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P M S Blackett, G Occhialini and the invention of the counter-controlled cloud chamber (1931–32)

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Abstract

Among the most important detecting devices in the 1930s, cosmic-ray experimental physics figures the so-called 'counter controlled cloud chamber'. This apparatus was jointly developed in 1932 by P M S Blackett, the cloud chamber expert at the Cavendish Laboratory in Cambridge and by G Occhialini, who mastered the counting coincidence technique following his work under the guidance of B Rossi in Florence. In this paper we address the original technical description of the apparatus and place its development within the historical and scientific framework of 1930s physics.

1. Introduction

There is undoubtedly a good deal of truth in Ernest Rutherford's judgement that the cloud chamber was 'the most original and wonderful instrument in scientific history' ([1], p 216). This device had indeed the special honour of being the subject of two Nobel prizes in physics. In 1927, the Scottish physicist C T R Wilson was awarded the prize 'for his method of making the paths of electrically charged particles visible by condensation of vapour', i.e. for the construction of the cloud chamber. And 21 years later, the Cambridge physicist Patrick Blackett was the recipient of the prize 'for his development of the Wilson cloud chamber method, and his discoveries therewith in the fields of nuclear physics and cosmic radiation'. In particular, the immense value of the cloud chamber method for cosmic-ray research purposes was discovered in 1932, when its efficiency was multiplied many times over, following the development of the so-called 'counter-controlled cloud chamber'. By this method—designed by Blackett together with a young Italian physicist from the Florence Institute of Physics, Giuseppe Occhialini—the cloud chamber was 'brought into function only when the impulses from two Geiger–Muller tubes, placed one above and one below the vertical Wilson chamber, coincide as the result of the passing of an electrically charged particle through both of them' [2].

As it is well known, through their apparatus, Blackett and Occhialini discovered the cosmic-ray 'showers' and 'constructed a forceful case' [3] for the existence of a novel particle, the 'positron'. Owing to their lasting legacy to cosmic-ray experimental physics, the extensive secondary literature devoted to their 1930s collaboration should come as no surprise [4]. Broadly defined, research on Blackett and Occhialini's efforts ranges across investigations of their scientific backgrounds, especially institutional histories of physics in Cambridge and Florence [5, 6], analyses of their experimental contributions to the contemporary cosmic-ray physics [7, 8], discussions of how their joint work was born and how it drew a connection between the positron and P A M Dirac's 'anti-electron' [9, 10] and finally, publications of scientific biographies [4, 11] and autobiographies [12]. In spite of the above extensive literature, the actual apparatus which enabled Blackett and Occhialini's accomplishment, received comparatively minimal attention. The most detailed accounts usually covered the whole subject by sketching the apparatus and briefly discussing its advantages with respect to the standard Wilson chamber, and by endorsing Blackett's judgement that 'the marrying of the counter technique with cloud chamber was an obvious step' ([13], p 57).

In this paper, we have focused our attention on the original scientific descriptions of the counter-controlled cloud chamber with the goal of studying what the 'marrying of the counter technique with cloud chamber' actually meant, which were the advantages of this marrying, which were its possible drawbacks, and, finally, what were the problems Blackett and Occhialini had to overcome.

In order to place the counter-controlled cloud chamber within the historical and scientific framework of 1930s physics, we have structured our paper as follows: section 2 covers the most notable developments and achievements of the cloud chamber technique since the development of Wilson's apparatus; section 3 presents the Geiger–Müller counter and the coincidence technique; section 4 discusses the original description of Blackett and Occhialini's apparatus; section 5 covers advantages, drawbacks and achievements of this device; finally, section 6 contains some conclusions.

2. Cloud chambers

As it was discussed in a past issue of *Eur. J. Phys*, the cloud chamber was developed at the Cavendish Laboratory in 1911–12 by Wilson as a method for making visible and photographing the tracks left by ionizing particles such as α and β particles [14]. Wilson had indeed previously discovered that the ions act as nuclei of condensation of water vapour when a certain supersaturation is reached. This supersaturation was produced by the sudden expansion of dust-free air saturated with water vapour. The expansion apparatus (figure 1) consisted of an expansion chamber, cylindrical in shape and completely closed, whose movable base (A) slid inside a cylinder and served as a piston. The expansion was made by a valve (B) that put the space below A in communication with a vacuum chamber (C) through glass tubes. This expansion apparatus was synchronized, by means of a falling weight, with the illumination apparatus (a Leyden jar electric discharge through mercury vapour at atmospheric pressure) allowing to get photographs of the tracks left by ionizing particles in the supersaturated gas.

Among the most prominent achievements using this tool, there was the first visualization of the artificial transmutation of a nitrogen nucleus, by α particles bombardment, by Blackett at the Cavendish Laboratory in Cambridge (1924). While the occurrence of a nuclear transmutation had been suggested in 1919 by Rutherford, in order to explain the results of his α particle bombardment experiments eventually leading to the discovery of the proton, only Blackett's experiment provided definitive proof that an artificial disintegration actually occurred. Blackett's result was made possible by the previous development of an automatic cloud chamber by the Japanese physicist T Shimizu, then working at the Cavendish laboratory (see figure 2; Shimizu's automatic apparatus was very similar to Wilson's original one, the

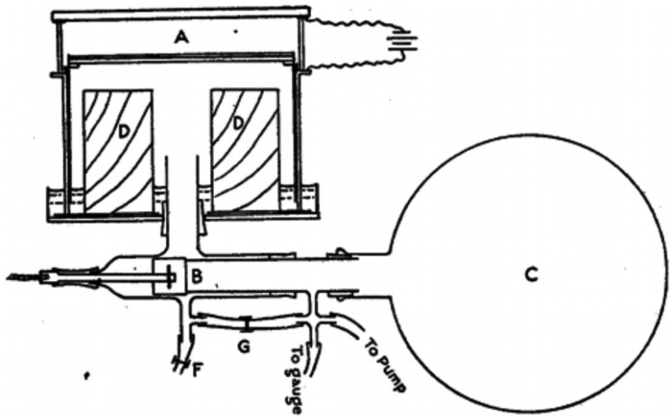

Figure 1. Schematic diagram of the Wilson cloud chamber's expansion apparatus [31]. (Reprinted with permission from the Royal Society, American Physical Society and Springer. Copyright 2007.)

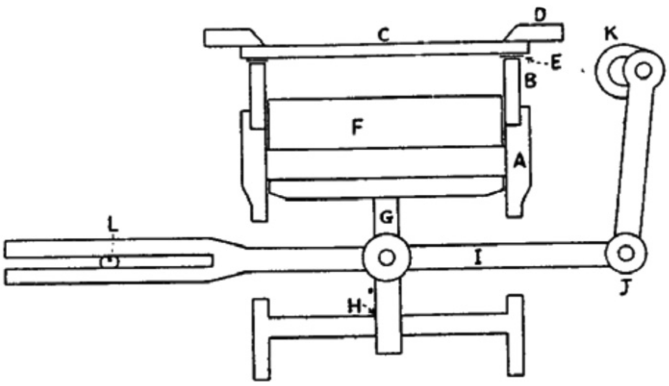

Figure 2. Schematic diagram of Shimizu's automatic apparatus. The piston (F) is connected to a rod (G), which is connected through a rod (I) to a shaft (K) driven by a motor. The end of the rod (J) thus executes a rocking motion when the shaft rotates (the stationary pin, L, serves as a fulcrum), so that the piston makes a reciprocating motion between two definite positions [32]). (Reprinted with permission from the Royal Society, American Physical Society and Springer. Copyright 2007.)

chief difference being only in the mode of working the piston). Shimizu's apparatus allowed the user to take a large number of photographs within a reasonable time ([15], p 432), and as in order to visualize an artificial transmutation the collection of a large number of photographs was a fundamental requirement, the automatic cloud chamber was a very convenient tool. By an improved version of Shimizu's apparatus, which was able to take one photograph every 10 or 15 s, Blackett was able to capture no less than 23 000 photographs, each one showing an average of 18 α particle tracks. Out of a set of about 415 000 tracks, Blackett discovered eight tracks showing the ejections of protons out of the nitrogen nuclei, i.e. the unequivocal hallmark of a nuclear transmutation (figure 3).

For the study of this sort of phenomena, whose occurrence while rare was foreseeable, the automatic cloud chamber was an excellent device. But where the phenomena to be studied were of random occurrence, the automatic chambers were at a disadvantage because of the very

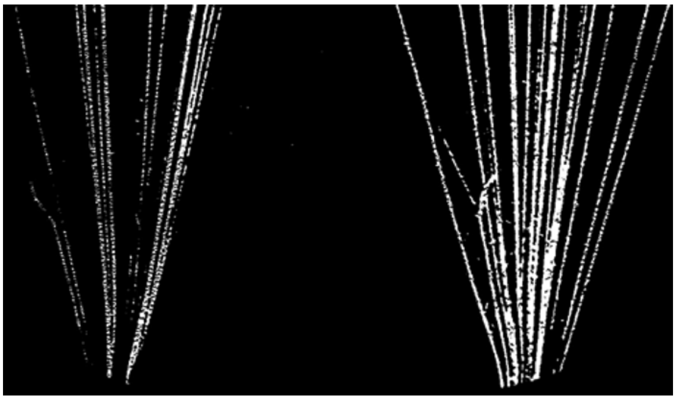

Figure 3. Disintegration of a nitrogen nuclei by α particle bombardment. The photographs show a fan-shaped α particle beam where two forks, both of them showing the ejection of a proton from a nitrogen nucleus and the recoil nucleus [33]. (Reprinted with permission from the Royal Society, American Physical Society and Springer. Copyright 2007.)

short sensitive time. Therefore, when by the end of the 1920s,[1] the automatic cloud chamber technology was adopted to study a phenomenon of rare and random occurrence, such as the high-energy cosmic rays, the experimental results, while interesting, were largely inconclusive and no significant results were obtained until 1932 (see section 5). In the meantime, another experimental device, the Geiger–Müller counter, and a new experimental arrangement, the coincidence method, entered the picture.

3. Geiger–Müller counters and the method of coincidences

Geiger–Müller counters (GM in the following) were developed in 1928 by H Geiger and W Müller, as a technical improvement of the 1913 'point counter' [16]. A GM consists of a cylindrical cathode with a central thin wire anode held by insulators. Between the cathode and the anode is applied a potential difference (several hundreds of volts) allowing the electrons released by an ionizing particle to drift towards the wire.[2] In the close proximity of the wire the electric field becomes strong enough to make the electrons acquire sufficient energy to ionize the gas molecules with which they collide, producing secondary electrons. These, in turn, produce more electrons reaching the wire, whose number is eventually nearly proportional to the number of primary ion pairs. Therefore, a GM is able to count ionizing particles crossing the cylindrical cathode [17].

In 1929 W Bothe and W Kolhörster used GMs to study the nature of cosmic rays. If these were energetic γ rays, as it was generally believed at the time, the secondary electrons generated by the Compton effect were thought to be responsible for the observed ionization in ionization chambers. In order to test this hypothesis, Bothe and Kolhörster developed a 'coincidence method', i.e. they made use of two GMs, one above the other in a vertical plane, each connected to a separate fibre electrometer, whose deflection was recorded on a moving

[1] In 1929, Russian physicist D Skobeltsyn, while observing by means of a cloud chamber in a magnetic field of 0.15 T the β particles produced by a radioactive source, noted a few tracks whose occurrence was quite unconnected with the presence of the radioactive source. These tracks had a very little curvature, indicating an energy over 15 MeV, that is much higher than any known β particle.

[2] In contrast, if the voltage is below a critical value of a few hundred volts, the GM operates as an ionization chamber.

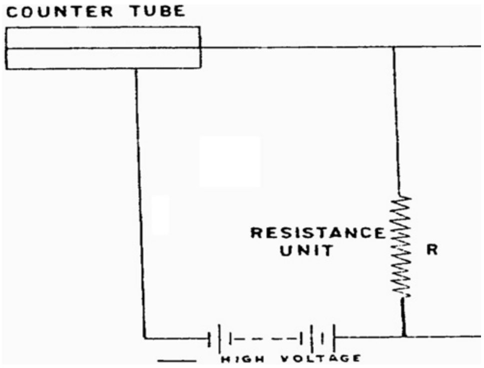

Figure 4. Schematic diagram of a Geiger–Müller counter circuit. Between the cylindrical cathode and the wire of the GM (counter tube) is applied a potential difference allowing the electrons released by a ionizing particle to drift towards the wire [34]. (Reprinted with permission from the American Physical Society. Copyright (2007) by the American Physical Society.)

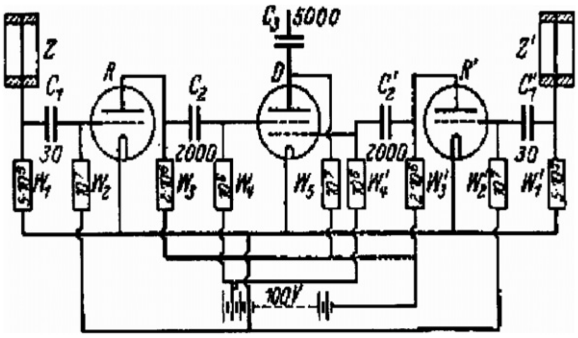

Figure 5. Schematic diagram of Bothe's coincidence circuit [35]. (Reprinted with permission from Springer. Copyright (2007) by Springer.)

film. If the deflection occurred within a small fraction of a second, then this indicated a passage of a single ionizing cosmic ray particle through both counters. The discovery that a gold brick inserted between the two counters did not sensibly affect the rate of coincidences led them to conclude that the ionization was not due to secondary electrons out of energetic γ rays, because these electrons could not have enough energy to pass into both counters when a screen was placed in the middle. The full potentialities of the coincidence method were, however, achieved only through the development of electronic recording devices. It was again Bothe who took a first step in this direction by developing a 'series circuit' that made use of a two-grid vacuum tube: only when pulses were applied to the two grids by simultaneous discharges out of both counters would a pulse of current appear in the plate circuit. Bothe's circuit (figure 5) was the first AND logic gate ([17], pp 462–3).

The greatest step towards a more efficient registration system was taken in 1930 when a multiple-coincident circuit, similar to Bothe's one, was developed in Florence, Italy, by Bruno Rossi, a young physicist who, since 1929, was interested in cosmic rays. Rossi's circuit was not limited, as Bothe's one, to the recording of twofold coincidences, but allowed to record three or more coincidences. Furthermore, through the help of his device, Rossi was able to reduce the resolving time from the 0.01 s reached by Bothe and Kolhörster to a time scale of less than 0.001 s. At the end of 1931, Rossi discovered that a component of cosmic rays (later to be recognized as muons) was able to penetrate through 1 m of lead, and succeeded in detecting the production of an abundant secondary radiation (later identified as electrons and positrons), by means of a threefold coincidence experiment. These were just the firsts of a long series of surprising discoveries about cosmic rays that would then make Rossi one of the leading figures in cosmic-ray physics.

Rossi's laboratory work on cosmic rays, however, was not his only lasting contribution to 1930s physics. In Florence, he also laid the foundation of a modern school of physics enabling him to transfer his experience on coincidence circuits with GMs to a young group of researchers. Among the most promising members of this group figured Giuseppe Occhialini ([17], pp 463–4, 470–1).

4. The counter-controlled cloud chamber

In 1931 Occhialini got a CNR (Italian National Council of Research) fellowship to learn the cloud chamber technique at Cambridge, under the direction of Blackett [18]. Indeed, after his research on the visualization of artificial disintegrations, the British physicist kept being committed to Wilson's method by carrying out accurate angular measurements of collisions of alpha particles with oxygen, hydrogen and helium nuclei, by developing a theory on the vibrations of the piston when it strikes the bottom of the chamber [19], and by designing and using a double camera for photographing artificial disintegrations. This latest work was carried out with the goal of increasing the number of tracks in each photograph, granted that it was not possible to increase the number of expansions above about four a minute without detriment to the tracks [20]. Thus, Blackett was definitely involved in the cloud chamber technique. In contrast, before his Cambridge fellowship, the young Occhialini had been working with the GM counter technology at the Florence Institute of Physics, and his only scientific publication concerned the development—by means of a GM counter—of a magnetic spectrometer for β particles emitted by weak radioactive substances [21].

As of fall 1931, neither Blackett nor Occhialini had been working specifically on cosmic rays. However, different than Blackett, whose activity was carried out at the Cavendish laboratory, i.e. in a laboratory where the cosmic-ray physics was extraneous to the research programme pursued there, Occhialini's institute of physics, mostly through Rossi's efforts, had been in the front line of cosmic-ray physics since the beginning of 1930. Furthermore, in his above-mentioned paper on the magnetic spectrometer, Occhialini had emphasized that a number of counter pulses might be due to the penetrating radiation. Although Occhialini conceded that no definite conclusions could be drawn out of these data, the contents of this paper shows that he was both trained in the use of the GM counters and interested in the cosmic-ray subject. Thus, not surprisingly, Occhialini's arrival at the Cavendish laboratory marked a change in the priorities of work there: 'in the autumn of 1931 in collaboration with Occhialini—Blackett later wrote—I started to study the energetic particles found in cosmic rays by means of the cloud method' ([2], p 104).

As discussed in section 2, since 1929 this 'cloud method' had been adopted by a number of physicists devoted to the cosmic-ray studies, notably Dmitry Skobeltsyn (Leningrad Polytechnic) and Carl Anderson (Caltech). However, as Blackett and Occhialini reported in their letter to *Nature* on 21 August 1932, where the counter-controlled cloud chamber was introduced for the first time, previous experiences by these physicists adopting the standard automatic cloud chamber technique to study cosmic rays had shown that 'such work is laborious, since [the] tracks [left by high-energy cosmic rays] occur in only a small fraction of the total number of expansions made [by the cloud chamber]' [22]. While Skobeltsyn had obtained in 1929 as many as one track every ten expansions of the cloud chamber, in the work of Anderson 'the number of tracks which were long enough to be suitable for energy measurements was only 1 in 50 photographs' ([23], p 699). As previously reported by Anderson himself, out of 3000 photographs taken only 62 showed cosmic ray tracks of length sufficient for energy measurement ([24], p 405). The apparatus employed by Anderson was planned in 1930 by Robert Millikan and Anderson, and consisted of an automatic, vertical cloud chamber set in the midst of a 'strong magnetic field up to 21 000 gauss' ([24], p 405). Anderson's apparatus, though automatic, but operated in an exceedingly powerful magnetic field, made expansions at random, and therefore, as remarked by Blackett and Occhialini in their detailed February 1933 report to the Royal Society, '[when] the usual method of making expansions at random [. . .] is used it is only on a small fraction of the photographs that a track will be found.' ([23], p 699).

> The average number of photographs required to obtain one track will depend on the size and orientation of the chamber and on the effective time of expansion. The latter is not likely to be more than $1/20$ s ([23], p 699).

As the random method consumed much time and photographic film, Blackett and Occhialini set about devising an alternative method, which was a perfect marriage of Blackett's expertise on cloud chambers, dating back to the days of the first visualization of an artificial disintegration and Occhialini's mastery of GM in coincidence technique acquired at the Rossi's school in Florence. By this new method, that allowed them to overcome the difficulties intrinsic in the standard automatic cloud chamber technique,

> [T]he high speed particles associated with penetrating radiation *can be made to take their own cloud photographs*. [. . .] By our method, tracks are found on 80 per cent of the photographs [emphasis added] ([23], p 699).

According to Blackett and Occhialini's set-up, a cloud chamber of diameter 13 cm and depth 3 cm was arranged with its plane vertical (dimensions of the chamber and vertical arrangement were in agreement with Anderson's automatic apparatus). Two GM counters, each 10 cm $\times$ 2 cm were placed one above and one below the chamber so that any ray which passed straight through both counters had also to pass through the illuminated part of the chamber; see figure 6, where the counters are labelled C and the piston of the chamber is A; the expansion was made by moving a trigger F holding the valve E. The counters C were connected to a coincidence circuit arranged to record only simultaneous discharges of the two counters. A magnetic field of 3000 gauss (i.e. one-seventh of the magnitude in Anderson's chamber) was applied at right angles to the plane of the chamber (D). When the cloud chamber had been made ready for use, the arrival of a coincidence was awaited. After an average wait of about 2 min, a coincidence occurred and a relay mechanism started the expansion (when the impulse arrived, it short circuited a small electromagnet and allowed an armature to fly off; the movement of the armature was transmitted by the nut K to the arm M and so to the trigger F; see figure 7) [25].

Of course, the diffusion of the ions during the time between the passage of the ray and the attainment of the supersaturation might be a problem. However, by careful attention to the detailed design of the various parts of the apparatus, Blackett and Occhialini were able to overcome this problem.

> It has been possible to make the total time from the discharge of the counters to the end of the expansion as small as $1/100$ s. In this time the ions produced by an ionizing particle only diffuse a short distance from the position where they are

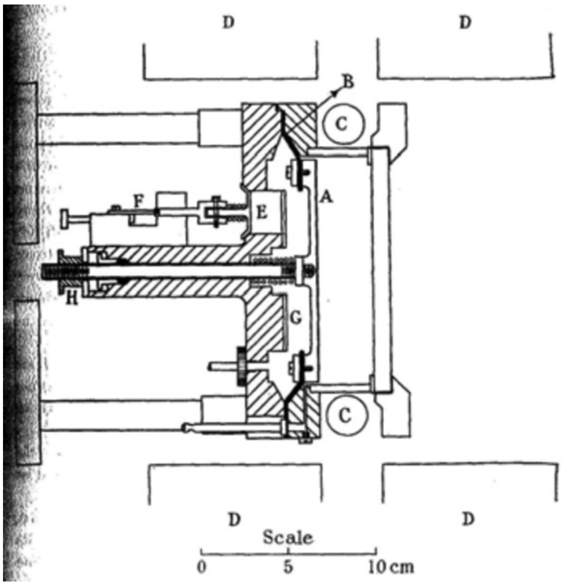

Figure 6. Design of the Blackett–Occhialini chamber. The cloud chamber (A) is placed between the counters (C). A magnetic field (D) is applied at right angles to the plane of the chamber. The expansion is made by moving a trigger (F) holding the valve (E) [36]. (Reprinted with permission from the Royal Society, American Physical Society and Springer. Copyright 2007.)

> formed: the resulting tracks have a breadth, in oxygen at 1.7 atmospheres, of only 0.8 mm and this breadth, though of course much larger than that of tracks formed by particles passing through the end of the expansion, is small enough to allow a very accurate measurement ([21], p 700).

The observed breadth was in good agreement with that calculated from the known rate of diffusion of the ions. This result was indeed theoretically estimated by Blackett in a paper published in 1934, i.e. at the end of Occhialini's CNR fellowships. If we define x as that width of the image which contains 90% of the ion images, then this is found to be given by

$$x = 4.68\sqrt{D\tau}$$

where D is the diffusion coefficient of the ions and τ is the time after the passage of the ray. Since the mean value of D for the positive and negative ions in air at ntp conditions is 0.034 cm^2 s^{-1} [29], we have $x = 0.86\sqrt{D}$ cm at ntp. So 'if we demand that the tracks shall not be more than 1 mm broad, then we must have τ not more than $1/70$ s' ([25], p 282).

5. Advantages, drawbacks and earliest achievements

Notwithstanding the obvious advantage of the counter-controlled cloud chamber method as regards to the efficiency (about 80% of the photographs yielded tracks as opposed to the 2% obtained out of the random chambers), Blackett and Occhialini's apparatus was not free from drawbacks.

It was soon acknowledged that there is a problem concerning the sharpness of the tracks for when the passage of the particle itself precedes the expansion, as it obviously must do if it produces it, this expansion may, and often does, seriously distort the track. A few

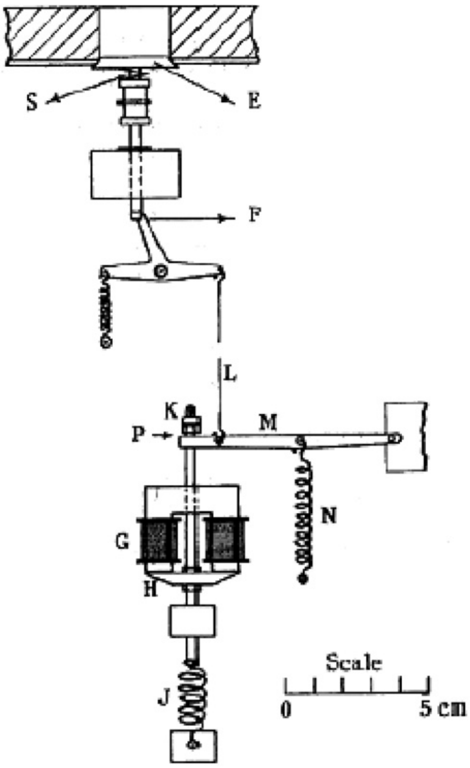

Figure 7. Releasing mechanism of the Blackett–Occhialini chamber. When the coincidence impulse arrived, it short circuited a small electromagnet and allowed an armature to fly off. The movement of the armature was transmitted by the nut K to the arm M and so to the trigger F that started the expansion [37]. (Reprinted with permission from the Royal Society, American Physical Society and Springer. Copyright 2007.)

months after Blackett and Occhialini's 1933 paper to the Royal Society, Anderson and Millikan stressed that, while the counter-controlled apparatus was affected by distortion problem, 'when the random method is used the sharpest tracks are obtained, and without distortion' ([26], p 353). Then, the method had some bias in favour or against some particular phenomenon so that there might be conspicuous discrepancies between the relative frequency of different types of particles as in Blackett and Occhialini's photographs and the 'ratio of their actual occurrence' ([23], p 709). Finally, when a magnet is used to measure the energy of the particles recorded, either the magnet must be a permanent one, in which case it will not be possible to use a high field, or the electromagnet must be run continuously, i.e. a tremendous demand on electric power is required. As a consequence of this the majority of Blackett and Occhialini's primary tracks were not appreciably deflected ([18], p 373).

Yet, the new method rapidly proved very useful for the investigation of cosmic rays. As Blackett and Occhialini reported in their February 1933 paper, during the late autumn 1932, they accumulated some 700 photographs of cosmic rays, among which were groups of associated rays that came to be known as 'showers' of cosmic ray particles. 18 photographs were obtained on which are the tracks of more than 8 particles of high energy, 'and four photographs show more than 20 tracks' (figure 8) ([23], p 702). Yet, notwithstanding the

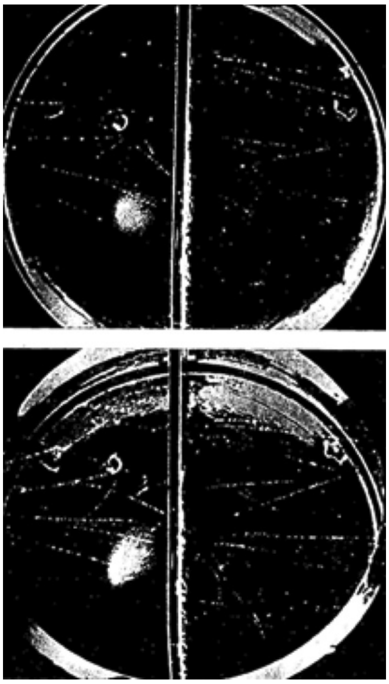

Figure 8. Pair of Blackett and Occhialini's photographs showing about 23 separate tracks [38]. (Reprinted with permission from the Royal Society, American Physical Society and Springer. Copyright 2007.)

counter-controlled cloud chamber was more efficient than the random apparatus, Blackett and Occhialini failed to get the priority of the positron discovery. On 9 September, 1932, i.e. a few days after their 21 August 1932 letter to *Nature*, where they first reported about the counter controlled method, Anderson communicated to *Science* having discovered in cosmic radiation the 'apparent existence of easily deflectable positives', later to be named 'positrons' [27]. Out of several thousands of photographs obtained via his random automatic cloud chamber, Anderson had succeeded in capturing the photograph of a positive particle passing through the lead plate in the centre of the cloud chamber. As the change in curvature of the path on the two sides of the lead plate showed the direction of travel, and the track was thinner than the usual proton tracks, it was definitely a positively charged electron-like particle.

While the standard, random, cloud chamber method allowed Anderson to first discover the positron, Blackett and Occhialini provided in February 1933 a wealth of supporting evidence for the existence of this particle. About half of the shower rays photographed by Blackett and Occhialini were apparently due to positively charged particles and half to negatively charged particles ([23], p 707). From their ionization and range, Blackett and Occhialini conclusively established that the masses of the positive particles were 'comparable with that of an electron rather than with that of a proton' ([23], p 706). Although the Cavendish researchers had lost the priority in the positron discovery, by the wealth of evidence collected through the counter-controlled cloud chamber, they confirmed Anderson's discovery, proved that the newly discovered particles occurred mainly in showers and eventually got rid of all resistance to the existence of positrons.

Finally, not only was Anderson's discovery conclusively confirmed, but thanks to Blackett and Occhialini's involvement the new particle found its place in a general theoretical framework. In 'the hypothetical properties of the positive electron' chapter of their February 1933 paper on the results obtained by the new apparatus, Blackett and Occhialini discussed the fate of the positive electron in the light of P A M Dirac's theory of the electron, where it was forecasted that the existence of a positive electron envisaged as a 'hole' in a sea consisting of an infinite number of negative electrons in states of negative kinetic energy. Most importantly, Blackett and Occhialini explicitly acknowledged Dirac's help not only for the most valuable discussions on the theory of the electron, 'but also for allowing us to quote the result of a calculation made by him of the actual probability of [the] annihilation process' ([23], p 715). Dirac, who in 1932 was the newly appointed Lucasian Professor of Mathematics at Cambridge, later recalled that he was 'quite intimate with Blackett at the time and had told him about my relativistic theory of the electron' ([28], p 61). On this theory it was legitimate to suppose that via the cloud chamber method might be possible to observe a positron. As Blackett and Occhialini emphasized in their paper,

> There appears to be no evidence as yet against [the] validity [of Dirac's theory], and in its favour is the fact that it predicts a time of life for the positive electron that it is long enough for it to be observed in the cloud chamber but short enough to explain why it had not been discovered by other methods ([23], p 716).

6. Conclusions

The case of the development of the counter-controlled cloud chamber is a wonderful example of the way in which the scientific priorities shape the arrangements of the experimental devices.

The search for evidence to indicate the artificial disintegration of atoms by α particles required the collection of 'a large number of photographs within a reasonable time' and eventually led to the development of Shimizu's automatic cloud chamber (1921) and the consequent Blackett's visualization of artificial transmutations (1924). When the phenomena to be studied were easily controllable like the nuclear phenomena, where strong sources might be employed and the geometry of the tracks was clear, there was a little difficulty in obtaining a number of tracks of α or β particles in every picture obtained via random, automatic, cloud chambers. But where the phenomena to be studied were of rare occurrence, such as the high-energy particles in cosmic rays, chambers operated at random were at a disadvantage. The need for a more performing strategy eventually led to the counter-triggered cloud chamber (1932).

To use Blackett's metaphor, if Blackett and Occhialini's apparatus was an obvious marrying of techniques, quite less obvious were the marrying procedures that had to be followed in order to enable a particle to take its own photograph. As we have seen, one of the most notable difficulties Blackett and Occhialini had to face was the devising of a Wilson chamber that was able to attain the supersaturation phase very soon after the passage of the ionizing particle. The occurrence of the expansion after the passage of the particle had also, as an unwanted consequence, led to the distortion of the tracks. Furthermore, while a random cloud chamber might benefit from strong magnetic fields (allowing energy measurements of energetic particles), the marrying of the cloud chamber with the coincidence technique was forced to use low fields because of the tremendous demand of electric power when a continuously run field was involved.

In spite of difficulties and limitations of the novel marrying, the new apparatus outnumbered the efficiency of random chambers. The efficiency factor allowed Blackett and Occhialini to confirm beyond any reasonable doubt the discovery of the positron (1932), and to discover the processes of 'pair creation' and annihilation of electrons and positrons in cosmic radiation (1932–33). Yet, a full appreciation of the advantages of the counter-controlled cloud chambers was gained only when it was realized that the apparatus allowed the discovery of still more rare events. For example, in 1947, G D Rochester and C C Butler observed by means of this device the occasional presence of curious forked tracks—'V' events—in a series of cosmic-ray experiments that indicated the existence of a new type of unstable elementary particle, namely the K mesons, the first 'strange' particles. How many years would it take to get photographs of very occasional phenomena by random photography? As it was later estimated, the rate at which they would be obtained is extremely low:

> A cloud chamber with 30 cm diameter and 5 cm depth will probably give good tracks, sufficiently undistorted, for most purposes, for $1/20$ s, and will take perhaps 4 min to reset after each expansion [. . .]. The fraction of operating time for which the chamber is effectively receptive is then $1/5000$. Particles traversing the full depth of the chamber, say in a solid angle restricted to $1/10$, will occur at the rate of about 10 per minute, and hence will be photographed, if the apparatus is in continuous operation, once in 8 h. Particular particles present to 1% of the whole flux will be recorded only once per month of continuous operation, while such events as the penetrating showers [. . .], which occur at the sea level approximately once per 10^5 particles, will not be photographed at the required level of quality oftener than once in 80 years! ([29], p 66).

By sheer luck, the counter-controlled cloud chamber allows us to spare all this time.

Acknowledgment

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