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Physics in Perspective

The Physical Tourist

Physics in Bristol*

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We trace the history of physics in Bristol, before and after the foundation of the University, describing the important locations and events and contributions by notable individuals. As well as the Nobel prizewinners Paul Dirac, Cecil Powell, and Nevill Mott, these include Arthur Tyndall, Charles Frank, Yakir Aharonov, and David Bohm.

Key words: Bristol; University of Bristol; Henry Herbert Wills; Paul A.M. Dirac; Arthur P. Chattock; Silvanus P. Thompson; Arthur M. Tyndall; Nevill F. Mott; Cecil F. Powell; Charles Frank; Maurice Pryce; Andrew Keller; John Ziman.

Bristol Science Prehistory

The River Severn, whose estuary broadens into the Bristol Channel separating England and Wales, possesses the world's second-highest tidal range. As well as causing the celebrated Severn Bore – a undular hydraulic jump, in which very high tides travel upstream in the form of a great wave – these tides made navigation difficult. Therefore it was natural that in the early Middle Ages the port city of Bristol was founded not on the Severn but ten miles upstream on one of its tributaries, the River Avon (not to be confused with Shakespeare's river of the same name).

With its access to the Atlantic and therefore the Americas, Bristol established itself as the country's leading maritime city in the seventeenth and eighteenth centuries. Even before the foundation of its University College in 1876, Bristol had become a center for science and physics-based technology.

Every Bristol schoolchild learns about the engineer Isambard Kingdom Brunel (1806–1859), whose magnificent suspension bridge spans the Avon Gorge. In several of his projects, he was opposed by the science popularizer Dionysius Lardner (1793–1859), but was able to demonstrate by reasoning and experiment that Lardner's objections were based on bad physics. For example, when Brunel proposed that his Great Western Railway between London and Bristol (the world's first to link major cities) should include a long tunnel with a 1:100 slope, Lardner argued that this would

* For detailed historical material and personal reminiscences relating to the Bristol Physics Department, see the website <http://www.phy.bris.ac.uk/history.html>.

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be a hazard, because if the brakes failed the train would accelerate to the unprecedented speed of 120 miles per hour and cause passengers to die from asphyxiation. Brunel pointed out that Lardner had neglected mechanical and air friction. And when Brunel designed the S.S. Great Britain (the first transatlantic propeller-driven iron steamship) Lardner objected that no ship could carry sufficient coal to cross the Atlantic. Brunel proved him wrong by showing that water resistance increases only as the square of the ship's length, while coal storage capacity increases as the cube: in modern terms, Brunel found the correct scaling law.

One such attack took place in 1836, at an early meeting of the British Association for the Advancement of Science, which had chosen Bristol as its venue because of its central place in the new technologies. Among the luminaries present were Charles Babbage (1792–1871), David Brewster (1781–1868), John Dalton (1766–1844), William Rowan Hamilton (1805–1865), Humphrey Lloyd (1800–1881), John Scott Russell (1808–1882), Henry Fox Talbot (1800–1877), and Charles Wheatstone (1802–1875). Talbot was a polymath who lived in the neighboring county of Wiltshire and became known for his invention of the photographic negative, the polarizing microscope, and the discovery of the Talbot effect in diffraction optics.*

In the city of Bath had lived another near neighbor, the astronomer William Herschel (1738–1832), who in the kitchen of his modest house, now a museum,** improved the technology of "speculum metal" mirrors for his telescopes, leading to his discovery of the planet Uranus.

There are many other early Bristol physics connections. Earlier generations of physics students will recall measuring the acceleration of gravity using Kater's pendulum, invented by the Bristolian Captain Henry Kater (1777–1835). The Irish physicist George Gabriel Stokes (1819–1903) was sent to Bristol as a schoolboy, to study at Bristol College, then famous for its teaching of mathematics; this was housed in buildings (now demolished) in Park Row. The Bristol physician William Bird Herapath (1820–1868) discovered the material that a century later was developed into the polarizing filters now widely employed in optics. Herapath favored medical procedures based on quinine, and treated a dog in this way; his assistant Phelps added iodine to the dog's urine, and noticed that this produced brilliant green crystals with powerful polarizing properties.

University College Bristol, 1876–1909

From the start, this forerunner of Bristol University included physics teaching (combined with "electrotechnics"), originally in a building in Park Row (figure 1) and then (1883–1909) in a building on the east side of University Road (figure 2), in what now

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* The Fox Talbot Museum, Lacock Abbey, Lacock, Wiltshire SN15 2LG, 51°24'52"N, 2°07'12"W, ST917683, is devoted to his work. Here and in subsequent footnotes, and in figure captions, for each place of interest we give the postal address, latitude and longitude, and the United Kingdom Ordnance Survey map reference.

** Herschel House and Museum, 19 New King Street, Bath BA1 2BL, 51°22'57"N, 2°22'00"W, ST745648.

Fig. 1. University College (original location, now demolished), Park Row, Bristol BS1 5LS, 51°27'19"N, 2°36'04"W, ST582730. *Credit*: University of Bristol Library Special Collections.

houses Biological Sciences. A photograph of a physics class from those days (figure 3) shows that a surprisingly large proportion of students were women.

The first lecturer in physics was Silvanus P. Thompson (1851–1916). He was an early electrician, noted for his tireless promotion of this new science in public lectures and in his thirty-nine-times reprinted text, *Elementary Lessons in Electricity and Magnetism*. In 1878 he advised on the installation of electric light in the Redcliff Street factory (now demolished) of the tobacco firm of W.D. & H.O. Wills of Bristol, thereby increasing the length of time available for production beyond the duration of daylight. This anticipated another interaction between a physicist and the Wills family some forty years later, which had the most profound consequences for the development of physics in Bristol.

In the 1880s the College was close to bankruptcy, and Thompson's successor, Arthur P. Chattock (1860–1934), financed the equipment of his laboratory out of his private means, on occasion spending £800, which was twice his annual salary. Even as late as 1906, the entire Bristol University College possessed only one telephone, on a party line shared with the Bristol Blind Asylum.

A significant physics event in this period took place in Horfield, a suburb north of the center of Bristol, in a modest house in Monk Road (figure 4). This was the birth of Paul Adrien Maurice Dirac (1902–1984). When one of us visited the house in prepara-

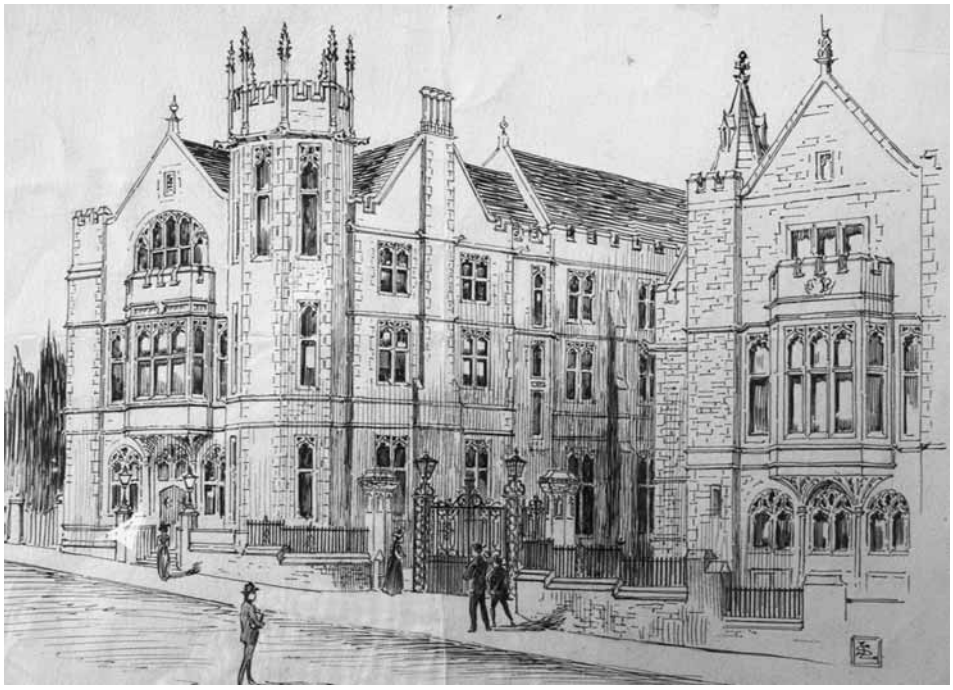

Fig. 2. University College, Bristol, in the 1880s, University Road, Bristol, BS8 1SS, 51°27'23"N, 2°36'16"W, ST581732. *Credit*: Samuel Loxton Collection. Reproduced by kind permission of the Bristol Central Reference Library.

tion for Dirac's centenary celebration, and was explaining to a current tenant that a great theoretical physicist had been born there, she interrupted: "I am sorry but I have never heard of him." "But have you heard of antimatter?" "Oh yes! of course!" Dirac attended Bishop Road Elementary School (figure 4), overlapping there with Archibald Alex Leach (1904–1986), later known as Cary Grant.

Bristol University Physics, 1909–1927

When Bristol University was founded in 1909, Chattock resigned as Professor, arguing that he was not qualified to award physics degrees because he did not have one himself. After several years in retirement as a farmer, he was appointed an Emeritus Professor and returned to the department in 1919 as a researcher. In collaboration with Leslie F. Bates (1897–1978), he measured the gyromagnetic ratio of iron (Einstein-de Haas-Richardson effect), demonstrating definitive agreement with quantum theory (half the value predicted classically). Their delicate experiments were conducted at night after the trams had stopped running, in the basement of Elmdale House (now privately owned) on University Road.

Chattock was soon replaced by Arthur M. Tyndall (1881–1961, figure 5), who had been a student in the department. Tyndall should be regarded as the founding father of

Fig. 3. Physics staff and senior students in a class in the mid-1890s, on the steps of the quadrangle of University College (figure 2). We have been able to identify Professor Arthur Chattock (1); Lecturer and Demonstrator Llewellyn Tyack (2); Samuel Milner, later Professor of Physics at Sheffield University (3); Winifred Walker (later Mrs Milner) (4); and F.B. Fawcett (5). *Credit*: Bristol Physics Department Archive.

the Bristol physics department. He should not be confused with other people with a similar name – common in this part of England: John Tyndall (1820–1893), the Royal Institution physicist who discovered the scattering mechanism explaining the blue sky; Kevin Tindall (1922–2008), for many years the laboratory superintendent of the Bristol department; William Tyndale (ca. 1494–1536), who translated the Bible into English; or indeed the Tyndalls of Royal Fort house, whose name is still commemorated in Tyndall Avenue, which is the address of the physics department today.

In 1916 it was decided as part of the plans for the new main buildings of the University at the top of Park Street to provide an emergency power supply in the form of a large bank of batteries in a room nearby. Tyndall realized that, suitably sited, this power supply could be used for physics experiments. Tyndall thus met the Bristol industrialist Henry Herbert ("Harry") Wills (1856–1922), who with his brother George Alfred Wills (1854–1928) was endowing the main university building as a memorial to their father Henry Overton Wills (1828–1911), the first Chancellor of the University. As Tyndall wrote: "No-one could have forecasted the future consequences of that meeting."[1] Harry Wills was sympathetic to physics, having realized the importance of basic science from his years in the tobacco industry, and formed the idea of endowing a new

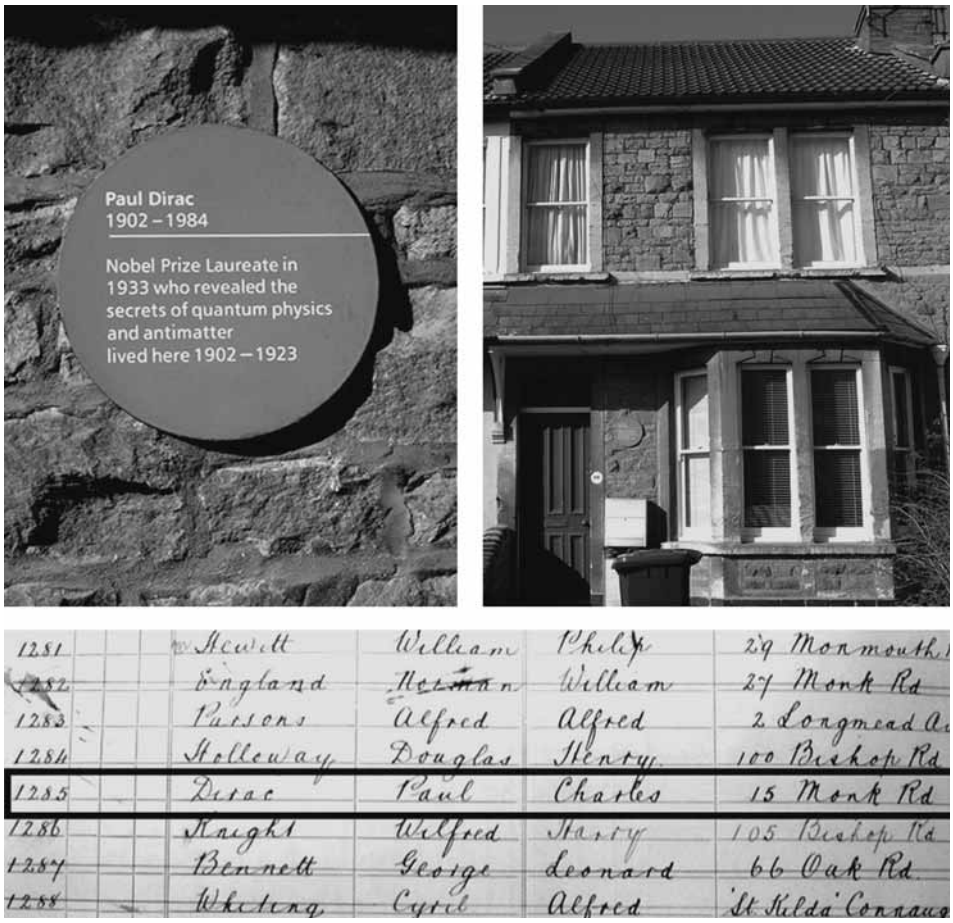

Fig. 4. Plaque on the birthplace of Paul Dirac (1902–1984), 15 Monk Road, Bristol, Bristol BS7 8LE, 51°28'43"N, 2°35'42"W, ST587756. Another plaque is at 42 Cotham Road, Bristol BS6 6DP, 51°27'48"N, 2°35'51"W, ST585739, and yet another plaque is at Bishop Road Primary School, Bishop Road, Bristol BS7 8LS, 51°28'46"N, 2°35'35"W, ST589757, where his matriculation in 1909 is recorded. Photographs by MB.

laboratory for the physics department. After several years of detailed discussion, he bought the Royal Fort estate from the Tyndall family and presented it to the University, along with an unprecedented gift of £200,000 – not for a mere battery room but for a completely new purpose-built modern laboratory.

Tyndall was a visionary. As Nevill Mott later wrote: "I cannot imagine a man whose life was more bound up with his laboratory and with the personal achievements of his staff.... He was indeed a wonderful father to the laboratory."[2] As well as masterminding the design and construction of the new laboratory, Tyndall had a talent for discovering exactly the right people to develop physics in Bristol. In particular, he recognized the growing importance of theoretical physics, and in 1925 appointed John Jones

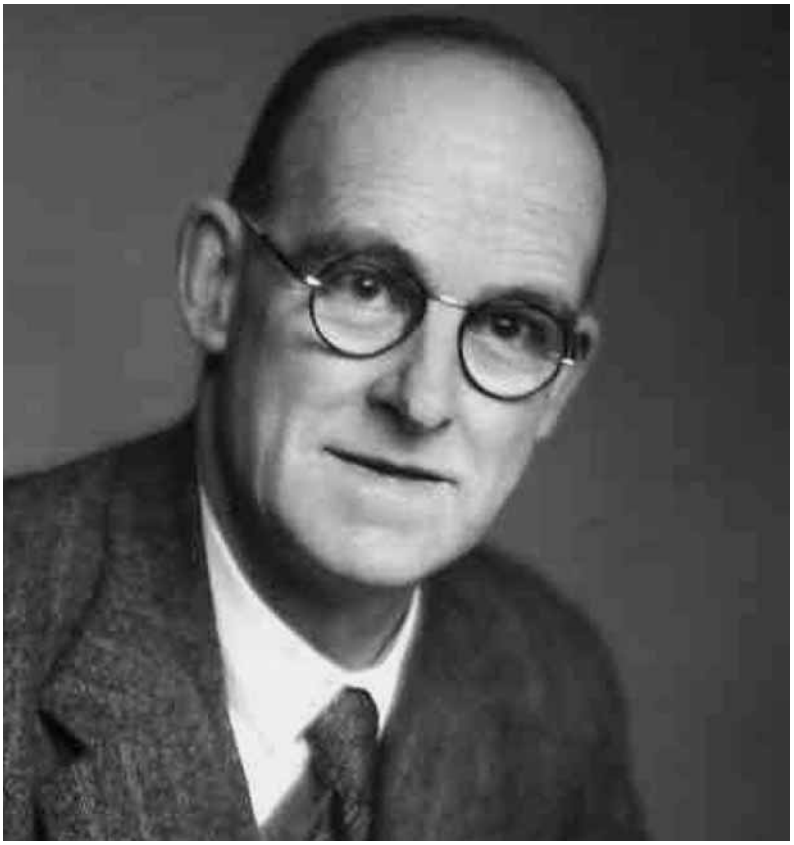

Fig. 5. Arthur Mannering Tyndall (1881–1961). *Credit*: Bristol Physics Department Archive.

(1894–1954), who following his marriage adopted the surname of Lennard-Jones, who became the first of a long line of distinguished Bristol theorists.

Meanwhile, Paul Dirac entered Bristol University at the age of 16, studying for a degree in electrical engineering. The Engineering department was then housed in the Merchant Venturers' Technical College (now converted to apartments) in Unity Street at the foot of Park Street.* At that time (1918), Dirac and others were pushed as fast as they were able, to fill classrooms empty because of the Great War. After graduating in 1921, he moved "up the hill" to the mathematics department for two further years, also attending physics lectures, including those by Tyndall. These studies prepared him for the epoch-making discoveries in quantum mechanics that he was soon to make in Cambridge, for which he received the Nobel Prize in 1933.

* Merchant Venturers' College, Unity Street, Bristol BS15HH, 51°27'12"N, 2°36'02"W, ST583728.

Physical tourists in Bristol can see Dirac remembered in several ways. As well as plaques on 15 Monk Road (figure 4), and 42 Cotham Road where he is reputed to have lived as an infant, the City Council has created Dirac Road in the suburb of Ashley Down.* In 1997 the Institute of Physics Publishing division opened its new offices in Dirac House by the River Avon in the center of Bristol.** And outside the science center Explore@Bristol, in the old dockside,*** can be seen the strange conical sculpture "Small Worlds," created to mark the centenary of Dirac's birth by Simon Thomas (b. 1960), who for several years was artist-in-residence in the Bristol physics department.

H.H. Wills Physics Laboratory, 1927–1964

The laboratory is the highest point in central Bristol, so directions to the physics department can be given in easy geometric form (at least for scientific visitors): the H.H. Wills Physics Laboratory is the attractor of upwards. The exterior of the building (figure 6), inspired by its situation in the Royal Fort estate, resembles castles of a former era, making the laboratory a fitting ornament for the city, visible from miles around. The Gothic tower, one of several originally envisaged by the architect Sir George Oatley (1863–1950), has a Doric portico, decorated with symbolic representations of Newton's prism experiment and Wilson cloud-chamber tracks. The lecture-theater wing is Jacobean, so the building is an architectural mix, prompting Roger Gill to comment: "The result would have startled the Greeks, the Goths and the Stuarts, but did not apparently startle the academics of the University."[3] At the grand opening ceremony, on October 27, 1927, honorary degrees were conferred on Max Born (1882–1970), Sir William Bragg (1862–1942), Sir Arthur Eddington (1882–1944), Alfred Fowler (1868–1940), Paul Langevin (1872–1946), and Sir Ernest (later Lord) Rutherford (1871–1937).

Cecil F. Powell (1903–1969) arrived in Bristol in 1927, and began as Tyndall's assistant, measuring the mobility of ions in gases. In the early 1930s, he embarked on the research into nuclear physics and cosmic rays that was to bear spectacular fruit in subsequent decades.

Tyndall's enthusiasm for theorists culminated in his appointment in 1933 of Nevill Mott (1905–1996, figure 7), later Sir Nevill Mott, who soon realized the tremendous explanatory potential of quantum mechanics and began applying the new physics to metals and semiconductors, laying the ground for research he was to develop many years later and for which he would receive the Nobel Prize in 1978 with Philip Anderson (b. 1923) and John H. Van Vleck (1899–1980). He also devised, with Ronald W. Gurney (1898–1953), the theory of the photographic process.

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* Dirac Road, Bristol BS7 9LP, 51°28'41"N, 2°34'43"W, ST599756.

** Dirac House, Institute of Physics Publishing, Temple Back, Bristol BS1 6BE, 51°27'10"N, 2°35'08"W, ST594728. For the opening of Dirac House, see the website <http://www.iop.org/EJ/news/-topic=0084i/journal/-page=about/0957-0233/1>.

*** Explore@Bristol, Anchor Road, Harbourside, Bristol BS1 5DB, 51°27'03"N, 2°35'57"W, ST584725.

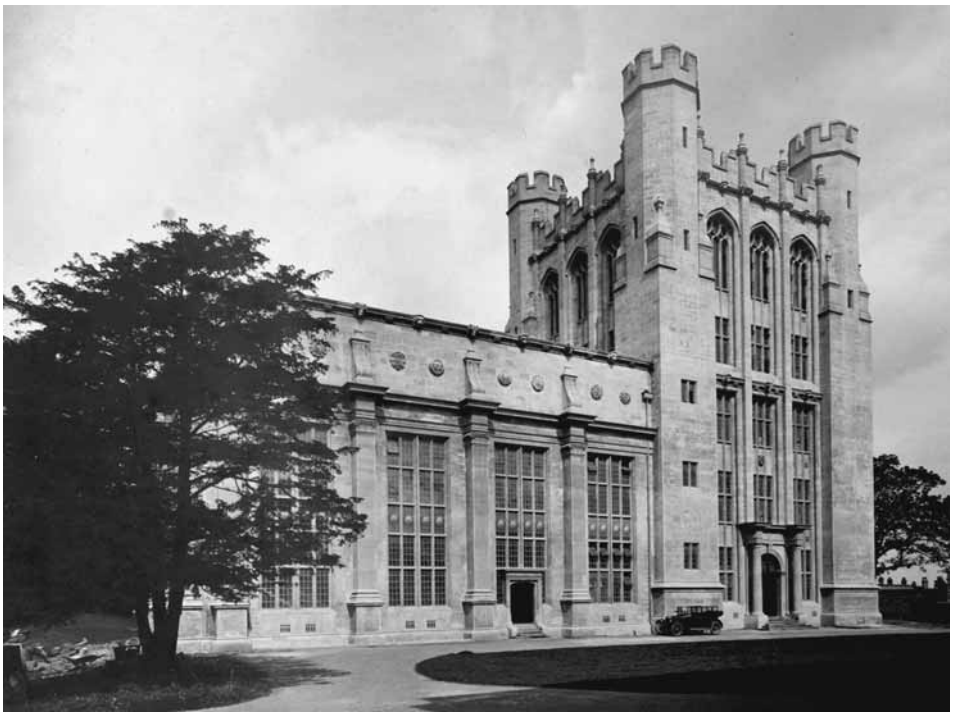

Fig. 6. H.H. Wills Physics Laboratory, Royal Fort, Tyndall Avenue, Bristol BS8 1TL, 51°27'30"N, 2°36'07W, ST582734. *Credit*: Bristol Physics Department Archive.

In the 1930s, Bristol welcomed many physicists from Germany and central Europe who fled from the Nazis. Some, such as Hans A. Bethe (1906–2005), were "birds of passage." Others stayed for several years before moving on; these included Herbert Fröhlich (1905–1991), Walter Heitler (1904–1981), Heinz London (1907–1970), and Klaus Fuchs (1911–1988), later convicted for passing nuclear secrets to the Soviet Union.

After the war, Tyndall retired and Mott returned from wartime work and became Head of Department. Of the several excellent appointments he made, the most inspired was Frederick Charles Frank (1911–1998, figure 8), later Sir Charles Frank. With his geometric genius, Frank helped create the modern theory of crystal dislocations in collaboration with Bristol colleagues Jacques Friedel (b. 1921), Frank Nabarro (1916–2006), and John ("Jock") Eshelby (1916–1988). In addition, he predicted muon-catalysed cold fusion, created the theory of disclination singularities of liquid crystals, and explained the curvature of island arcs.

The mood in the department in the 1950s, and the central role of Charles Frank, were summed up by Andrew Keller (1925–1999), who arrived in 1955 and created the polymer physics group:

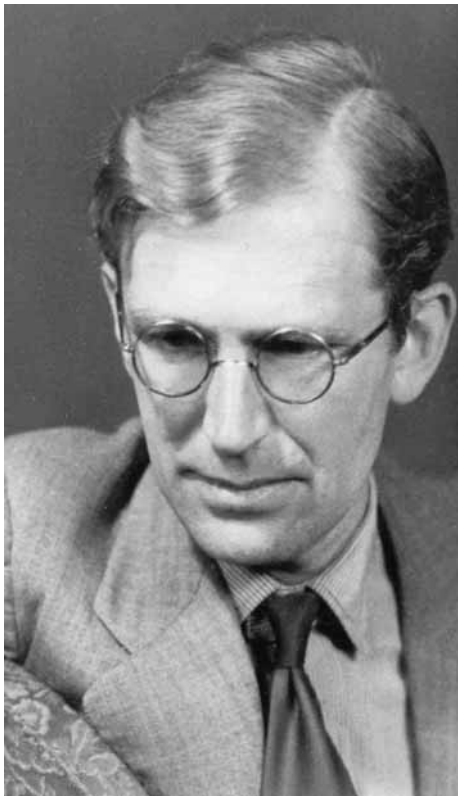

Fig. 7. Nevill Francis Mott (1905–1996). *Credit*: Bristol Physics Department Archive.

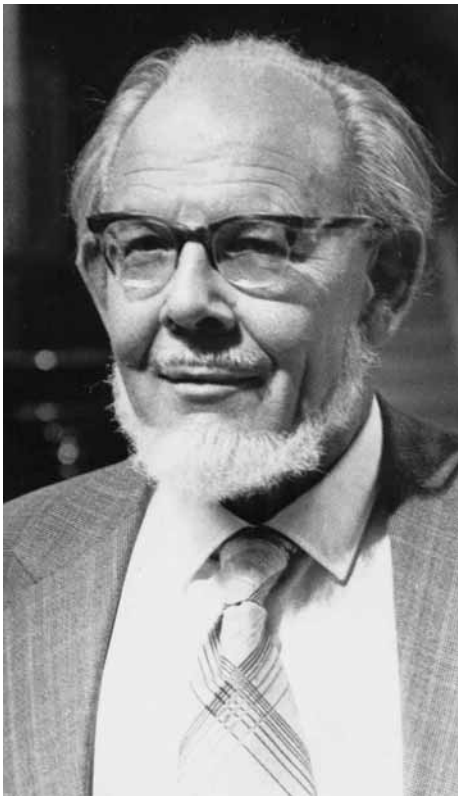

Fig. 8. Frederick Charles Frank (1911–1998). *Credit*: Bristol Physics Department Archive

I was rather stunned by what I saw….

The most positive aspect was the extraordinary intellectual ferment coupled with open-mindedness which permeated the whole place. Physics was in the air, was discussed everywhere: on the stairs, over tea, in the doors (in the process of leaving the building – which could become protracted to the despair of spouses waiting with the dinner at home); passage of time was simply forgotten or ignored. The topics themselves were as wide as the universe. There was no distinction between high and low brow, it was all one intellectual adventure. That is how polymers eventually slotted in between quantum mechanics, dislocations, particle physics, liquid helium, design of new optical instruments and much else. Here I saw science in action, not as fragmented into specialities but as an indivisible whole, a single enterprise of the human mind. It is this spirit that has guided me ever since in my research and in my associated educational activities and which, in my own way, I am still trying to perpetuate. And Sir Charles [Frank] was central to it all! Like a chess virtuoso playing several games simultaneously he was conducting these unforgettable tea-time discussions

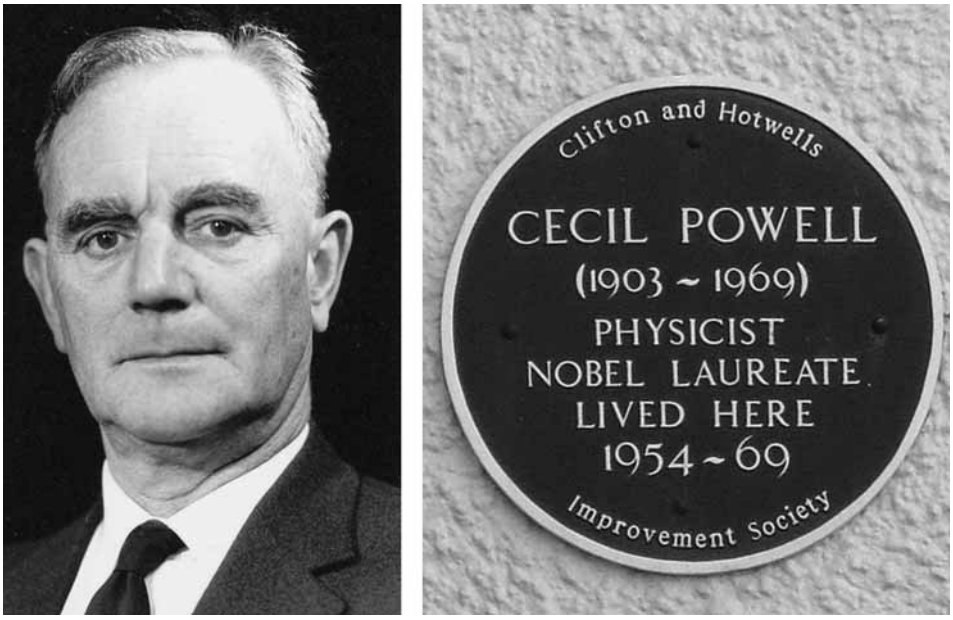

Fig. 9. Cecil Frank Powell (1903–1969) and commemorative plaque on his house at 12 Goldney Avenue, Bristol BS8 4RA, 51°27'10"N, 2°37'02"W, ST571728. *Credit*: Bristol Physics Department Archive and photograph of plaque by MB.

> on virtually all subjects in science. While a protagonist in one subject was pausing to think for a reply Charles was turning to something quite different with somebody else only to return to the previous subject when the reply arrived….[4]

In the cosmic-ray group, Powell (figure 9) was applying the photographic-emulsion techniques that led him, in collaboration with Giuseppe P.S. Occhialini (1907–1993) and Cesare M.G. Lattes (1924-2005), to discover the pi-meson in 1947, and bring him the Nobel Prize in 1950. The tourist can see a plaque on the house at 12 Goldney Avenue where Powell lived for many years. Another member of his group was Peter Fowler (1923–1996), son of Ralph H. Fowler (1889–1944) and grandson of Lord Rutherford.

After Mott left for Cambridge, he was succeeded as Head of Department in 1954 by Maurice Pryce (1913-2003), a theorist of wide interests and acerbic personality who came to Bristol from Oxford. Pryce appointed David Bohm (1917–1994), who arrived in 1957 with his student Yakir Aharonov (b. 1932). Their discovery that quantum electrons could be influenced by distant magnetic-flux lines (Aharonov-Bohm effect) was central to the formulation of modern gauge theories of fundamental interactions.

We choose to end this story of physics in Bristol in 1964, when Pryce left for southern California and Powell took over as Head of Department. We arrived several years later, soon after John Ziman (1925–2005, figure 10), who created the modern theory

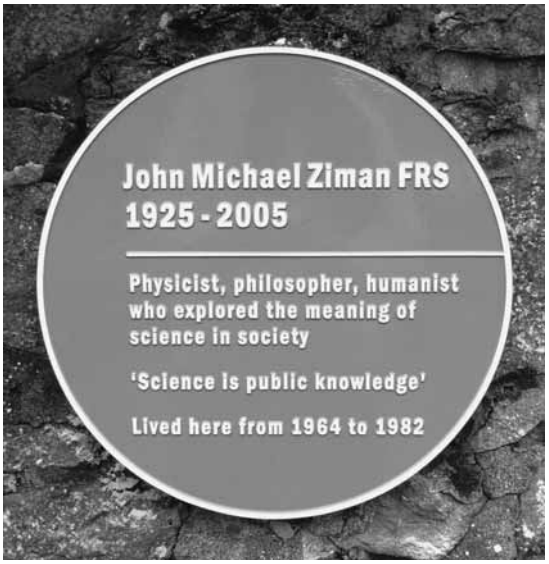

Fig. 10. Commemorative plaque on the house of John Michael Ziman (1925–2005) at 20 Eastfield, Westbury-on-Trym, Bristol BS9 4BE, 51°29'30"N, 2°36'41"W, ST576770. Photograph by MB.

group in the department. One of us (MB) remembers his first encounter with Powell, in the gentlemen's toilet. Powell declared: "The plumbing was unreliable in 1927 and it doesn't work properly even now." (Nor does it still, in 2008.) Plumbing aside, the building required no significant maintenance for many decades, as H.H. Wills had stipulated. The innovative 1927 design included interior walls that could be moved or removed, and indeed this has happened recently, to accommodate new undergraduate laboratories.

Through the 1960s, the "New Wing" was constructed, as an unattractive addition to the top of the hill on Tyndall Avenue. As we write, both this and the 1927 laboratory are undergoing a thorough renovation, and a new Centre for Nanoscience and Quantum Information is being built next door.

References

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2 Speech by Sir Nevill Mott, FRS, at the Golden Jubilee of the H.H. Wills Physics Laboratory, July 11, 1977, *University of Bristol Alumni Gazette* (Centenary Edition, 1977), p. 24.

3 Roger Gill, "The University and the Bristol Environment. 1. The Buildings of the Main Precinct," in J.G. McQueen and S.W. Taylor, ed., *University & Community: Essays to mark the Centenary of the founding of University College, Bristol* (Bristol: University of Bristol, 1976), pp. 15–30; on p. 22.

4 A. Keller, FRS, "Chain-Folded Crystallisation of Polymers From Discovery to Present Day: A Personalised Journey," in R.G. Chambers, J.E. Enderby, A. Keller, A.R. Lang, and J.W. Steeds, ed., *Sir Charles Frank, OBE, FRS: An eightieth birthday tribute* (Bristol, Philadelphia, New York: Adam Hilger, 1991), pp. 265–306; on pp. 268–269.

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Sign Mistake

George Gamow recounts the following story showing Dirac's quick quantitative wit:

> Dirac's sense of quantum humor was often demonstrated at scientific meetings. Once, in Copenhagen, Klein and Nishina reported their derivation of the famous Klein-Nishina formula describing collisions between electrons and gamma quanta. After the final formula was written on the board, somebody in the audience who already had seen the manuscript of the paper remarked that in the formula as written on the blackboard the second term had the negative sign, whereas in the manuscript the sign was positive.
>
> "Oh," said Nishina, who was delivering the talk, "in the manuscript the signs are certainly correct, but here on the blackboard I must have made a sign mistake in some place."
>
> "In some odd number of places!" commented Dirac.

Source: George Gamow, *Thirty Years that Shook Physics: The Story of Quantum Theory* (Garden City, N.Y.: Doubleday, 1966), p. 121.
