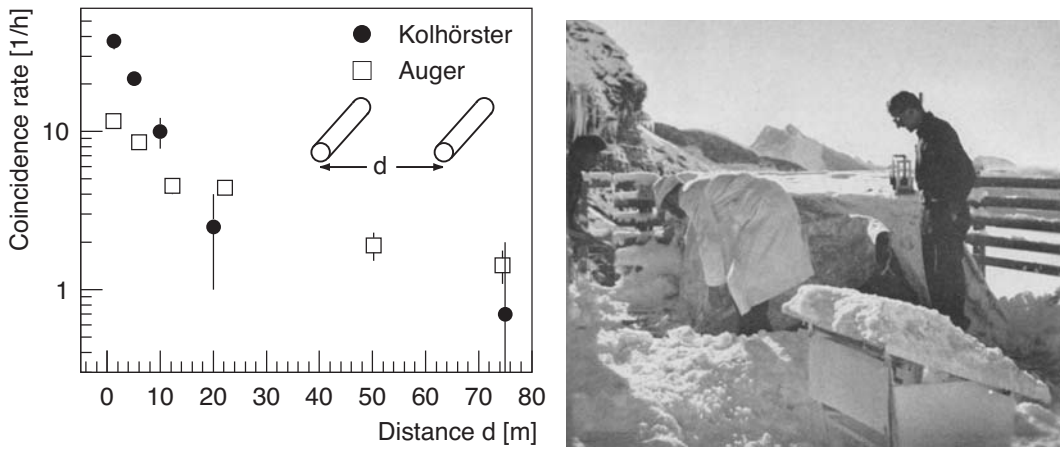

FIGURE 7. *Left*: Coincidence rate as a function of the distance between two Geiger-Müller counters as obtained by W. Kolhörster [23] and P. Auger [24]. *Right*: P. Auger measuring air showers at the Jungfraujoch in Switzerland [25].

the ground. Coincidences have been registered even up to a distance of 75 m. To prove his findings he also conducted an additional experiment, using three counters, operated in a three-fold coincidence with a good time resolution of 5 μs. Also with this set-up he found an excess of coincidences, clearly confirming his discovery of air showers.

Similar investigations were conducted by P. Auger on the Jungfraujoch in the Swiss Alps, see Fig. 7 (*right*), and at other places [24]. The results obtained by Auger are in good agreement with the measurements by Kolhörster and colleagues as can be inferred from Fig. 7 (*left*).

However, the physical interpretation of the measured showers was not easy. The development of electromagnetic cascades has been known (e.g. [26] and later written up in [27]). But without knowing the pion (discovered in 1947 [28]) and the development of hadronic showers, it was hard to fully understand the measured attenuation coefficients. A first step towards this was the discovery of hadronic interactions.

V. Hess has established a high-altitude laboratory to study cosmic rays at the Hafelekar mountain at an altitude of 2300 m a.s.l. above Innsbruck in Austria. The laboratory is shown in Fig. 8 (*left*). M. Blau and H. Wambacher worked in this laboratory and they used photographic plates to investigate cosmic rays and their interactions. They studied "Disintegration processes by cosmic rays with the simultaneous emission of several heavy particles" [29]. They found hadronic interactions of cosmic particles with the nuclei inside the photographic emulsion. Such a "star" is depicted in Fig. 8 (*right*). Such processes were interpreted as the disintegration of an atom(ic nucleus) in the emulsion. This was the birth of the emulsion technique to study the interactions of particles.

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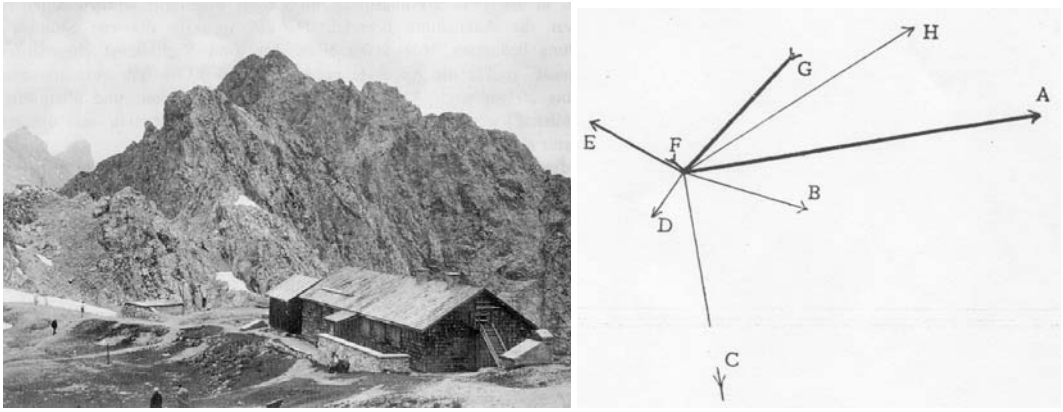

FIGURE 8. *Left*: High-altitude laboratory to study cosmic rays and their interactions, established by V. Hess on the Hafelekar mountain [2]. *Right*: A hadronic interaction process (a "star") recorded in a photographic emulsion [29].

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