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Spontaneous ionization to subatomic physics: Victor Hess to Peter Higgs

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Abstract

The discovery of cosmic rays, a milestone in science, was based on the work by scientists in Europe and the New World. Many scientists that took part in this research a century ago were intrigued by the penetrating radiation and tried to understand the origin of it. Cosmic ray physics is at the foundations of modern particle physics, and some of the recent discoveries in particle physics find their roots in cosmic-ray physics.

1. The spontaneous discharge of electroscopes

A typical electroscope, in the configuration which was invented at the end of the XVIII century (Figure 1), consists of a vertical metal rod from the end of which hang two gold leaves. A disk or ball terminal is attached to the top of the rod, where the charge to be tested is applied. To protect the gold leaves from drafts of air they are enclosed in a glass bottle. The gold leaves repel, and thus diverge, when the rod is charged.

One could think at first glance that, if isolation were perfect, an electroscope should always maintain its charge. An unexpected result came from the first experiments on electricity by Charles-Augustin de Coulomb, who found, around 1785 [1], that electroscopes can spontaneously discharge by the action of the air and not by defective insulation. He published this result in his famous "Mémoires sur l'électricité et le magnétisme".

Also Michael Faraday addressed the problem around 1835 [2], confirming with greater accuracy the results by Coulomb. Crookes [3] then measured in 1879 that the speed of discharge of an electroscope decreased when the air pressure was reduced. It became therefore clear that the direct cause of the discharge of the electroscope should be the ionization of the air contained in the instrument itself. But what was the cause of this ionization?

Figure 1: An electroscope of the end of XVIII century.

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The explanation of the phenomenon of spontaneous discharge came in the beginning of the 20th century and paved the way to one of mankind's revolutionary scientific discoveries [4]: cosmic rays.

2. The puzzle of atmospheric ionization

The study of the rate of discharge of an electroscope required a rather sophisticated experimental technology; fortunately this type of measurement was very popular since the late eighteenth century, as related to issues concerning atmospheric electricity, and ultimately meteorology. The technique was also developed in the United States, Canada, Italy, Germany, and particularly in Austria. In most cases these studies were financed thanks to the possible interest for agriculture and military science, two areas which would have greatly benefited from the possibility that humans were able to influence the weather thanks to electricity.

In 1896 Becquerel [5] discovered spontaneous radioactivity. A few years later, Marie and Pierre Curie discovered [6] that the elements Polonium and Radium suffered transmutations generating radioactivity: such transmutation processes were then called "radioactive decays". In the presence of a radioactive material, a charged electroscope promptly discharges. It was concluded that some elements were able to emit charged particles, that in turn caused the discharge of electroscopes. The discharge rate of electroscopes was then used to gauge the level of radioactivity.

This observation opened in Europe and the New World (US and Canada in particular) a new era in research related to studies on natural radioactivity, and somehow unified, thanks to the common experimental technique, studies of ionization in the context of meteorology and research related to natural radioactivity.

Around 1900, Elster and Geitel in Germany, and Wilson in England, improved the technique for a careful insulation of electroscopes in a closed vessel, thus improving the sensitivity of the electroscope itself. As a result, they could make quantitative measurements of the rate of spontaneous discharge.

Julius Elster (1854-1920) and Hans Geitel (1855-1923), a key experiment in 1899, isolated the electroscope by putting it in a thick metal box. Also in these conditions they found a decrease in radioactivity, thus concluding [7] that the discharge was largely due to highly penetrating ionising agents. The obvious question was if the radiation measured was coming from the ground, from the atmosphere, or if it was extraterrestrial. The simplest hypothesis was that its origin was linked to radioactive materials, and thus the terrestrial origin was the common assumption; however a demonstration seemed difficult to achieve.

Charles Thomson Rees Wilson (1869 – 1959) was a Scottish physicist; in 1911 he will invent the detector called "cloud chamber" or "Wilson chamber", which has been fundamental for the history of physics and of cosmic rays in particular – in 1927 he will be awarded the Nobel prize for physics. Wilson was interested to the problem of the origin of penetrating radiation, and immediately in 1901 confirmed the result by Elster and Geitel, and suggested the possibility that the source of the ionization could be extraterrestrial [8]. He wrote: "we must conduct experiments to determine if the production of ions in the air free of impurities can be explained as arising from external sources, probably Röntgen radiation rays or cathode rays, but largely more penetrating". Wilson carried his electroscope in a tunnel in Scotland, screened by the surrounding rock, but could not measure, because of experimental uncertainties, a reduction of radioactivity with respect to the open air as he expected to find if the extraterrestrial hypothesis had been true. The theory of an extraterrestrial origin of the radiation, although occasionally discussed, was abandoned for the next ten years.

The result of the many experiments performed up to 1909 was that the spontaneous discharge was consistent with the hypothesis that even in insulated environments a background radiation did exist. Calculations were made of how this radiation, thought to be gamma radiation due to its penetrating power, should decrease with height (in particular by the Eve), and attenuation measurements were performed.

3. Father Wulf

The electroscope was a delicate instrument, difficult to transport: a technical improvement was needed to make measurements easier. In addition, new ideas on what to look for in measurements were possibly needed. Although the leading institute for the research on atmospheric ionization was Vienna, these questions were answered by the fundamental work of an independent researcher, father Wulf. Theodor Wulf (1868 - 1946), a German scientist and jesuits priest, designed and built a more sensitive, and above all, more transportable, electrometer than normal gold-leaf electroscopes: in Wulf's electroscope the two leaves were replaced by two strips of metalised glass in tension.

In 1909 and 1910 [9, 10] he traveled to Paris bringing his electroscope (Figures 2,3) with him, and measured the ionization rate on the top of the Eiffel Tower (about