Cecil Powell's discovery of the pion 50 years ago led to a Nobel prize and opened the door to modern particle physics. But Powell was more than just a physicist – he supported peace, had strong left-wing views and was a keen advocate of the public understanding of science

Cecil Powell: pions, peace and politics

Owen Lock

IN 1947 a relatively unknown physicist at Bristol University in the UK, Cecil Powell, discovered a new particle – the pion – in the cosmic radiation. At the time, the pion was thought to be the particle that had been predicted in 1935 by Hideki Yukawa as the carrier of the strong nuclear force that binds the protons and neutrons in the nucleus. Although we now know that this is not the case – the pion is just one of a family of strongly interacting mesons – Powell's discovery earned him the Nobel Prize for Physics in 1950.

Powell discovered the pion using specially manufactured photographic emulsions as detectors. The first major discovery of the post-war era, it showed the potential of cosmic-ray studies using the emulsion technique and opened the door to the discovery of many other fundamental particles. The international collaborations that grew up between the various emulsion groups were also the forerunner of what was to happen later around the big high-energy particle accelerators, which gradually replaced cosmic-ray experiments in the study of elementary particles.

Powell circa 1948 holding a montage of six photomicrographs, each showing the decay of pions into muons of constant energy.

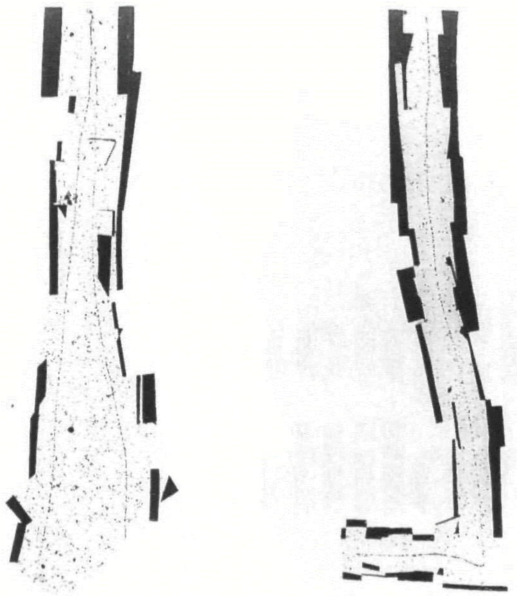
Charles Frank and Donald Perkins, both close colleagues of Powell at Bristol, wrote in their Royal Society biographical memoir of him: "The impact of the discovery of the pion on the scientific world in general and on physics in particular was profound. It stimulated the building of a new generation of accelerators with which to probe the newly discovered domain of sub-nuclear physics and to uncover the richness of completely new and unexpected phenomena. In a very real way Powell can be said to have been the father of particle physics".

As well as being a milestone in physics history, this major discovery marked Powell's first step on a path that led him to international fame, which extended far beyond the confines of sub-nuclear physics. For Powell was far from being an "ivory tower" physicist. His political views were well to the left, and the award of the Nobel prize allowed him a wider audience for his ideas on the abolition of nuclear weapons and the need for international collaboration in science. In 1954 he became president of the Association of Scientific Workers – a UK trade union – and in 1956 he was made president of the World Federation of Scientific Workers. He was also one of the 11 signatories of the Russell–Einstein manifesto of July 1955, which called upon scientists to "assemble in conference to appraise the perils that have arisen as a result of the development of weapons of mass destruction". The manifesto led to the foundation of the Pugwash movement, with Powell succeeding Bertrand Russell as chairman in 1967.

On the European scene, Powell played a major role in the establishment of CERN, the European laboratory for particle physics in Geneva, and in developing its research programme. A leading exponent of the need for pure science – and a great believer in the public understanding of science – he became a highly respected figure in the international science community before his untimely death in 1969, at the age of 65.

Early years

Cecil Powell was a quietly spoken man of slight build and medium height. He was born in Tonbridge, Kent, on 5 December 1903. His father was a gunsmith and his mother was the



The first (left) and second (right) observed decays of a pion into a muon and a neutral particle, later shown to be a neutrino. For this discovery of the pion, Powell was awarded the 1950 Nobel Prize for Physics.

daughter of a schoolteacher. A lawsuit arising from a shooting accident led to his father being declared bankrupt when Powell was only three years old. Cecil's mother, who was forced to take in lodgers to make ends meet, was anxious that he and his younger sister should escape from similar drudgery. Her elder brother had succeeded in getting in to Trinity College, Cambridge, to become an electrical engineer, and she was determined that her son should secure a similar emancipation.

When he was 12, Powell won a scholarship to Judd School in Tonbridge. Although he was initially interested in chemistry, he came under the influence of an able physics teacher and in 1921 obtained a state scholarship and an open scholarship to read natural sciences at Sidney Sussex College, Cambridge. Powell graduated in 1925 with first-class honours in both parts of the tripos, coming second in his year for physics.

Unsure what to do next, he obtained a post at a well known public school, but wondered whether teaching would suit him. He therefore asked Ernest Rutherford – who had succeeded J J Thomson as Cavendish professor of physics at Cambridge in 1919 – if he could be accepted as a research student. Rutherford duly arranged for him to work with the inventor of the cloud chamber, Charles Wilson. Powell built an all-glass cloud chamber to study how the condensation of water droplets in dust-free air was affected by the degree of expansion of the chamber. From this work he concluded that there was nothing to be gained in operating such chambers at temperatures other than room temperature, although the results did help him to show how steam flows through nozzles, which contributed to the design of steam turbines.

The move to Bristol

University College Bristol, founded in 1876, became a university in 1909, helped by generous benefactions from various members of the Wills tobacco family. In the early 1920s Henry Herbert Wills gave £200 000 for the construction of a physics laboratory and in October 1927 the H H Wills Physics Laboratory was formally opened by Rutherford. The following year the government gave the lab's director, Arthur Tyndall, funds to recruit an assistant. He naturally turned to the Cavendish Laboratory, and eventually chose Powell, who arrived in Bristol in the spring of 1928 and stayed there for the rest of his life.

Tyndall and Powell carried out extensive measurements on the mobility of positive ions in gases. Tyndall was greatly impressed by Powell's experimental ingenuity and skills, which included carpentry, an interest he had acquired as a boy. Powell was appointed lecturer in 1931 and the following year he married Isobel Artner, the German-born daughter of an Austrian industrialist and a Scottish mother. The first of Powell's two daughters was born in 1933 and an immediate consequence was that Powell found that his university income was inadequate. He secured a job at twice the salary with the electrical-engineering firm British Thomson-Houston at Rugby, but his wife was sure that he would not be happy in industry. Fortunately, Tyndall arranged an increase in Powell's salary at Bristol, and a crisis was averted.

Tyndall, who was always looking to the future, began to wonder if any laboratory could become internationally prominent unless it did some sort of experimental nuclear physics. Powell had become excited by key breakthroughs that had been made at the Cavendish, including the discovery of the neutron by James Chadwick and of electron–positron pair production by Patrick Blackett and Giuseppe Occhialini. Tyndall later recalled that in 1933 Powell had been "dead keen on starting on a Blackett cosmic-ray experiment". However, it was eventually decided that Powell should be given the responsibility of building a 700 keV Cockcroft–Walton generator to accelerate protons and deuterons. The deuterons would be used to bombard light-element targets to produce neutrons, and Powell would then study neutron–proton scattering using a Wilson chamber filled with hydrogen. With the aid of a brilliant young physicist, Geoffrey Fertel, the accelerator became operational in May 1938.

Photographic emulsions

In 1938 the theorist Walter Heitler, who was then at Bristol, drew Powell's attention to the work of two Viennese physicists – Marietta Blau and Herta Wambacher – who had exposed photographic emulsions to cosmic rays in the Austrian Alps. They had observed the tracks of low-energy protons as well as "stars" – nuclear disintegrations that had presumably been produced by cosmic rays. Powell was impressed by the relative simplicity of the method, and in the summer of 1938 Heitler took some "half-tone" emulsions made by Ilford to the Jungfraujoch in the Swiss Alps, where they were exposed for 230 days. Subsequent examination in Bristol confirmed the Austrian observations. Since the Wilson chamber was not ready when the Bristol accelerator was completed, Powell bought a box of normal half-tone photographic plates – which were normally used for making lantern slides – and exposed one tangentially to his proton beam. Impressed by the results, he considered the possibility of using the plates to detect and measure the energy of neutrons.

Powell realized that if a neutron collides head-on with a proton in the gelatin of the emulsion and scatters the proton by less than 5°, the proton takes up more than 99% of the neutron's energy. The neutron's energy could then be determined simply by measuring the range distribution of the recoiling protons. To test this method, Powell decided to study a reaction that had already been investigated using a Wilson chamber, namely $B^{11}_5 + H^2_1 \rightarrow C^{12}_6 + n^1_0$. He therefore placed some half-tone emulsions near a boron target in the accelerator and recorded the tracks of thousands of recoiling protons in the emulsion. Using this approach, he was able to determine the neutron energy spectrum much faster and with a higher precision than was possible with a Wilson chamber.

Powell became convinced that the emulsion technique could be developed into a precision instrument for nuclear-physics studies, ignoring the view of the "experts" of the time that the photographic method was not suitable for quantitative work. He believed that with precision microscopes, proper attention to processing, and emulsions of greater sensitivity and thickness, the technique would prove to be of great value. Meanwhile, Chadwick, who was already involved in fission studies at Liverpool University, learnt of Powell's emulsion technique for neutron detection and in late 1939 invited him to use the new 4 MeV cyclotron to extend his scattering experiments. Powell eagerly accepted and an active Liverpool–Bristol collaboration soon began, with Powell studying high-energy neutron spectroscopy as part of the British Atomic Energy Project.


As the intensity of cosmic rays increases with altitude, Powell began a series of balloon flights to expose photographic emulsions high in the atmosphere. This enabled him to obtain more events and of higher energy than could be obtained at mountain altitudes. Here he and four of his "scanners" are checking the polyethylene that was used for the balloons.

Meanwhile, back at Bristol, Powell acquired more microscopes and hired a young woman to search the emulsions for "events" to be measured. This was the beginning of the employment of people with little or no scientific knowledge as microscope observers or "scanners". After the Second World War more were recruited and, since they were mostly young women, they became known as "Cecil's beauty chorus". This tradition continued later for scanning films from bubble and spark chambers.

Cosmic-ray studies

Following Chadwick's discovery of the neutron in 1932, one of the challenges in physics was to understand the nature of the force that held the protons and neutrons together in a nucleus – despite the immense electrical repulsion between the protons. Yukawa realized that the range of any quantum force is inversely proportional to the mass of the exchanged particle that transmits the force. In electromagnetism, for example, this particle is the photon, which has zero mass and hence an infinite range. For the short-range nuclear force, however, Yukawa postulated the exchange of a massive particle with several hundred times the mass of the electron, m_e. This particle was called a "meson", although the term was eventually used to denote any particle whose mass lay between that of an electron and a proton. In 1935, to explain radioactive beta-decay, Yukawa postulated that this nuclear-force meson would be unstable. He believed that it would decay into an electron and have a half-life of about 10^{-8} s.

Although no such particle was known at the time, cosmic-ray studies with cloud chambers soon revealed mesons of mass 200–300 m_e. They were tentatively identified as the mesons that Yukawa had postulated and were initially termed "mesotrons". However, a series of elegant experiments, in particular those carried out in Rome in 1943 by Marcello Conversi, Ettore Pancini and Oreste Piccioni, showed that negative mesotrons stopping in carbon almost always decayed spontaneously instead of being captured by a carbon nucleus, as would be expected for a Yukawa meson. It thus became clear that the mesotron was not the particle that Yukawa had predicted.

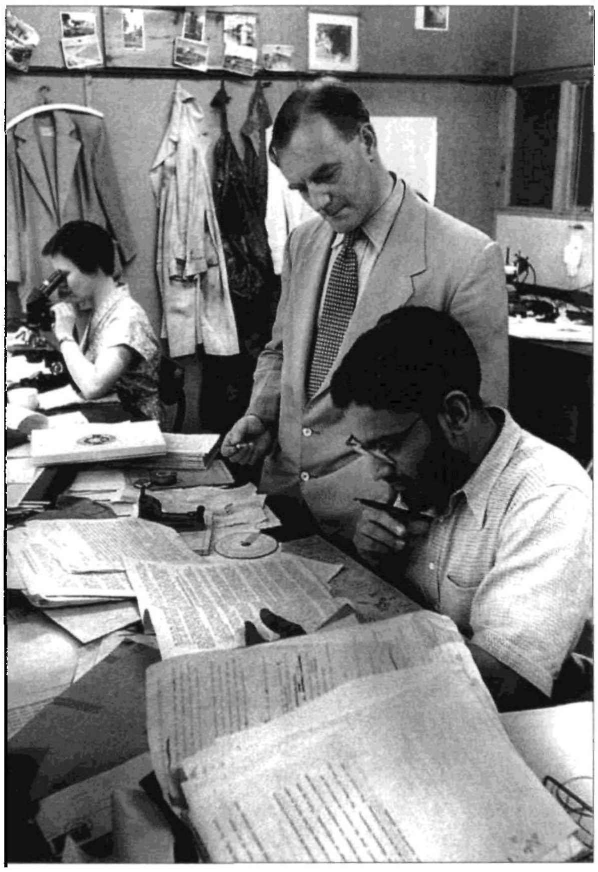
Then, at a meeting of US theorists at Shelter Island in early 1947, Robert Marshak from Rochester University suggested that there are in fact two kinds of meson. He proposed that one type of meson interacts with nuclear matter and decays to form the other type of meson, which does not interact with nuclei. (Unknown to him, the same idea had been proposed in Japan by Yasutaka Tanikawa in 1942, and by Shoichi Sakata and Takeshi Inoue in 1943.) However, what those at the Shelter Island meeting had not realized was that Powell and his colleagues at Bristol had just published a paper that proved that this interpretation was indeed correct. This was the work that led to Powell's award of the Nobel prize. His faith in the emulsion technique had been justified.

The discovery of the pion

Throughout the war years Chadwick stayed in touch with Powell in Bristol, who continued the analysis of the emulsions from scattering experiments at the Liverpool cyclotron. These emulsions provided valuable data on, for example, the scattering of neutrons by uranium, and the importance of the emulsion technique – and of particle accelerators – soon became known to the UK government. Towards the end of 1945 the Ministry of Supply set up two panels: one, chaired by Blackett, to plan accelerator building in the UK; and the other, led by Joseph Rotblat, to encourage the development of sensitive emulsions. For the latter purpose a contract was placed by the ministry with Ilford early in 1946 and later also with Kodak. By mid-1946 Ilford was able to supply a new range of nuclear-research emulsions that were much more sensitive to particle tracks.

In the summer of 1945 Occhialini – a brilliant and original experimentalist who had invented the counter-controlled cloud chamber with Blackett – joined Powell at Bristol. He was soon followed by his student Giulio Lattes. Occhialini took the first of the new emulsions – which were only 2 inches by 1 inch and 50 μm thick – to the Pic-du-Midi in the Pyrenees, while Perkins of Imperial College in London exposed some in a Royal Air Force plane flying at high altitudes. As Powell had already noted in 1938, mesons could be easily identified in the emulsions. Like other charged particles, mesons undergo many small changes of direction as they scatter from electrons and nuclei in an emulsion. However, mesons are much lighter than protons and so scatter much more, leaving distinctive tracks in the processed emulsion plates.

By the end of 1946 both groups had observed the tracks of single mesons that moved slowly, came to rest in the emulsion and then produced a nuclear disintegration – as was expected from the mesons that Yukawa had predicted. However, in spring 1947 one of the scanners at Bristol found something completely different – an event that showed one slow-moving meson stopping and then emitting a second meson, which left the emulsion after 565 μm, nearly at the end of its range. Powell and a young Bristol graduate, Hugh Muirhead, immediately recognized that this event was due to two mesons, not just one. Within a few days a similar event was found; this time the second meson ended in the emulsion with a range of 610 μm. The similarity in range of the two secondary particles indicated that in both events a heavier, primary meson had decayed into a secondary, lighter meson and a neutral particle. In other words, Powell had witnessed two-body decays.



Cecil Powell (standing) with a collaborator, the Indian scientist M G K ("Goku") Menon, at Bristol University in about 1950.

Lattes, Muirhead, Occhialini and Powell published their findings in *Nature* on 24 May 1947 (volume 159, page 654). They suggested that what they had found was a new mode of meson decay, but added that further evidence was needed to justify such a radical conclusion. Lattes, armed with further emulsion plates, therefore travelled to Mount Chacaltaya in the Bolivian Andes, which lies 5600 m above sea level – much higher than the Pic-du-Midi. These plates yielded 10 more two-meson decays. In all cases the secondary meson came to rest in the emulsion with a range of about 600 μm.

Lattes, Occhialini and Powell published these new results in *Nature* on 4 October (volume 160, page 453) and 11 October 1947 (volume 160, page 486). They concluded that they had seen a primary meson, which they named the "pion", decaying into a secondary meson, which they called the "muon". Powell also found that there were as many of these two-meson events as there were events in which a single meson produced a nuclear disintegration. He therefore concluded that there were in fact two types of pion – positive and negative. In the two-meson events, a positive pion was repelled by the positively charged nucleus before decaying into a muon. In the single-meson events, a negative pion was captured by the nucleus, causing the nucleus to disintegrate.

From subsequent measurements of 20 events, Powell also concluded that the pion had a mass of $260 \pm 30\ m_e$ and a lifetime of about 10^{-8} s, and that the muon had a mass of $205 \pm 20\ m_e$. This compares favourably with current values of $273.31\ m_e$, 2.6×10^{-8} s. and $206.76\ m_e$, respectively. He also found that when a pion decayed into a muon, it produced a neutral particle, which was later shown to be a neutrino. And in 1948, with the advent of even more sensitive emulsions, Powell found that when a muon comes to rest, it in turn decays into a positron and two neutral particles, later shown to be a neutrino and an anti-neutrino.

For a time, people thought that the pion would hold the key to the mysterious forces that bind the nucleus together. We now believe that the only distinction of the pion is that in the Standard Model of particle physics it is the lightest member of the family of strongly interacting mesons, which are composed of various combinations of quark–antiquark pairs. Meanwhile, the muon, which interacted weakly with nuclei and seemed to behave like a heavy electron, was a great puzzle. We now know that the muon is just one of six weakly interacting members of the lepton family.

Meson complexity

By 1948/9 Occhialini and his wife Constance had perfected a method for processing emulsions as thick as 600 μm, which meant that much longer particle tracks could be recorded. Ilford and Kodak, meanwhile, continued their efforts to produce emulsions that could record tracks of relativistic particles. Kodak succeeded by late summer 1948, followed in 1949 by Ilford, which was soon able to start commercial production of the "G5" emulsion. Powell's group exposed the new Kodak emulsions on the Jungfraujoch. They revealed the complete decay sequence of a positive pion into a muon into a positron, as well as high-energy nuclear disintegrations that produced showers of relativistic particles – mostly positive and negative pions. Powell also obtained clear evidence for neutral pions, which decay into two gamma rays that produce electron–positron pairs.

Soon mesons heavier than the pion were also seen. In 1947 George Rochester and Clifford Butler at Manchester University in the UK recorded two cloud-chamber events that they interpreted as the decay of a charged particle with a mass of about 1000 m_e and the decay of a neutral particle with a mass above 800 m_e. They were termed "V-particles" from the appearance of their associated tracks. A meeting to celebrate the 50th anniversary of their discovery was held in Manchester in September.

Using the Kodak emulsions, the Bristol group also found an event that showed a meson with a mass of about 985 m_e decaying into three charged pions, as well as two clear examples of mesons with masses of about 1000 m_e decaying into single charged particles. We now know that these events – and those of Rochester and Butler – represent different decay modes of what are now called K-mesons. The proliferation of these many different decays caused much confusion at the time, which was only resolved with the advent of the new generation of accelerators.

To obtain events at even higher energies, Powell and his Bristol group embarked in 1949 on a programme of balloon flights to expose emulsions high in the atmosphere. Early flights were carried out from the university sports ground, and later from Sardinia, with the support of several Italian universities and the Italian military. Several years of successful balloon flying followed, and an increasing number of European research groups became involved in a major effort to unravel the complexities of heavy mesons. Powell was the driving force behind all these activities, and in the early 1950s he could always be relied upon to give masterly reviews of the subject at conferences.

Politics and Pugwash

Weisskopf, who was CERN's director general at the er recalled Powell's role: "The task that we had in the 60s was the creation of a European spirit of scientific nd venture, a spirit of scientific leadership of the type had in the 1920s. It was the purpose of CERN to provide it and – most importantly – to provide it on an interna- let me say, supra-national basis. I believe we have suc- in doing so, but it would have been impossible to have without Cecil's vision; his unquestionable leadership onceiving of these aims and in formulating them. We all at there is nobody, and there will be nobody for a long o is able to formulate the aims of science and the role of in society, and the role of science in bringing nations ; such as was Cecil Powell."

l also believed strongly in the social responsibility of sci- nd tried to put his ideas into action. In particular, when essed the UK Trades Union Congress in 1954 as presi- he Association of Scientific Workers, he proposed that a ice of the nuclear powers should be held to secure the n of atomic and nuclear weapons. He also wanted the nce to speed up research on the development of atomic or peaceful purposes.

dio broadcast in December 1945, Bertrand Russell had d the danger of the development of nuclear weapons – ly hydrogen bombs – and of the catastrophic conse- that would follow another war. He followed this up by a manifesto to be signed by eminent scientists from all world. Einstein signed two days before his death in 55, and the document became known as the Russell– manifesto. Among the 11 signatories were Powell, and Yukawa.

ctical outcome of the manifesto was the launch of a conferences, the first of which was held in July 1957 in l village of Pugwash in Nova Scotia, Canada. A continu- mittee was set up with Russell as chairman, and with nd Rotblat among the four members. Aided by Rotblat, played a major role in what became known as the sh movement". He often acted as chairman in Russell's

point of a discussion and summing it up in a masterly fashion; by his amazing skill in bringing together divergent views".

Being such a prominent figure in both the trade union movement and in Pugwash was not, however, without consequence for Powell's academic career. In 1950, when the Poynting professor of physics at Birmingham University, Mark Oliphant, resigned to return to Australia, Powell was approached informally and expressed an interest in the chair. But as Rudolf Peierls describes in his autobiography *Bird of Passage* (Princeton University Press, 1985) some members of the science faculty board at Birmingham feared that Powell would devote too much attention to his own research and not enough to the 1 GeV proton accelerator that was then under construction, while others felt that his left-wing views would inhibit government grants. In the end, Powell did not get the job.

Four years later, a similar situation arose in Bristol. Nevill Mott had resigned to go to Cambridge, and it was widely expected that Powell – who was by then number two in the department – would succeed him as H O Wills professor and head of physics. Instead, Maurice Pryce from Oxford was appointed. As Frank and Perkins have written: "It can hardly be doubted that nervousness regarding his political stance influenced that decision. Powell would have known better himself. He never allowed political difference to impinge on his loyalty to a colleague, or to the university, or to colour his judgement of scientific work."

Eventually, in 1964, Powell was made H O Wills professor and director of the H H Wills Physics Laboratory. He also became pro-vice chancellor of Bristol University from 1964–1967, and was one of the university's leading statesmen during the time of student unrest in 1968, helping to allay suspicions of professors and students alike.

Cecil Powell – the legacy

Cecil Powell was a courteous man, who treated others as equals – physicists, technicians and scanners alike. Neat and precise in dress, manner and speech, he rarely, if ever, lost his temper and was generally rather tolerant of human weaknesses. He also had a nice sense of humour, and enjoyed telling stories about his eccentric and inventive Uncle Horace. When it came to writing research papers, he took great care - whether he was a co-author or not. He had, after all, an enviable command and extensive knowledge of the English language. One of his favourite authors was Macaulay, to which his prose style bears witness.

In his talks and papers on science and society, Powell was also fond of quoting Francis Bacon, James Clerk Maxwell and Leonardo da Vinci. One of his most famous addresses was given to the CERN Council in October 1964. Speaking on the role of pure science in European civilization, he quoted Maxwell: "For us who breathe only the spirit of our own age and who know only the characteristics of contemporary thought, it is as impossible to anticipate the general tone of science of the future as to predict the particular discoveries it will make".

Rather than ordering people, Powell would suggest and persuade. He guided the progress of research projects with a firm but gentle hand. His personality ensured that the group of young people who came together to work under him in the late 1940s and early 1950s quickly formed a cohesive unit with a strong team spirit, and the international element grew rapidly. Quite often there were informal parties or excursions to the nearby Mendip hills. Powell frequently spent his summer holiday at Cerro di Laveno on Lake Maggiore in Italy, while the summer of 1951 saw him and his wife Isobel mountain walking and climbing in the Dolomites with several of the research group, including two of the women scanners.

Eight days after his retirement, Powell died of a heart attack on 9 August 1969, in the hills above Lake Como at Alpe Guimello, Commune di Casargo. Two years later, largely at the instigation of the Occhialinis and other Italian friends, a seat was placed in his memory near the spot where he died. Earlier, at a commemorative meeting in 1970, Bristol University named its centre for science education after him, while a portrait and plaque now hang in the foyer of the H H Wills Physics Laboratory. The late Eric Burhop, who succeeded Powell as president of the World Federation of Scientific Workers, also endowed the Cecil Powell memorial lecture, which is given at the European Physical Society's triennial congress. As well as his scientific discoveries, Powell's contributions to culture and the mark that he left on society remain as a memory to a truly remarkable man, who was an inspiration to all who came to know him.

Further reading

E H S Burhop, W 0 Lock and M G K Menon (ed) 1972 *Selected Papers of Cecil Frank Powell* (North Holland, Amsterdam)

B Foster and P H Fowler (ed) 1988 40 Years of *Particle Physics* (Adam Hilger, Bristol)

F C Frank 1981 *Dictionary of National Biography 1961-1970* p855 (Oxford University Press)

F C Frank and D H Perkins 1971 *Biographical Memoirs of Fellows of the Royal Society* 17 541

W 0 Lock 1990 Origins and early days of the Bristol school of cosmic ray physics *Eur.J.Phys* **11** 193

W 0 Lock 1997 Half a century ago - the pion pioneers CERN *Courier* **37(5)** 2

Owen Lock was part of Cecil Powell's group at Bristol University from 1948 to 1952. He was then at the Universities of Manchester and Birmingham before joining CERN in 1959, from which he retired in 1992. He lives in Geneva