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INTRODUCTION

A life in science: a tribute to Professor Sir Nevill Mott

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The death in 1996 of Sir Nevill Mott brought to a close the illustrious career of a man who spent his life unravelling, with a powerful combination of intuition and insight, the mysteries of condensed matter physics. His first paper was written in 1927, during the early days of quantum theory, and his last, on high-temperature superconductivity, was published in 1996, four months after his death at the age of 90. The numerous ideas and concepts, many of which carry his name—Mott transition, Mott insulator, Mott scattering, Mott–Hubbard gap, Mott variable-range hopping, etc—live on, as clearly exemplified by the papers in this special issue.

Nevill Mott was a theoretical physicist—a label too narrow and restrictive to describe his output and methods of working. His principal posts were at Bristol and Cambridge, but he was the 'father' of a much larger community, communicating with hundreds of scientists, theorists and experimentalists alike, in numerous countries via handwritten letters, most of which contained gems of ideas that were treasured by their recipients. In this way, and by organizing mini-conferences and workshops in topical fields, he drew together ideas and people from different disciplines.

Early years

Mott's mother and father both worked in the Cavendish Laboratory in Cambridge with J J Thomson, a few years before JJ's identification of cathode rays with 'corpuscles' (electrons) in 1897, and so it was natural he should take an early interest in physics. In his autobiography *A Life in Science* [1] he records that from a young age his parents had communicated to him the excitement and importance of the subject. He also recalls realizing, at the age of 16, why any number raised to the power zero equalled unity! After reading for the mathematical tripos at St John's College, Cambridge, he graduated in 1926 at around the time that Heisenberg, Schrödinger and others were revolutionizing physics with the development of quantum mechanics. He taught himself German in order to be able to read their papers and, after spending some time in Copenhagen with Niels Bohr, made an important prediction relating to the scattering of alpha particles, namely that when these were scattered by helium nuclei, the identity of the two particles, together with the fact that they were bosons, caused twice as many to be deflected at 45° than would be expected from Rutherford's classical theory. Rutherford's reaction to Mott's result was 'If you think of anything else like this, come and tell me'.

A short spell at Manchester University under W L Bragg saw the publication of his first book *An Outline of Wave Mechanics*, written when he was just 25. It was at Manchester where his interest in materials was aroused, encouraged no doubt by the power of the new technique of x-ray crystallography to determine the structure of solids—a method that earned W L Bragg the Nobel prize for physics jointly with his father W H Bragg.

An invitation to return to Cambridge came in 1930 and Mott accepted a fellowship at Gonville & Caius, a college at which he was to be appointed Master 29 years later. The prime interest at the Cavendish was still atomic physics and 1932 was its *annus mirabilis* when the neutron was discovered and the atom split. Stimulated in this extraordinary atmosphere, he collaborated with Harrie Massey to produce a classic tome *The Theory of Atomic Collisions*, which ran to several editions.

Bristol

In 1933 Mott accepted his first Chair, that of Professor of Theoretical Physics at Bristol University. For 6 years, up to the outbreak of the Second World War, he played a significant role in establishing Bristol as a foremost centre for solid-state physics. His philosophy, which he never abandoned during the whole of his working life, was to have theoreticians and experimentalists working closely together. Mott's ability to draw theory and experiment together—to persuade practitioners on both sides to work on common problems—was a hallmark for which he will be remembered.

Great success had been achieved in Europe, particularly in Germany, by the application of quantum mechanics to the understanding of the properties of metals and of the difference between metals and semiconductors. The work of Sommerfeld, Bloch, Peierls and Bethe was especially successful and Mott set about continuing this tradition. He found an enthusiastic supporter in Harry Jones and together they wrote a famous textbook *Theory of the Properties of Metals and Alloys*. Numerous problems and puzzling properties of metals were solved at Bristol during these heady days—advancing the subject and also providing much of benefit to industrial metallurgists.

In his six pre-war years at Bristol, Mott did not only confine his attention to understanding the physics of metals; he also began his first work on insulators and semiconductors. The initial stimulus came from Ronald Gurney who, like Mott, had a remarkable talent for visualizing solids in terms of their constituent atoms and electron waves, without the need for detailed mathematics. Together they wrote *Electronic Processes in Ionic Crystals*, a book that laid the foundation of the field of colour centres in alkali halides by providing a description of the defects involved. They also worked out the physics behind the photographic process—why light falling on a grain of silver bromide was able to produce a speck of silver, the latent image. In 1940 Mott was awarded the Harker and Driffield medal from the Royal Photographic Society for this work. Four years earlier, at the age of 31, he had been elected a Fellow of the Royal Society.

Mott's personal qualities and humanitarianism were evident after the German occupation of the Sudetenland, when there was a movement to rescue children of Jewish descent from Czechoslovakia. He and his wife Ruth, with help from his sister Joan, housed two young refugees, daughters of a Jewish musician. Lilly and Ilse Spielman, who stayed in England after the war, recall their gratitude to this day.

The war and return to Bristol

During the Second World War, Mott was involved in various defence projects relating to radar, shell fragmentation, the deployment of searchlights and mathematical analysis of armaments generally. In a collection of contributions to a book *Nevill Mott: Reminiscences* *and Appreciations* [2], a war-time colleague, Frank Nabarro, recalls how he was required to determine the optimum distance an operator should stand from his searchlight in order not to blinded by light reflected back from particles in the air. The problem involved an awkward integral and Nabarro consulted a professor of mathematics for help in solving it. Mott stepped in and did the required calculation on the back of an envelope. This gift of insight, which enabled him to get to the heart of any problem and to say to theoreticians 'look if you solve such and such a problem properly, this is the result you'll get', was to astound many who worked with him. He wrote a paper on why German shells, which were made of steel with a high carbon content, fragmented into smaller pieces than the British shells.

During the last days of the war, Mott was offered Chairs both in Metallurgy and in Theoretical Physics at Cambridge, but an assurance that if he returned to Bristol he would succeed to Tyndall's position as Head of Department attracted him back there. Many of the scientists at Bristol before the war, for example Skinner, Gurney, Harry Jones and Frölich, took positions elsewhere and did not return. In their place, Mott appointed, amongst others, Jack Mitchell, Charles Frank, Jacques Friedel (who married Ruth's sister) and Nicolas Cabrera. These great men and their works made the Bristol Physics Department once again a leading research establishment. In 1949 Mott published his first paper on metal–insulator transitions—a topic that was to retain his interest to the end of his life. This was also the period that saw the invention of the transistor at the Bell Telephone Laboratories in the USA, a discovery in which Mott took a keen interest. He was later to develop a theory for what became known as Mott–Schottky barriers in semiconductors.

Aside from research, Mott was appointed President of the Physical Society, overseeing its amalgamation with the Institute of Physics. He also took on the Editorship of the *Philosophical Magazine* and became Chairman of the Board of Taylor & Francis, its publisher. Other activities that continued to occupy his time for many years were his campaigning against the atomic bomb and his Chairmanship of the Atomic Scientist's Association, the aims of which were to explain the true facts about nuclear energy to a wide audience.

Cavendish professorship

In 1953 Mott received an offer of the Cavendish Chair of Experimental Physics, which, although he was unhappy at the prospect of leaving Bristol, he accepted. The previous holders of this prestigious position had been James Clerk Maxwell, Lord Rayleigh, J J Thomson, Ernest Rutherford and Lawrence Bragg.

Administrative duties and matters unrelated to his own research occupied Mott's attention for a great deal of his time as Cavendish Professor. Reform of the natural sciences degree at Cambridge, as well as the physical sciences curriculum in schools (through the Nuffield Foundation), were two activities of note. Another was to suggest and support the creation of a science park on the outskirts of Cambridge by Trinity College, which attracted science-based industries to the city—an initiative subsequently copied by many other universities. In 1959 he was elected Master of Gonville & Caius College, an appointment that did not require him to give up the Cavendish Chair. He hosted a Pugwash Conference in the college at which, in his book *A Life in Science*, he recalls Henry Kissinger arguing with the Russian representatives about their country's hostility to China. It was during his Mastership of Caius that Mott was awarded a Knighthood.

Non-crystalline solids

When the present writer arrived in Cambridge in 1967, Mott was still head of the Cavendish and had once again begun to turn his attention seriously to solid-state physics. His interest in metal–insulator transitions had never waned and when I described to him the research work I had undertaken at the University of Illinois on heavily doped semiconductors, which behave as metals when the concentration of donors or acceptors exceeds a critical value, he showed an interest far beyond my expectations, particularly as I had not been the first to make such measurements; Hellmut Fritzsche in Chicago and others had made similar measurements. What Mott saw, with his customary and extraordinary insight, was that the metal–insulator transition in doped semiconductors was intimately related to another kind of transition described in a paper by Phil Anderson on the effects of disorder on the electronic states in solids. Anderson's classic paper of 1958 (which he was later to describe as one that is often quoted but seldom read) showed how disorder 'localizes' electronic states, distinguishing these from band-like 'extended' states. A metal–insulator transition occurs when the Fermi level passes through the energy separating extended from localized states. The disorder in the case of an n-type heavily doped semiconductors arises from the random positions of the donors and from the random electric fields associated with charged compensating acceptors. Mott was able to show that the critical concentration of dopants for the 'Anderson transition' was similar to that for the 'Mott transition', the theory of which was based on a screening argument. In considering electrical conduction on the insulating side of the transition, he formulated what is now known as the Mott $T^{-1/4}$ law to describe how carriers hop between localized states over a distance that is temperature dependent—so-called variable-range hopping. I recall his making a back-of the-envelope derivation of this relationship, a calculation that was subsequently done 'properly', with essentially the same result. This was, however, only the beginning of a decade or more of activity on other disordered systems—in particular amorphous or non-crystalline semiconductors and glasses—work that was eventually to lead to the award of the Nobel prize for physics, which he shared with Anderson and Van Vleck.

The concepts of mobility edges, hopping conduction, minimum metallic conductivity, the '8-N' rule, relaxation of the k-selection rule, tail states, dangling bonds etc were added to the vocabulary of practitioners in the field of non-crystalline semiconductors and glasses; it would not be too generous to give Mott credit for introducing most of these. Interestingly, although he abandoned the idea of a minimum metallic conductivity following the publication of experimental work undertaken by Gordon Thomas and colleagues at Bell Laboratories, many people still believe in it!

Mott's contributions to the above field continued through his retirement in 1971. The first edition of a book, co-authored with the present writer, *Electronic Processes in Non-Crystalline Materials* was published in that year and a second edition, extensively rewritten, appeared in 1979. In the intervening years he had also written *Metal–Insulator Transitions* (1974) and a book for sixth-formers *Elementary Quantum Mechanics* (1972). When the Cavendish Laboratory moved from its old home in Free School Lane to its present site in West Cambridge, Mott collaborated with Abe Yoffe and Mike Pepper in their respective studies of low-dimensional crystals and silicon inversion layers, as well as with numerous others, such as Jenny Acrivos, Moshe Kaveh, Hiroshi Kamimura, Bob Street, Walter Spear, Marshall Stoneham and Peter Edwards. Many visitors were attracted to Cambridge by his late bursts of activity and by the interest he showed in their work. A volume *Nevill Mott: Reminiscences and Appreciations* [2] contains many insightful articles written by his colleagues, friends and members of his family.

During the late 1980s, Mott turned his attention to another major field of scientific discovery—that of high-temperature superconductivity. In this endeavour he collaborated with Yao Liang and with Sasha Alexandrov—then a Russian theoretician, now Head of Physics at Loughborough University and organizer of the workshop that has spawned this special issue.

With Alexandrov, Mott wrote two more books (*High Temperature Superconductors and other Superfluids* and *Polarons and Bipolarons*) and, in turn, Alexandrov produced a most valuable volume, *Sir Nevill Mott: 65 Years in Physics* [3], containing a selection of Mott's papers, each preceded by short illuminating commentaries from Sir Nevill himself.

Throughout his long career, Mott directed his enthusiasm, energy and insight towards a detailed understanding of a broad spectrum of topics in condensed matter physics. His appetite for new challenges seemed inexhaustible and his contributions to science made during almost the whole of the twentieth century will continue to be quoted throughout the present one. What may not be sufficiently remembered is the influence he had on the lives and careers of numerous people whom he befriended, advised and encouraged with great generosity.

References

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