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THEN & NOW

How the Geiger Counter started to crackle: Electrical counting methods in early radioactivity research

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The Geiger (or Geiger–Müller) Counter is probably one of the most widely known scientific instruments of our times. It stands for protection against radioactivity and, at the same time, for the fear of it. In the postwar period, it came to be a sixth sense for society and was a "watchdog of the Atomic Age" [1]. The Geiger–Müller Counter was one of the first electrical devices that could detect α-, β-, and γ-radiation equally well. In the spring of 1928, Walter Müller (Fig. 1b) developed the first prototype counter in Kiel, Germany, supervised by his former doctoral advisor, Hans Geiger (Fig. 1a).

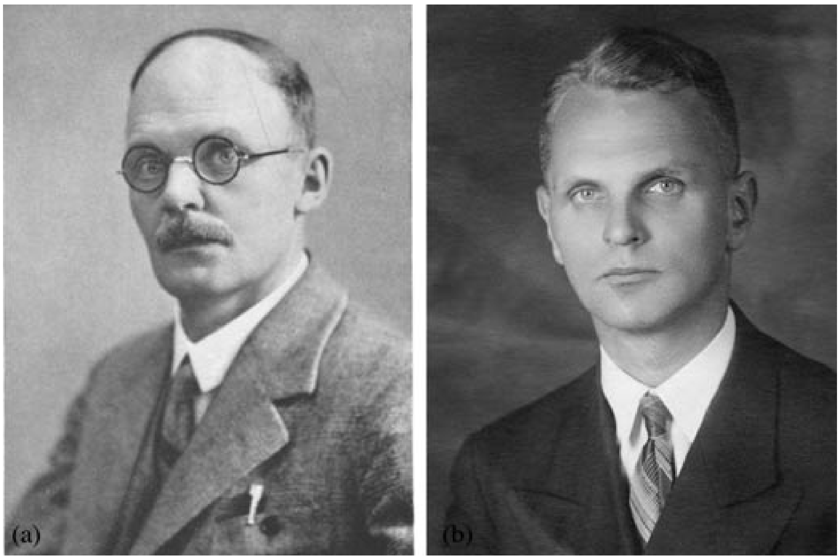

Figure 1 Hans Geiger (1889–1945) [2] and Walter Müller (1905–1979) (Deutsches Museum, NL24).

The events, on which the development of the "most sensitive organ of humanity"[1] was based, had their origin before the Great War. In the early 20th century, several methods had already been developed for electrically counting radiation events. Geiger had been involved in the development of some of these devices, for which lateral cuts are displayed in Fig. 2.

Geiger had been an assistant to Rutherford in Manchester since 1906. Together, they had developed an ionization chamber for the electrical counting of α-particles in 1908 (Fig. 2a). In 1912, Geiger returned from Manchester to become the director of the new radioactivity laboratory at Physikalisch-Technische Reichsanstalt (PTR) in Berlin. One hundred years ago, in 1913, he published about the development of the Point Counter (Fig. 2c) in the *Verhandlungen* of the German Physical Society [4]. However, his initial intention had been to reconstruct a hemispherical counter, which he had developed together with Rutherford shortly before his departure to Germany (Fig. 2b, [5]). Later, he would describe this counter as a kind of "lucky punch" (Geiger cf. [6] p. 16), because he was not able to reproduce the device. He therefore varied the setup, replacing the central ball by a sharp point and changing the shape of the casing. Geiger was astonished that this new cylindrical design—contrary to its two predecessors—could be operated under atmospheric pressure without the need for a stable vacuum and with a negative potential on the point (Fig. 2c). The 1908 Rutherford–Geiger Counter (Fig. 2a, [3]) refused to work with standard pressure and opposite polarity. Moreover, the Geiger Point Counter was sensitive not only to α-particles, like the 1908 Rutherford–Geiger counter and basic scintillation detectors, but to β-radiation as well. Although "the actual physical principle of its [the Point Counter's]

[1] Einstein to Geiger cf. Müller's letter to his parents, April, 15th 1929, Deutsches Museum, NL24, 7/30.

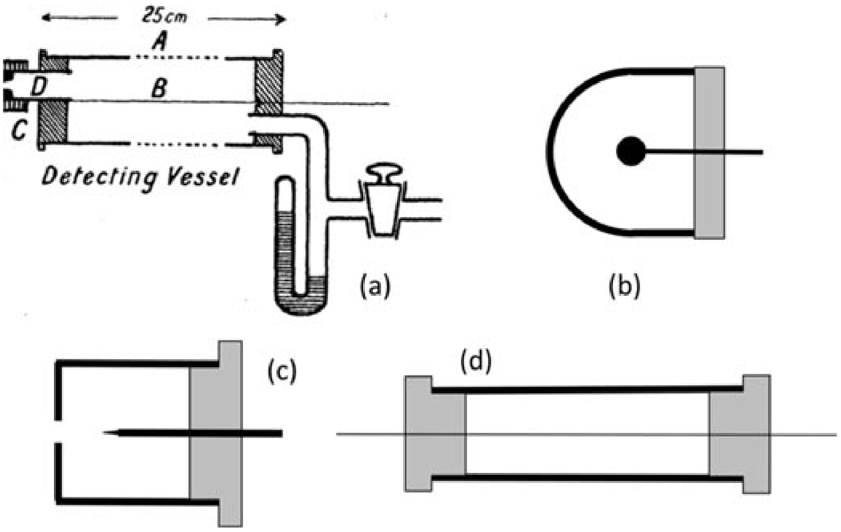

Figure 2 The 1908 Rutherford–Geiger Counter (a, [3]), the 1912 Hemispherical Counter (b), the 1913 Geiger Point Counter (c) and the 1928 Geiger–Müller Counter (d).

working was not yet clear by the mid-1920s the point counter had come into standard use." [7].

The key scientific criticism raised about Geiger's new Point Counter as well as about the Rutherford–Geiger Counter (see, e.g., [8, 9]) was the appearance of spontaneous discharges inside the chamber and how they could be distinguished from 'real' counting events of α- or β-radiation. In 1908, the reason for such disturbances was believed to be an artifact of the radioactively contaminated casing of the counter, or to be a mere constructional defect. Geiger's and Rutherford's pragmatic solution was to reduce the amount of material by scaling down the diameter of the casing.

In the Point Counter's case it soon became clear that the point was the crucial part for a well-working device with a minimum of disturbances. Several methods, such as sharpening the point of a sewing needle with a leather belt, tempering the point in a flame, adding a flaring around the point, or melting on a small platinum ball were used to guarantee the proper functioning of a Point Counter – however, not without a fair amount of 'tacit' knowledge[2]. Despite its great "simplicity and sensitivity" [4] p.535, only a handful of researchers, among them Walther Bothe and Lise Meitner, were able to handle both the Point Counter and its construction. Walter Müller wrote in 1957:

> "The Geiger-Point-Counter was not easy to handle. It was very difficult to activate the point in the right manner and to operate it over a longer period. [...] Nevertheless, outstanding results have been achieved with Geiger's Point Counter due to the 'Experimentierkunst' particularly of Geiger himself but also others, such as Bothe and Miss Meitner."[3]

A famous example for Geiger's 'experimental craftiness' [Experimentierkunst] is the coincidence experiment by Geiger and Bothe. They designed the experiment to confirm the validity of energy conservation in the Compton scattering of X-rays. They demonstrated the temporal coincidence of the scattered photon and the electron with two Point Counters, for which Bothe was awarded the Nobel Prize in Physics in 1954.[4]

A few years later, in 1925, Geiger became full professor of experimental physics at the University of Kiel. Walter Müller (1905–1979) at that time was studying physics and mathematics in Kiel. He applied for a position as a PhD student in Geiger's laboratory. In the spring of 1928, he completed his dissertation on the sparking potential in ionization chambers and became Geiger's assistant. According to Müller's notebooks, his first task was to prepare Point Counters for experiments with X-rays in a way that had been proposed in a short article in *Physical Review* [12]. Instead of the 'traditional' tempering of the point with a flame, which had been proposed by Geiger back in 1913, he treated the point with phosphoric acid—with astonishing results. He wrote in his notebook that the altered counter registered 8.5 times more particles than an ordinary counter.[5] In his spare time, Müller tested this point variant in the ionization chamber he had used for his earlier experiments. This Chamber was similar to the setup that had been designed by Rutherford and Geiger in 1908. Like Rutherford and Geiger and a few others before him, he came across the spurious discharges inside the chamber, which made a quantitative

2 For more details, see e.g. [11].
3 Letter from Walter Müller to Eduard Wildhagen, 10 May 1957, Deutsches Museum Archive Munich, NL 24–7/30, author's translation.
4 For more details, see [11].
5 Lab Book No.3 by Walther Müller, p.18, Dibner Library of Rare Books, Smithsonian Institution Washington D.C., MSS 001707 B, v3.

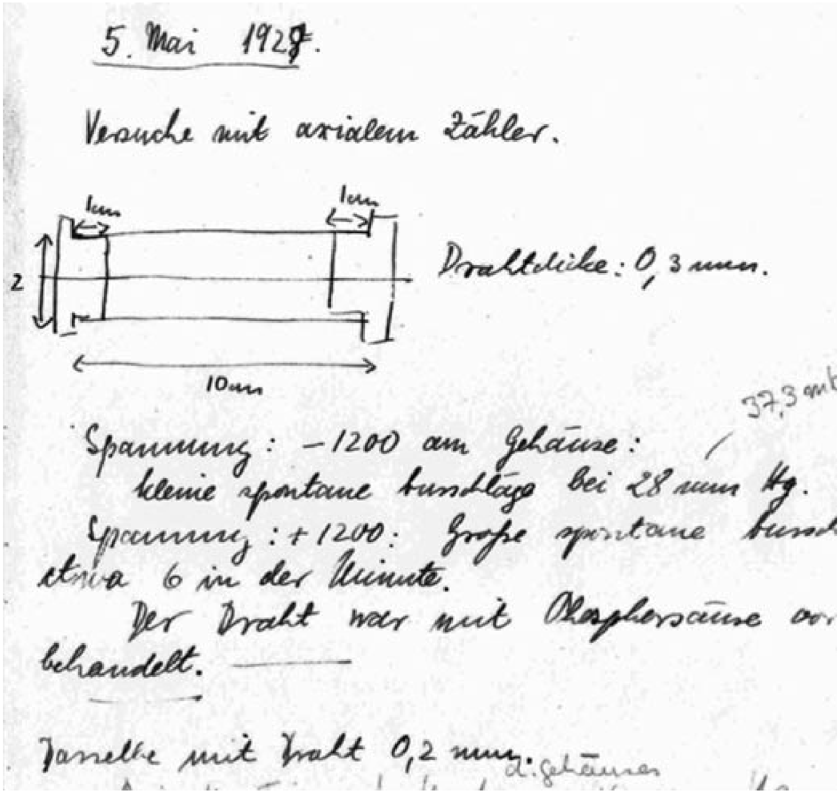

Figure 3 Lab book entry from 5 May 1928 by Walter Müller. This entry probably contains the first sketch of a Geiger–Müller Counter.[6]

measurement very delicate. Müller and Geiger identified these discharges as actual counts of cosmic rays at sea level. These had recently been proposed by Geiger's former colleague Werner Kolhörster [13, 14]. The number of counts was constant over time and depended on the thickness of the applied lead and iron shielding. Geiger and Müller also verified the less-intense γ-decay of potassium chloride with only a few gram of the salt. Figure 3 shows the first page in Müller's notebook dealing with the device later to be known as the Geiger–Müller Counter.

The measurement principle of the new counting device was different from its predecessor. It did not detect β- and γ-radiation directly, but secondary electrons, which were released at the inner surface of the counter under the influence of the external radiation. It is because of this mechanism that the device was at first made public under the name electron counting tube [Elektronenzählrohr] in July 1928 [15]. Very rapidly thereafter, it came to be known as the Geiger–Müller Counter. However, until the 1930s, the Point Counter and the scintillation method were primarily used for the purpose of counting α-particles. To also enable the Geiger–Müller Counter to detect α-particles a thin mica window was added that enables the Helium nuclei to get inside the counter. This constructional change as well as the rising confidence in the accuracy and reliability of electrical amplification methods of counting atomic particles [16] made at least the 1913 Geiger Point Counter obsolete. The scintillation method was revived in the 1950s in the context of novel optical amplification methods.[7]

However, the construction of suitable Geiger–Müller Counters for third parties was as difficult as it had been in the case of the Point Counter. The success or failure of experiments with the counter in the new developing field of cosmic-ray research depended on technical skills and factual knowledge. Patrick Blackett described it as follows: "The Geiger counter was a very delicate instrument [. . .]. In order to make it work you had to spit on the wire on some Friday evening in Lent."[8] Bruno Rossi, who had learned the 'art' of constructing a counter at Bothe's Berlin laboratory, in 1981 wrote that building "a Geiger–Müller counter was, at that time, a kind of witchcraft." [18] p.35.

In order to understand why there were so many difficulties in handling the counter, so many obscure instructions for their construction and for dealing with the appearance of unexplainable discharges, one needs to analyze the different kinds of Geiger Counters that evolved between 1908 and 1928.

There are actually four different 'Geiger Counters'. One can divide them into two categories: Unlike the Point Counter (Fig. 2c), the three other devices (Figs. 2a, b and d) work at low pressure—between 20 and 80 mbar—and with negative potential on the wall. Inside these

6 Lab Book No.3 by Walther Müller, p.21, Dibner Library of Rare Books, Smithsonian Institution Washington D.C., MSS 001707 B, v3 (by courtesy of the SI and H. Gillem).

7 For more details, see [17].

8 Summary of Oral History Interview of Blackett by John Heilbron, 17 December 1962 in London, Archive for the History of Quantum Physics, American Philosophical Society, Philadelphia, PA.

simple capacitors, the charge of an incoming α-particle or electron is detected by producing an electron avalanche right next to the wire. The resulting current is high enough to create a voltage drop at the serial resistance of 1 GΩ that could be registered—in Geiger's time—with a suitable string electrometer or a loudspeaker. This method with its distinct crackling noise was used by Geiger and Müller for demonstration purposes from very early on. The several milliseconds that are needed for the process of quenching the discharge is the time constant τ in the RC-circuit formed by the Geiger–Müller Counter and the resistor. The long dead time (compared to today's standards) and the loss of counts at high count rates was only considered from the mid-1930s onwards. The detection mechanism of the Point Counter is misleadingly similar. Although the applied potential of about 1.4 kV is of the same order of magnitude, the electrical field of the Point Counter is much less homogeneous compared to the other three devices due to their cylindrical shape. The field of the Point Counter gets stronger the closer one gets to the point. However, despite this comparably stronger electrical field, because of the short mean free path under atmospheric pressure, an incoming α- or β-particle cannot ionize the gas molecules sufficiently in the case of the Point Counter. An ionizing particle rather induces a spark discharge, which will be quenched by a high resistance connected to earth potential. Hence, to achieve such a discharge only strongly radioactive elements like radium could be used for experiments with the Point Counter.

Looking back to Geiger's first counter of 1908, one can speculate that the unexplained spurious discharges were probably caused by cosmic rays as well. The shape and the working parameters of this counter and the Geiger–Müller Counter of 1928 are strikingly similar. The surface of both counters is proportional to the number of released electrons and, therefore, to the number of counts of γ-radiation or cosmic rays at sea level. Hence, one can state that the Geiger–Müller Counter was not superior to its predecessors from 1908 or 1912 on a physical or technical level. The achievement of Geiger and Müller was to improve the prototype of the counter in a way that allowed a stable experimental setup with reliable and reproducible results. The constructional changes concerning the sealing, the material, the wire, or the external registration circuit affected the establishment of the new counting device, which used the well-known principle of ionization by collision in a superior way. Müller designed at least three different versions of the early Geiger–Müller Counters, which, on the one hand, display constructional and technical problems and, on the other hand, show necessary improvements, such as airtight sealing. A recent historical analysis of the Geiger–Müller Counter's genesis with the replication method [19] describes the constructional development from a modern viewpoint. Dealing with this method, one tries to reconstruct the instrument and re-enact experiments based on primary sources in order to understand the factual or artisan dimension of a researcher's work that is usually not documented or conveyed. Reconstructing an early Geiger–Müller Counter has shown that at least Blackett's and Rossi's reviews can be understood easily. One has to acquire knowledge about all undocumented details such as material, constructional procedures, and experimental behavior. Only a few of Geiger's and Müller's counters were shipped to close colleagues, e.g., to Rutherford at the Cavendish Laboratory in Cambridge. Other researchers sent their assistants to Kiel to work hands-on with the counter because they had so many problems getting it to work. Müller's tacit and factual knowledge about the instruments and experiments was at least as essential as Geiger's social status and influence in the scientific community of experimental physicists in the early 20th century.

Thus, simplicity, constructional skills, and social status were the ideals for experimental physical research in the early days of radioactivity and cosmic-ray research. As it still holds today, the success of experiments depended crucially on the technical ability and skills of the staff in the laboratory, which consisted of mostly tacit knowledge about material and constructional details. In the case of the Geiger–Müller Counter, these details were kept secret on purpose at least until Geiger became professor at the university of Tübingen in October 1929. Since then, the Geiger–Müller Counter has been produced by a company in Kiel for a broader group of users. More recent Geiger–Müller counters are often more sophisticated, yet they share with their 1928 ancestors not only their fundamental principle of measurement, but also their unambiguous crackling sound.

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