Part I

John Stewart Bell: The Physicist

1

John Bell – The Irish Connection

ANDREW WHITAKER

John Bell lived in Ireland for only 21 years, but throughout his life he remembered his Irish upbringing with fond memories, pride and gratitude.

1.1 Irish Physics and the Irish Tradition

Ireland has a very respectable tradition in physics, and particularly mathematical physics [1]. As early as the eighteenth century, Robert Boyle is usually given credit for establishing the experimental tradition in physics [2, 3]. Through the nineteenth century, luminaries such as William Rowan Hamilton [4], James MacCullagh [5], Thomas Andrews [6], George Francis FitzGerald [7, 8] and Joseph Larmor [9] all made very important contributions to the establishment of physics as an intellectual discipline in its own right, while it should not be forgotten that although the academic careers of George Gabriel Stokes [10], William Thomson [Lord Kelvin] [11] and John Tyndall [12] were spent in England or Scotland, all had Irish origins which they never forgot.

An important aspect of Irish mathematical physics in the nineteenth century was the existence of the so-called Irish tradition, which consisted of studying the wave theory of light and the ether. It was a tradition that was to be important for John Bell and it was to transcend what may be described as the most important event in nineteenth century physics – James Clerk Maxwell's theory of electromagnetism, and his conclusion that light was an electromagnetic wave [13]. The work of MacCullagh and Hamilton was performed in the 1830s and 1840s, while Maxwell's mature work was not to emerge until the 1860s.

MacCullagh improved the theory of Christian Huygens and Augustine Fresnel, being able first to derive the laws of reflection and refraction of light at the surfaces of crystals and metals, and then to write down equations for a light-bearing ether that justified his previous work. He was also able to handle the phenomenon of total internal reflection, and his model of the ether involved an effect that he called 'rotational elasticity', which was easy to describe mathematically but difficult to picture physically [14].

MacCullagh is probably not very well known even among physicists. One physicist, though, who was well aware of his achievements was Richard Feynman. In his famous lectures [15], he discusses MacCullagh's work in his very first chapter of his volume on

electromagnetism, where he argues that one should not look for a mechanical model for electric and magnetic fields.

Feynman comments that 'It is interesting that the correct equations for the behavior of light were worked out by MacCullagh in 1839. But people said to him: "Yes, but there is no real material whose mechanical properties could possibly satisfy those equations, and since light is an oscillation that must vibrate in *something*, we cannot believe this abstract equation business." If people had been more open-minded, they might have believed in the right equations for the behavior of light a lot earlier than they did.'

Hamilton was broadly a contemporary of MacCullagh, though, of course, much better known, principally for his theory of quaternions and his invention of what is now known as 'Hamiltonian mechanics'. His work on optics used the same general methods as that on mechanics, and he also studied the wave surface in detail, making the important prediction of conical refraction, a prediction soon verified by another Irish physicist, Humphrey Lloyd.

FitzGerald and Larmor, whose main work was performed after Maxwell's discoveries, in the 1880s and 1890s, respectively, were thus, of course, working in a completely different scientific context than MacCullagh and Hamilton. They were to become central members of the group often known as the 'Maxwellians' [16, 17], the other main members being Oliver Lodge, Oliver Heaviside and Heinrich Hertz; the last was the first to generate and detect the electromagnetic waves predicted by Maxwell.

While Maxwell's work was undoubtedly brilliant in the extreme, Yeang describes it as 'promising but esoteric and somehow puzzling' and he argues that it was largely FitzGerald, Lodge and Heaviside who transformed his theory into a 'fully-fledged research programme', while Larmor was able to supplement the field-based paradigm of Maxwell with a microphysics in which charge and current 'regained the status of fundamental physical entities'. This blended in neatly with J.J. Thomson's 'discovery' of the electron [18] and the new age in physics thus entered. As is well known, Hendrik Lorentz came to conclusions similar to Larmor's in the same period.

It is interesting to note the extent to which the work of FitzGerald and Larmor was based on the much earlier ideas of MacCullagh and Hamilton, particularly the former. O'Hara [5] writes that '[MacCullagh's] work was received with scepticism by many contemporaries … His dynamical theory did, however, find supporters, particularly among the Anglo-Irish, decades after his death.'

An important idea of FitzGerald, his vortex ether model, was based wholly on MacCullagh's model of the ether. Working by analogy with MacCullagh, he was able to interpret the potential and kinetic energy of the ether in terms of the energy of the field, and use this to derive the laws of reflection and refraction [17]. FitzGerald was also able to use MacCullagh's model of the ether to explain the propagation of radiant heat and electromagnetic radiation in general [14].

Larmor drew on the ideas of both Hamilton and MacCullagh [14]. He followed Hamilton in his statement that 'The great *desideratum* for any science is its reduction to the smallest number of dominating principles. This has been achieved for dynamical science mainly by Sir William Rowan Hamilton of Dublin.'

In his famous book *Aether and Matter*, Larmor [19] developed MacCullagh's model of the ether to include electric charges. For Larmor the ether was not a material medium; rather he visualised electric particles or 'electrons' as moving in the ether and following Maxwell's laws, while an electron itself was not a material particle but a nucleus of intrinsic strain in the ether [14]. Larmor was so impressed by MacCullagh's ideas that he described him as one of the great figures of optics.

Their work on the ether led both FitzGerald and Larmor to become involved with the search for signs of the motion of the earth through the ether, and it was in this context that Bell might have considered himself to be an honorary member of the Irish tradition. As is well known, FitzGerald and also Lorentz postulated a contraction of the length of the object along the direction of its motion through the ether that would serve to make its motion through the ether unobservable.

Larmor went rather further by discussing the equilibrium conditions of his electrons or intrinsic strains for different states of motion. The relations he obtained between the various conditions are what are now known as the Lorentz transformations. Larmor was thus the first person to write these down, although his argument showed only that they were correct to second order; at the time he did not realise that they were correct to all orders.

The ideas of FitzGerald and Larmor were of interest to Einstein early in the following century, although, of course, his stance was notably different; as we shall see, they were also of interest to John Bell much later in the century.

Let us now turn to the first half of the twentieth century before Bell entered university, and note again the significant contributions of Irish physicists during this period, such as John Synge [20], John Desmond Bernal [21] and Ernest Walton [22]. It should also be remembered that the Dublin Institute for Advanced Studies gave sanctuary to Erwin Schrödinger [23] and Walter Heitler [24] in World War II, and Cornelius Lanczos [25] a little after the war.

The majority of those mentioned so far were associated with Dublin, and particularly with Trinity College Dublin, which was founded as early as 1592, but after 1849, when Queen's College Belfast [from 1908 Queen's University Belfast] had been founded, a substantial contribution was made to physical science there as well. Kelvin, Andrews and Larmor were linked to Belfast, as well as such worthy figures as Peter Guthrie Tait [26] and James Thomson [27].

It is also interesting that, a few years before Bell entered Queen's University Belfast, just before World War II in fact, there was quite a remarkable flowering of potential talent in physics and mathematics at the university [28]. Three of the rather small group became Fellows of the Royal Society (FRS) and were also knighted. These were William McCrea, then Head of Mathematics, who became a very well-known astronomer, Harrie Massey, Head of Mathematical Physics, who after the war was the UK's leading atomic and space physicist, and David Bates, who was to set up a large and influential group working on atomic physics and geophysics in Belfast itself.

Samuel Francis Boys also became an FRS; James Hamilton became one of the world's leading particle physicists and had a period as Head of NORDITA, the Nordic

[Scandinavian] Institute for Theoretical Physics, an international organisation set up by Niels Bohr, while Richard Buckingham became the world's leading expert on the application of computers in education, and the first Chair of the Technical Committee for Education of the International Federation for Information Processing.

1.2 John Bell – The Belfast Background

As would be expected, this group had largely dispersed to carry out war work before John Bell was to arrive at Queen's, but nevertheless it is clear that traditions and standards were high. Indeed, in 1949, when John was interviewed for his first scientific job at the UK atomic energy station at Harwell, a little concerned that he might not be considered as seriously as a graduate of Oxbridge or one of the leading London colleges, the main question was not whether he would be given a job – that was soon taken for granted – but which of the panel members, Klaus Fuchs or Bill Walkinshaw, should gain his services. Of course this was partly, perhaps largely, because of John's ability, but obviously his education must have been of a high standard as well. (Fuchs as the senior person obtained Bell for his atomic reactor group, but within months he was unmasked as the 'atomic spy' and almost by default Bell ended up with Walkinshaw and accelerators.)

Yet there must have been differences between studying at a major university and at a university which, whatever its merits, was rather remote and had a much greater emphasis on medicine than on physical science. However, before considering this, and in particular how it would have affected John's studies, let us think about his background and especially any effect his Irish roots may have had on his intellectual development and aspirations.

In the 1930s, the Bell family were not well off. This should certainly not be exaggerated – they were certainly no worse off than hundreds of thousands of others in the industrial cities of the United Kingdom. Indeed, shrewd management by his mother Annie meant that the family did not go without any essentials, and could even scrape up a few luxuries, such as second-hand bicycles for the children. And John found education up to the age of 11 enjoyable and interesting. Fortunately it was also free!

After that age everything was much more difficult, and it was rather more difficult in Northern Ireland than in the rest of the United Kingdom. It was only to be a few years before free secondary education was to become law in 1947, actually three years after it had done so in England. In 1939, though, it was not only not free but expensive, and although John passed the actual entrance examination for grammar school with ease, he sat the scholarship examination in every grammar school without success.

In Northern Ireland there seemed to be little leeway even for the obviously extremely talented. Each grammar school had its own junior or 'preparatory' department, where pupils paid to study up to age of 11, and the school was likely to award post-11 scholarships to those who had already paid into the system, rather than to the poorer child without perhaps such a posh accent.

While it must be admitted that different parts of the United Kingdom had their own policies and practices, an interesting comparison might be with Fred Hoyle [29, 30], a

distinguished scientist of the future, though, like John Bell, with parents who were not very well off. Hoyle did obtain a scholarship to Bingley Grammar School in Yorkshire, admittedly only after an appeal, and thereafter Yorkshire Education Committee financed him throughout his university studies.

In contrast, John Bell obtained a small amount of support, sufficient only to attend the much less prestigious Technical School, and he was lucky to obtain that – he never knew where it came from. The course allowed him to matriculate at Queen's, but again he needed a small amount of money – obtained as a grant from the Cooperative Society – to be able to attend the first year at the university. He had actually finished school a year too young to commence at the university, and had been fortunate enough to get some experience and earn some money by working as a laboratory attendant in the very department where he hoped go become a student, but, as we have seen, it was touch and go whether this would be possible.

So at the time of his entry to university, John Bell had taken advantage of friendly and helpful teachers, and been very much encouraged by his mother. However, he had been sorely discouraged by the grammar schools of Belfast, and, to a lesser extent, by the problem of university entrance. His father's attitude – that the natural course was to leave school as early as possible and get a job [31] – must have been discouraging. (It must be admitted, though, that this attitude would probably have been far more common among working people at the time than that of his mother, which was that it was wise to get all the education that was possible.)

Also, helpful as all his teachers had been, and he was keen to praise them all [31], his personal intellectual wanderings must have by far transcended them. His library-based analysis of philosophy, physics and the writings of such figures as Cyril Joad, H.G. Wells, George Bernard Shaw and Bertrand Russell was to play a considerable part in determining the type of person he was to become, both in intellectual interests and in personal standards. Just as an example, his choice to become a vegetarian, following the example of Shaw, would have been exceptionally unusual in young men at that period.

1.3 Determination – A Protestant Characteristic?

It is clear that, at this time in his life, and despite his quiet demeanour and good behaviour, he had the ability to overcome obstacles and to decide on his own course of action, not being put off by a good deal of opposition. It is possible to suggest that these traits were encouraged by the political and social background in which he was situated.

It may not be too much of a simplification of Irish history to say that while, from the end of the seventeenth century, the minority Protestant community had exercised full domination over the majority Catholics, from the 1860s with renewed talk of Home Rule, and particularly from 1885, with the conversion of William Gladstone, leader of the Liberal Party, to the cause of Home Rule, the Protestant community had become more and more nervous and defensive about the political situation. Home Rule would have given Ireland a very limited form of devolution, but broadly the Protestants would have none of it [32].

By 1922, though, 26 of Ireland's 32 counties had gained a degree of freedom much greater than that offered by Home Rule, with the 'Irish Free State' being a self-governing dominion within the British empire of the same nature as Canada, though an oath of allegiance to the crown was still required. Protestants in these counties obviously had to come to terms with their minority status. However, the six counties in the northeast of the island, where there was a Protestant: Catholic ratio of roughly 2:1, had gained their own form of Home Rule, a 'Province' of 'Northern Ireland', with a Parliament in Belfast which had control of security and internal matters, but also with representation in and subservient to the British Parliament.

The Protestants in Northern Ireland had a permanent majority in the Parliament and took the opportunity to strengthen the sectarian nature of the Province by gerrymandering electoral boundaries and considerable use of discrimination, though it has to be said that the minority community assisted the process by refusal to take part in the new political institutions.

Without entering into rights and wrongs, it is undoubtedly the case that the Protestant community in Northern Ireland felt themselves to be beleaguered from two directions: from outside, by the government of the remaining 26 counties, which never recognised Northern Ireland, which described its own territory as the full 32 counties of the island, and which maintained the right, in principle, to subsume the six northeastern counties, however little it might do in practice; and from inside, from the recalcitrant minority, who also refused to accept the present constitutional position, and who would, from time to time, turn to passive resistance and guerrilla activities. They also suspected that, when the chips were down, they would receive precious little support from the rest of the United Kingdom.

While it will be readily admitted that the minority population in the north felt *themselves* to be a beleaguered minority *within* Northern Ireland, it is only to be expected that the typical psyche of the Northern Irish Protestant tended to be rather defensive and determined, unafraid of being in a minority on the island, keen to assert rights, keen to maintain the dominance of the majority community in the province, and especially keen to eliminate any influence of the Catholic church!

John Bell was certainly not interested in Protestantism as such – his wife Mary [33] has reported that he was an atheist most of his life. Though feeling a broad affinity to the Protestant community, he was very open to fruitful political discussion between the two communities, and while at Queen's had interesting theological discussions with a Catholic friend.

Nevertheless it is at least plausible to surmise that he took over some of the better qualities of his community – determination, honesty, stickability, and the willingness of take on a minority cause even at the risk of some ridicule. Fortunately he did not (except in very special and very exceptional cases) take on the pugnacity which often goes with these praiseworthy attributes.

Two other ways in which he may have assimilated qualities from his community may be tentatively suggested. First is perhaps a tendency not to promote one's own

achievements – not so much a desire for privacy or to limit attention to oneself, but more a preference for the attention to be drawn by others. The second is the tendency to ignore or wish away medical symptoms, just to hope that they will go away if left alone – anything better than attending the doctor.

It may well be argued that these two attitudes are by no means confined to Northern Irish Protestants, which is certainly true, the second perhaps applying to most men everywhere! However, there does seem to be a certain resonance with the stoical undemonstrative community in which John Bell was brought up, and it is very easy to relate these to John's own life.

1.4 Studying Physics at Queen's

Let us now return to John's studies at Queen's University Belfast. Queen's was very much a provincial university and definitely had been taken to the hearts of the local people. The noted poet Philip Larkin worked in the library at Queen's from 1950 to 1955 before his long period as (Chief) Librarian at the University of Hull [34], and his Belfast days were actually the happiest and the most successful creatively of his life; he very much enjoyed both the city and the university. At Leicester, where he had worked before, he felt that the University was regarded 'if at all, as an accidental impertinence'. In Belfast, on the other hand, the university had local character and was fully integrated into the community. 'Your doctor, your dentist, your minister, your solicitor would all be Queen's men, and would probably know each other. Queen's stood for something in the city and in the province … It was accepted for what it was.'

When Bell was at Queen's, the number of students was around 1500, but of these roughly half were studying medicine or dentistry [35]. There were about 300 in engineering, around 250 in arts, and half as many in science, with the remainder in law, agriculture and theology. Physics and mathematical physics each had about five students in any year, but medical and engineering students had to study physics in their first year, so that pushed up the number taking the subject in that year enormously. On the teaching side and across all subjects there were around 30 professors and around 120 others – readers, lecturers, clinical lecturers, assistants and demonstrators.

In physics at this period there were one or two temporary assistant lecturers or demonstrators, usually graduates of Queen's often working for PhDs, who did much of the first-year laboratory work at lower levels, but there were two permanent members of staff in experimental physics, Professor Karl George Emeléus and Dr Robert Harbinson Sloane. Both were known by their second names – George and Harbinson.

Professor Emeléus had worked under Rutherford at Cambridge, where he took some of the first pictures of particle tracks and helped to develop the Geiger counter. He had spent a brief period working on plasma physics with Edward Appleton at King's College London before he was appointed to a lectureship at Queen's in 1927, and promoted to professor in 1933. He was an excellent research worker, publishing over 250 papers in his field of conduction of electricity through plasmas at low temperatures. In 1929, he wrote

the definitive monograph on the topic, *The Conduction of Electricity through Gases* [36], and this was reprinted in 1936 and 1951.

He may have been disappointed that he was not elected as an FRS, unlike his brother, Harry Julius Emeléus, who was Professor of Inorganic Chemistry at Cambridge University from 1945, but the reason must surely be that he dedicated his life to undergraduate teaching. He delivered the great majority of the lectures in the department, and was well known for his ability to present the most difficult topics in a clear and indeed captivating way. Though a rather formal person, he was eminently concerned and helpful with the problems and requirements of his students.

Dr Sloane was equally dedicated to his students. A protégé of Emeléus, he carried out research in the same area and he was particularly skilled in constructing the highly sophisticated equipment that was required. In Bell's day his teaching was mostly restricted to laboratory work at the higher levels and also a course for the final year students, of which more shortly. Sloane was an excellent physicist, becoming a reader, equivalent to an associate professor elsewhere, and, like Emeléus, a Member of the Royal Irish Academy.

What did the limited size of the department, in numbers of both students and lecturing staff, mean for John Bell and the other students? One might also mention the geographical separation of Northern Ireland from the rest of the United Kingdom and the political division from southern Ireland. Such separation does not imply actual remoteness – physically it was easy enough to get to, for instance, Glasgow, Liverpool or Dublin. Nevertheless there was a certain parochialism. Extremely few students would come to Queen's from outside Northern Ireland, while it seems quite probable that, for example, John Bell might never have left the province until he left to work at Harwell.

The first point, an entirely positive one, would be that, with such a small number of students, coupled with the helpfulness of Emeléus and Sloane, the students were in the favourable position of being able to solicit help and obtain answers to worrying questions. An excellent example of this occurred with John Bell even before he became a student, in his year as a laboratory assistant. Recognising his great interest and ability, the staff lent him books, and allowed him to attend the first year lectures and take the exams at the end of the year. This allowed him to have a year over at the end of the course, which was extremely beneficial for him, as it allowed him to add a second degree in mathematical physics to the one he already had in experimental physics. He obtained first-class honours in both degrees.

Another important example for him, from Professor Emeléus in particular, was the importance of developing a wide-ranging understanding of physics. This was to be very important in his research career. When he began work on particle accelerators at Harwell, his task was to trace the paths of particles through the various arrays of electric and magnetic fields in any particular design. His deep understanding of electromagnetism allowed him to make substantial contributions to the work immediately, and, when the all-important 'strong focussing' was discovered [37], he was able to write a seminal report [38]. Similarly, when he returned to work on accelerators and the Unruh effect in the 1980s, he was able to make superb use of his knowledge of thermodynamics [39]. Last, as we shall see