Alan Q. Morton

The Electron Made Public: The Exhibition of Pure Science in the British Empire Exhibition, 1924–5

In 1997 the centenary of the discovery of the electron was celebrated in numerous lectures, exhibitions, and publications. These events commemorated the outcome of an experiment described in a standard physics text in the following terms.

'In 1897 J. J. Thomson, working at the Cavendish Laboratory in Cambridge, measured the ratio of the charge e of the electron to its mass m by observing its deflection in combined electric and magnetic fields. The discovery of the electron is usually said to date from this historic experiment. ...'[1]

For the physics community the celebrations commemorated an important episode the history of their discipline. For not only did Thomson and his colleagues represent the first generation of professional physicists, their work on X-rays, radioactivity, and the electron led to remarkable breakthroughs in understanding the internal working of atoms. In turn understanding the atom provided a new basis for research in many areas of physics. This new knowledge about the atom, quantum mechanics, and its practical outcomes, from electronic devices to nuclear weapons, changed the course of human history.[2] Consequently, the celebrations marking the discovery of the electron were opportunities for physicists to draw the attention of a wide audience to the benefits (but usually not to the disbenefits), of their work. In fact, accounts of the electron centenary reached a wide audience through mass media such as radio and television, and their newer electronic incarnations, whose operation depends on manipulating electrons.

Why should J. J. Thomson's experiment be singled out? To answer this question we shall consider the first public presentation of the account that Thomson discovered the electron in the course of a particular experiment in 1897. The occasion was the British Empire Exhibition held at Wembley, near London, in 1924–5 when the Exhibition of Pure Science displayed a cathode ray tube Thomson had used in his 1897 experiments. It was described as the

'Apparatus by which the existence of electrons was detected and their mass and velocity measured.'[3]

While this claim was in accord with the views of professional scientists, it was also shaped by the circumstances of public exhibition in Britain in the 1920s. We therefore have an example of how the technical discourse of scientists and the public's understanding of science are linked. In this case, not only was the public's understanding of science informed by scientific discourse, public attitudes to science influenced the technical discourse of scientists.[4] We will argue that the electron and sub-atomic physics were presented as pure science, not just because this was the view held by physicists about the technical content, but also as a consequence of two other factors. The first was the need by a growing community of professional physicists to draw public attention to their work; the second was the development of a space for science in British public life.[5]

Physics—a New Discipline

In Britain relationships among physicists, government, and public altered as physics became an established academic discipline from the mid-nineteenth century. To encourage teaching and research in physics there were new institutions, such as the first university laboratories for research and teaching physics, and the Physical Society of London. Furthermore, a new journal, *Nature,* and the South Kensington Museum brought developments in physics to the notice of wider audiences.[6]

J. J. Thomson's own career illustrates the developments both in teaching and in research. He was a modern in that he was Professor of Experimental Physics and head of the Cavendish Laboratory, established by James Clerk Maxwell in Cambridge in the early 1870s. But Thomson was also Professor of Natural Philosophy at the older Royal Institution where his work followed the pattern established early in the nineteenth century by practitioners such as Faraday. There Thomson lectured to a largely lay audience who also acted as patrons of scientific research insofar as they paid for assistants to help Thomson with his research.[7] Later, when a wider audience of taxpayers came to provide the resources for scientific research, government agencies rather than individual researchers increasingly set the priorities. For example, the founding of the National Physical Laboratory in Britain around 1900 provided a new home for the important work of precision measurement. Consequently, physicists working in university physics laboratories could devote themselves to more speculative researches.[8]

For those caught up in the changes in physics around 1900, it was an exciting time. By comparison, physics research in the proceeding period seemed dull and pedestrian. In the introduction to his book on X rays first published in 1914 G. W. C. Kaye wrote

> 'In the early nineties, it was not infrequently maintained that the science of physics had put its house in complete order, and that any future advances would only be along the lines of precision measurement. Such pessimism has been utterly confounded by a sequence of discoveries since 1895 unparalleled in their fundamental nature and promise.'[9]

According to the historian Badash, only a small minority of physicists in the late 19th century held the view that physics was 'complete'. Nevertheless many of the next generation of physicists shared Kaye's vision.[10] Why should this happen? Why did some physicists in the early 20th century underestimate the ambitions of their predecessors? By adopting this opinion later workers would, in effect, magnify their own achievements. But apart from such considerations of personal ambition, they took this view of their predecessors because their own perceptions of their subject and themselves as physicists had changed.

In order to describe these changes, let us compare two exhibitions; the Exhibition of Pure Science at the British Empire Exhibition mentioned already and an earlier exhibition, the Special Loan Collection of Scientific Apparatus held at South Kensington, London, in 1876.

Exhibitions

The British Empire Exhibition held at Wembley in 1924–5 was one of a series of exhibitions in Britain inaugurated by the Great Exhibition of 1851. The emphasis in 1851 was on contemporary industry. Although modern scientific instruments were displayed they were presented as products of industry rather than being an illustration of current scientific research.[11] Soon afterwards, the Department of Science and Art and then the South Kensington Museum, were set up to promote the useful arts more systematically. However, the South Kensington Museum did not promote science and technology as effectively as some had hoped.[12] To encourage the Museum to develop in this direction, the Devonshire Commission stepped in. This Commission had set out in the 1870s to examine many aspects of scientific and technical education in Britain. Its chair, the Duke of Devonshire, was then Vice-Chancellor of the University of Cambridge and had personally funded the building the Cavendish Laboratory. Its secretary was Norman Lockyer, editor of the recently-founded journal, Nature.[13] In their fourth report the commissioners recommended the establishment of a collection of physical and mechanical instruments.[14]

Special Loan Exhibition of 1876

The Commission's proposal came to fruition in 1876 with the mounting of the Special Loan Exhibition of Scientific Apparatus at the South Kensington Museum. Its catalogue explained the purpose of the exhibition.

'Their Lordships stated their conviction that the development of the Educational, and certain other Departments of the South Kensington Museum, and their enlargement into a Museum somewhat of the nature of the Conservatoire des Arts et Métiers in Paris and other similar institutions on the Continent, would tend to the advancement of science, and be of great service to the industrial progress of this country.'[15]

However, in order to achieve this aim, the Special Loan Exhibition had to have a radically different structure from that of contemporary industrial exhibitions.[16] The Catalogue explained some of the differences:

'In International Exhibitions a certain amount of space is allotted to each country. These spaces are then divided by the commissioners of each country among its exhibitions, who display their objects ... as they consider the most advantageous .... the Exhibitions appeal naturally, more or less exclusively, to the industrial or trade-producing interests of those countries.

This was not the idea of the proposed Loan Collection at South Kensington. For that collection it was desired to obtain not only apparatus and objects from manufacturers, but also objects of historic interest from museums and private cabinets, where they are treasured as sacred relics, as well as apparatus in present use in the laboratories of professors. ... all objects ... were to be handed over absolutely to the custody of the Science and Art Department for exhibition; the arrangement being not by countries but strictly according to the general classification.'[17]

Thus the Loan Collection included historical material and arranged the objects in groups according to subject, not by country of origin. In due course eleven different countries provided some 4,600 exhibits, ranging from the famous Magdeburg hemispheres and air pump used by Otto von Guericke to over fifty different designs of barometer. These were arranged under twenty-one subject headings including Arithmetic, Geometry, Molecular Physics, Electricity, and Chemistry.[18] Historical instruments were used to illustrate the development of different types of scientific instruments. In effect these instruments were used to create a history for science, this history being seen primarily in terms of technical progress rather than physical theories.

The arrangement of the scientific instruments at the Special Loan Collection was by subject which helped to facilitate international comparisons. This was an explicit policy of the organisers. The catalogue explained their reasoning.

'It had been the intention from the first to give the Loan Collection an international character, so as to afford men of science and those interested in education an opportunity of seeing what was being done by other countries than their own in the production of apparatus, both for research and for instruction—an opportunity which it was hoped would be of advantage also to the makers of instruments.'[20]

Their plan was to display instruments for teaching, research, and industrial use from several countries; the audience was to be an increasingly significant group of specialists including teachers, researchers, and instrument makers.[21] By encouraging comparisons regarding government support of science the organisers hoped to influence the British government to increase its funding for science and to develop a science museum.[22] But these plans took some years to come to fruition.

To sum up, the 1876 Special Loan Collection of Scientific Apparatus displayed a broad range of scientific instruments and said little about

Figure 1. Magdeburg hemispheres from 1876 exhibition.[19]

scientific ideas and theories. It was firmly international in coverage and illustrated how science had developed over centuries as the result of international exchange. All these characteristics are in marked contrast to the later Exhibition of Pure Science at the British Empire Exhibition.

1924 British Empire Exhibition

By the late 19th century the usual pattern for international exhibitions was to concentrate on the industry of the nation holding the exhibition, and on the life and products of that nation's colonies.[23] The British Empire Exhibition of 1924 proved no exception, with a dazzling range of industrial and colonial exhibits. The Palaces of Engineering and Industry showed the products from a wide range of British firms. Dominions from India to Sierra Leone displayed their produce. The exhibition was not short of spectacle: historical naval battles were re-enacted, and the newly discovered Tutankamen's tomb was reproduced. The Ford Motor Company assembled cars and a full-scale coal mine was built under the site. The Board of Education showed a working illustration of the Sun trying, in vain, to set on the British Empire.[24] The Canadian Pavilion

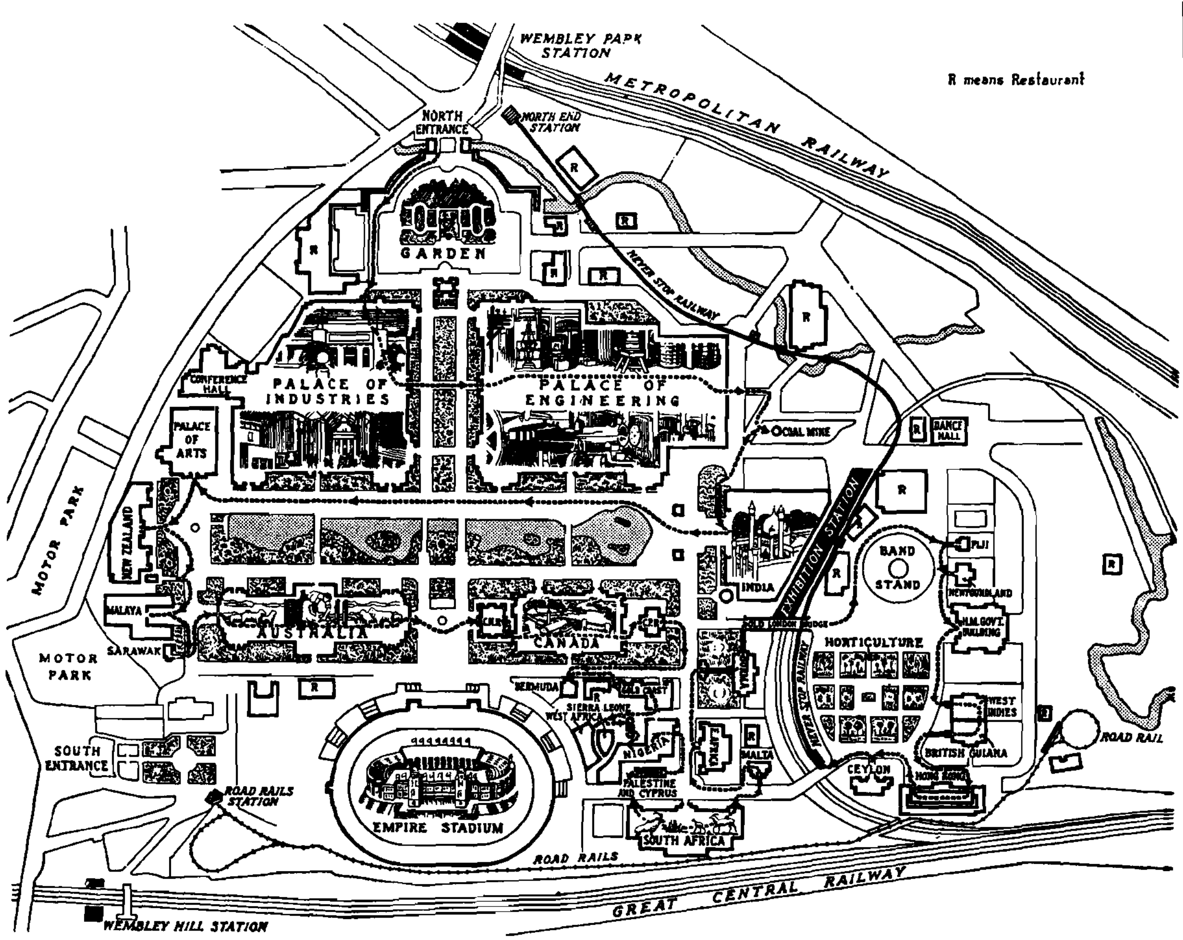

Figure 2. Map of the BEE.

featured a model of the Prince of Wales and his horse made out of butter in a special refrigerated case. Altogether, some 17.5 million visitors saw the exhibition during the six months of 1924 it was open, on average a staggering 100 thousand visitors a day.[25]

Many exhibits featured science and technology. The Palace of Engineering contained nine and a half acres of machinery from hundreds of engineering firms in a building 1000 feet long with 'no useless ornament'.[26] Collectively, the engineers were optimistic about their future prospects.

'For a hundred years there has not been such a need and such an opportunity as Engineering offers to the world today. A hundred years ago the condition of Europe was not unlike what it is at the present time. There had been a great and devastating war, in which practically all the civilised nations were engaged. Commerce had been brought to a standstill, finance dislocated, and industry, which had hardly yet begun in the form in which we know it was languishing. Some new impetus was required to give a fresh start to the flow of industrial life. That impetus came from modern engineering, which took its rise about that time. And it came from Great Britain. This country was the cradle of modern engineering. The greatest of the early pioneers came from here. In that world crisis of a hundred years ago, it is not too much to say that England (and Europe with her) was saved by her engineers. They are ready to come to our help again to-day.'[27]

The beginning of modern engineering was coupled with recovery from a world crisis, with specific historical circumstances providing the conditions for a new profession to emerge.

As for the work of scientists, in the Palace of Engineering, the British Engineers' Association provided space for an exhibition by the National Physical Laboratory.

'... of special interest to scientists, is the exhibit and demonstrations by the National Physical Laboratory, who have been granted by the Association a free gift of stand space, at a cost of £1,400, in recognition of the valuable services rendered by the Laboratory to the engineering industry.'[28]

Nearby, the Palace of Industry housed displays of the companies of the chemical industry, which celebrated the work of chemists. A feature common to the exhibits mounted by chemists and engineers was the public acknowledgement of the importance of their work in wartime.

Exhibition of Pure Science

There was also a display of scientific instruments, the Exhibition of Pure Science that included Thomson's cathode ray tube. However, the circumstances here differed markedly from the nearby Palaces of Engineering and Industry. Furthermore, the way Thomson's tube was presented also differed from the way objects were presented in the Special Loan Collection almost fifty years before. The remainder of this paper will consider how this context, the Exhibition of Pure Science at the British Empire Exhibition, shaped the account of Thomson's tube.

This Exhibition of Pure Science was the first important public exhibition dealing with subatomic physics. Even as it was being viewed, the construction of a new building for the Science Museum (delayed by the First World War) was nearing completion. A display on science was planned for the new accommodation, which was officially opened in 1928.

A committee of the Royal Society had organised the exhibition, which was housed in the Government Pavilion and paid for by the Department of Overseas Trade. The chair of the Royal Society British Empire Exhibition committee was the prominent scientist, F. E. Smith. Its members included eminent scientists and electrical engineers, such as Oliver Lodge, W. H. Bragg, Richard Glazebrook (Director of the National Physical Laboratory from 1900–19), Arthur Schuster, Napier Shaw (Director of the Meteorological Office), Campbell Swinton and Henry Lyons (Director of the Science Museum).

Figure 3. The Pure Science Exhibition at the 1924 BEE. Courtesy of the Royal Society.

According to a draft for the guidebook,

'This exhibition, which has been arranged by the Royal Society at the request of H.M. Government, is intended to illustrate, so far as the space available will permit, recent British research in the fundamental branches of pure science.'[29]

As the exhibition was restricted to research currently carried out in Britain, only a selection of recent developments in science were covered. The core described the new understanding of the structure of the atom with many of the exhibits coming from the Cavendish Laboratory.[30] The draft continues

'By means of the instruments and apparatus used in the experiments, and by models, diagrams and photographs indicating the results, the work of Sir J J Thomson on cathode rays, leading to the discovery of the electron, of Sir Ernest Rutherford on the structure of the atom, of Sir William Bragg on crystal structure is illustrated; as well as recent work by many other distinguished scientists in the Physical, Engineering, Geophysical, Biological and other branches of science.'[31]

But preparing an exhibition on these aspects of physics posed considerable problems, for not only were individual electrons and atoms quite invisible, the details of atomic structure were unfamiliar to the public.[32] To overcome these hurdles, the exhibition organisers used a combination of original experimental equipment and working demonstrations.

'In many cases the exhibits are shown by the scientific men actually engaged in the work, and are supplemented by instrument(s) loaned by some of the leading firms of scientific instrument makers. The majority of the exhibits are working demonstrations. Benches, fitted with gas, water and electricity are provided, and a staff of scientific assistants are in attendance throughout the exhibition.'[33]

Although both the 1924 pure science exhibition and the Special Loan Collection of 1876 ostensibly dealt with science, there were important differences both in terms of subject matter and approach. The 1876 exhibition displayed static groups of similar instruments (fifty barometers) used for a wide range of purposes in teaching, research, and industry. The results and knowledge obtained by experiment were only of secondary concern. By contrast, in 1924, the Exhibition of Pure Science had different priorities. The organisers set out to explain the results of recent research about the structure of the atom. This knowledge came solely from experiments carried out in university research laboratories using specially developed and unique instruments. Some of these instruments were shown working in the 1924 exhibition to replicate actual experiments.[34]

Furthermore, in 1924, the arrangement of the individual exhibits was according to physical principles. The first exhibit was a chart showing the different electromagnetic waves that acted as a key to the arrangement of the principal section of the physical exhibits.[35] The next part of the exhibit concerned 'The Atom.' Starting from the electron, the exhibition displayed a new subject, subatomic physics, a subject it portrayed as 'pure science,' the outcome of work by professional researchers working in university laboratories and partially funded by the government.

Doubt and Uncertainty

Today the experiment Thomson carried out to measure the ratio of the charge, e, to the mass, m, of the electron, is regarded as the most significant part of his work on the electron. It is the aspect of Thomson's work most illustrated in textbooks.[36] This view was first given public exposure at the British Empire Exhibition.[37] It had the virtue of summarising complex judgements about an individual's contribution.[38] Thus the description used at the British Empire Exhibition gives credit to Thomson for his work at the Cavendish Laboratory in Cambridge (rather than the German physicists, Wiechert or Kauffmann, for example), thereby settling questions of personal, institutional, and national credit. It names the entity, the electron, provides it with an origin, thereby indirectly detailing properties such as its mass (much smaller than an atom) and electric charge (negative), and legitimates associated technical practices about how electrons are to be found (in cathode ray tubes containing gas at very low pressure).[39]

Such accounts also are useful within science, providing a way to cope with doubt and uncertainty and conveniently to date and to classify change and discovery. Physicists acting collectively settled debates about the reality of the particle, and once its existence was generally accepted, sometime after the development of the Rutherford-Bohr atom of 1911–13, a shorthand and retrospective account of the electron's origins becomes useful. Emphasising what is novel about the electron distinguishes it from the earlier theoretical speculations of Stoney, for example. In addition, the account provides plausible and definite answers when the details are either debatable or cannot be recovered.[40] The discovery account thus identifies a time, a place and particular people—providing the starting point for future commemorations.

Artefact as Icon

At the British Empire Exhibition, the electron, an invisible entity, and its history were made tangible through objects. As already mentioned J. J. Thomson exhibited his cathode ray tube described as the

'Apparatus by which the existence of electrons was detected and their mass and velocity measured'[41]

However, the history of this particular tube reveals how it became transformed into an icon. The diagram in Thomson's 1897 paper does not correspond exactly to this tube. Indeed, Thomson's paper makes clear

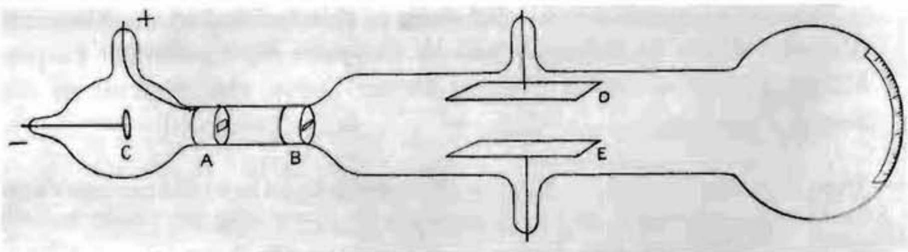

Figure 4. Diagram from J. J. Thomson's paper showing his experiment to measure the ratio of the charge to mass of cathode rays. Courtesy Trustees of the Science Museum.

that he made use of several different tubes in his experiments, in order to experiment with cathodes made from different materials, for example.[42]

Before this particular tube was shown at Wembley, it had been displayed at the Science Museum.[43] Information about how the tube was exhibited there comes from a letter written by the Secretary of the Royal Society British Empire Exhibition Committee in 1923.

'On the card attached to the apparatus in the Museum it is described as being that used by Sir J. J. Thomson for the measurement of the velocity of the Cathode [rays] and of the ratio m/e.'[44]

Significantly, this account describes the tube as an instrument for making measurements on cathode rays. So as a result of this tube becoming a museum exhibit, it came to stand for a range of experiments and apparatus. Furthermore, there is no explicit mention of the discovery of the electron. However, the measurements made with the tube could then, in a separate step, be interpreted as demonstrating the existence of the electron.

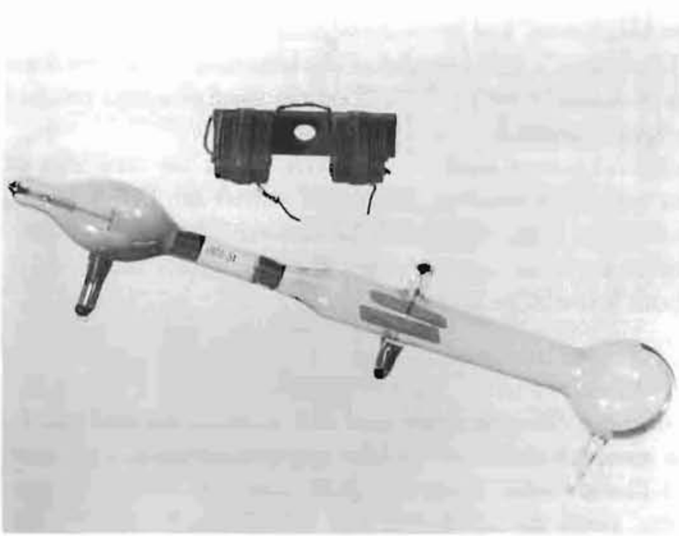

Figure 5. J. J. Thomson's tube from the Science Museum, Inventory Number 1901–51. Courtesy Trustees of the Science Museum.

Thomson himself was not immune to this revising of the historical account. When he arranged borrow this tube for the British Empire Exhibition, he wrote to Colonel Henry Lyons, the Director of the Science Museum,

'I have been asked to exhibit at Wembley the apparatus I used in my first experiments on the electron ... described I believe as apparatus for determining the velocity and the value of e/m for cathode rays.'[45]

So in 1924 Thomson viewed his earlier experiments as involving electrons (rather than 'corpuscles' as he called them for many years). Furthermore, he now stated the ratio as e/m rather than in the inverse form, m/e, he had used in his original paper and which had then been quoted in the label at the Science Museum.

By the time of the British Empire Exhibition in 1924, however, the account of Thomson's work had been pared down and simplified until the device becomes the tube used for the experiment. The artefact was now the actual device used for detecting the existence of an invisible entity, the electron.

Following this account of the electron at the Exhibition of Pure Science, the next section dealt with

'Some Aspects of Radio-Activity and their Bearing on Atomic Structure'.

was provided by Sir Ernest Rutherford, Thomson's successor as head of the Cavendish. This section included material on radium emanation (radon), the nature of the alpha particle, the scattering of alpha-particles, disintegration of elements, beta and gamma rays, and the work of Moseley on Atomic Number. After that came exhibits by D. R. Hartree, 'Models Illustrating Atomic Structure' (which provided a snapshot of atomic structure according to 'Old Quantum Mechanics' and immediately before the development of 'New Quantum Mechanics'), and a model of the structure of rocksalt from W. L. Bragg. Also illustrated were C. T. R. Wilson's cloud chamber method and Aston's Mass Spectrograph.[46]

Not only are contemporary scientific theories about the structure of the atom used to order the exhibits, historical events are fitted to this pattern too. The electron is the subject of the first exhibit, and its discovery is the first step in the historical story that unfolds, a story of discovery and progress in both knowledge and technique.

Empire

The Exhibition of Pure Science illustrated the research carried out in Britain. However, some of the scientists who contributed to it, including W. H. Bragg and Ernest Rutherford, had links with the British Empire which was apposite, given the exhibition was part of the British Empire

Exhibition. In Rutherford's case, not only had he been born in New Zealand, he had been professor of physics in McGill University, Montreal, before leaving for Manchester and later Cambridge.[47] Indeed Thomson's students, such as Rutherford, occupied many of the chairs of physics in the British Empire.[48]

But there were other links between science and Empire, which the pure science exhibition illustrated. The exhibition was shown in 1924, in the aftermath of the First World War, and, as a consequence, references to nation and empire replaced the explicit internationalism of the earlier Special Loan Exhibition.[49] As was pointed out above, the account given of the electron gave credit to Thomson but not to his German colleagues such as Wiechert or Kauffmann. Similarly, the part of the Exhibition of Pure Science dealing with X-rays made no mention of the German physicist, Wilhelm Röntgen, their discoverer, but instead mentioned Charles Barkla, an English physicist who discovered the characteristic X-rays emitted by different elements. Clearly these accounts owed much to contemporary political circumstances.

Although contact with scientists in Germany was restricted, they did not cease completely. When the time came to return the exhibits from the British Empire Exhibition to the Cavendish Laboratory, responsibility for the arrangements lay with Patrick Blackett. However, a disgruntled James Chadwick had to step in for Blackett who had gone to Germany in the meantime to work in James Franck's laboratory in Göttingen.[50]

The Professional Identity of Physicists

Another feature of the pure science exhibition at the British Empire Exhibition was the strong emphasis on the idea of research as worth doing for its own sake. There were no mention of any practical applications with the single exception of wireless waves. This work was carried by professional university researcher in physics, individuals doing research for its intellectual worth, and not engaged primarily in teaching (the traditional university occupation) nor in solving more mundane practical problems (the physicist in industry).

Concern among physicists about their professional identity became widespread in the early 1920s. The first society for professional physicists in Britain, the Physical Society of London, had been formed in February 1874 (significantly during the planning stages of the Special Loan Collection). Subsequently, the growth of university physics departments and the setting up of the National Physical Laboratory had greatly increased the number of professional physicists.[51] However, it was the experience of the First World War that convinced many physicists of the need for a professional body to represent their interests. For they felt that they had fallen behind their colleagues, the chemists, in terms of professional status.

Furthermore, the setting up the Department of Scientific and Industrial Research to channel Government money into scientific research offered new opportunities for physicists.[52] The inaugural meeting of the Institute of Physics was held in April 1921. This brought together representatives of the Faraday Society, the Optical Society, and the Physical Society of London. Sir Richard Glazebrook, recently retired as Director of the National Physical Laboratory, was its first President.[53]

At this Inaugural meeting, the first Honorary Fellow, J. J.Thomson drew attention to the increase in the numbers of physicists in Britain. In 1870, when he began his own career, he thought there had been no more than 100 whereas by 1920 he estimated their numbers to have grown to between 800 and 1000, a total which included science teachers with an interest in research. These were the potential members of the new Institute, and within the first year 300 had joined.[54] Now physicists in Britain had an organisation to pursue their professional interests.

Thus there was a significant conjunction in 1924. Prominent members of the new Institute of Physics, concerned about promoting the professional interests of physicists, arranged part of the Exhibition of Pure Science. They had an excellent opportunity to bring the work of their members to the attention of the public.

Pure Science

Some characteristics of a distinctive public identity for physicists emerge at the 1924 exhibition. Although many worked in industry, what was newly displayed in 1924 was pure science; a term that applied to work carried out by scientists in universities where they were free to research. A strong advocate of the value of curiosity-driven research was J. J. Thomson. In 1916, Thomson, then President of the Royal Society, explained his views at a meeting where the Government announced the establishment of the Million Fund to aid co-operative research in industry.[55]

> 'By research in pure science I mean research made without any idea of application to industrial matters but solely with the view of extending our knowledge of the Laws of Nature. I will give just one example of the "utility" of this kind of research, one that has been brought into great prominence by the War—I mean the use of X-rays in surgery. Now, not to speak of what is beyond money value, the saving of pain, or, it may be, of life to the wounded, and of bitter grief to those who loved them, the benefit which the State has derived from the restoration of so many to life and limb, able to render services which would otherwise have been lost, is almost incalculable. Now, how was this method discovered? It was not the result of a research in applied science starting to find an improved method of locating bullet wounds. This might have led to improved probes, but we cannot imagine it leading to the discovery of the X-rays. No, this method is due to an investigation in pure science, made with the object of discovering what is the nature of Electricity.'[56]

Thus, for Thomson, research in pure science carried out for curiosity's sake, may well be worth doing for its practical benefits—it is just that they are impossible to foresee. Thomson's argument was twofold; the researchers had the moral advantage of a 'pure' intention but their research might also provide practical advantages for humanity. Clearly, this vision of research in pure science fitted the work of researchers in universities who are 'free' to follow this kind of research, and the prospect of funding from the Department of Scientific and Industrial Research.[57] The notion of pure research distinguished what scientists in universities did from the types of research done by researchers working for particular ends, on standards or under contract at the NPL, or by electrical engineers, for example.[58]

There is another feature of the work of the 'pure' scientists is apparent at the British Empire Exhibition. There the work of Thomson, Rutherford, Bragg, and others, was represented as pure science and there was no mention of their wartime research for the Admiralty and other agencies. In contrast, elsewhere in the British Empire Exhibition, the chemists, engineers, and the physicists from the National Physical Laboratory, were forward in bringing their contribution to the war effort to public notice. But if applied researchers draw attention to the results of their labours in wartime, one function of the idea of pure science is to bring forward an idea of science as knowledge without destructive consequences. Thus pure science is not just about the lack of applications; it is about purity stemming from a lack of destructiveness.[59] The great irony, of course, is the subatomic physics displayed as Pure Science at the British Empire Exhibition developed into nuclear physics that had a great bearing on warfare during World War II with the development of nuclear weapons.

This irony was particularly acute for the physicists at the Cavendish. For they were strongly identified with the idea of pure science as knowledge for knowledge's sake, a factor which must have encouraged them to take part in the Exhibition of Pure Science.[60] A further example of the irony that the 'pure science' of atomic physics developed into something destructive comes from an interview with James Chadwick shortly after he published the results of his first experiments on the neutron at the Cavendish early in 1932.

> 'Dr Chadwick described his experiments as the normal and logical conclusion of the investigations of Lord Rutherford 10 years ago. Positive results in the search for 'neutrons' would add considerably to the existing knowledge on the subject of the construction of matter, and as such would be of the greatest interest to science, but, to humanity in general the ultimate success or ortherwise of the experiments that were being carried out in this direction would make no difference.'[61]

But if physicists had reasons for portraying atomic physics as pure science, then the public was receptive to this approach for related reasons. While questions about the structure of matter have fascinated both researchers and public alike through the centuries, around 1920, it seems the public took a greater interest in the structure of the atom for then it was a desperately needed escape from the problems created by the war.[62]

Conclusion

By examining how a tube used by J. J. Thomson was displayed to the public in 1924, we see how the image of physics held by both physicists and members of the public had changed since 1800. As research in physics became an activity funded by Government using money from taxes, physicists developed a public identity for their discipline. While the changes were due in large part to the new ideas and discoveries made by physicists around that time, a factor emphasised in accounts by physicists, the argument presented in this paper is that the changes were also the result of a new institutional structure. In the process, Thomson's tube and the electron became emblems of pure science.

What have been emphasised here are some of the events that led to the establishment of a permanent public space for science, what became the Science Museum in London. While this public space displayed images of science and technology that were the outcome of private discussions in government circles, professional bodies of scientists and engineers, and trade associations what was new for the public was a vision of pure science.

Notes

1. See D. Halliday and R. Resnick, *Physics* (New York, 1966), Part II, p. 835. Thomson published the results of this experiment in October. J. J. Thomson, 'Cathode Rays,' *Philosophical Magazine* 44 (1897), 293–316. The previous April Thomson had first made public his idea that subatomic particles existed at a lecture in the Royal Institution. These 'corpuscles,' as he called them, had negative electric charge and were constituents of all matter.
2. See, for example, S. Weinberg, 'The First Elementary Particle,' *Nature* 386 (20 March 1997), 213–215. T. Arabatzis, 'Rethinking the "Discovery" of the Electron,' *Stud. Hist. Phil. Mod. Phys.* 27(4) (1996), 405–435.
3. Royal Society, *Phases of Modern Science* (London, 1926), p. 146.
4. See P. Forman, 'Weimar Culture, Causality, and Quantum Theory 1918–1927: Adaption by German Physicists and Mathematicians to a Hostile Intellectual Environment.' *Historical Studies in the Physical Sciences* 3 (1971), 1–115.
5. We can now understand why commentators who have only considered the historical evidence from around 1897 have found this account of the electron wanting, for the conditions of the 1920s also have to be considered. See, for example, T. M. Brown, A. T. Dronsfield, and J. S. Parker, 'Did Thomson Really Discover the Electron?' *Education in Chemistry* (May 1997). Others have made less extravagant cases. Pais records in meticulous detail the several experimenters who have claims to have found the electron. His account offers a traditional conclusion with a new twist; Thomson did discover the electron, not in 1897, but in 1899 when he measured the charge on the electron, thus eliminating, in Pais's view the last significant obstacle to identification. A. Pais, *Inward Bound: Of Matter and Forces in the Physical World* (Oxford, 1986).
6. See D. S. L. Cardwell, *The Organisation of Science in England* (London, 1972). R. Sviedrys, 'The Rise of Physics Laboratories in Britain,' *Historical Studies in Physical Sciences* 7 (1976), 405–436. I. R. Morus, 'Manufacturing Nature: Science, Technology and Victorian Consumer Culture.' *BJSHS* 29 (1996), 403–434. G. Gooday, 'Precision Measurement and the Genesis of Physics Teaching Laboratories in Victorian Britain.' *BJHS* 23 (1990), 25–51. P. Forman, J. L. Heilbron, et al., 'Physics circa 1900: Personnel, Funding and Productivity of the Academic Establishments.' *Historical Studies in Physical Sciences* 5 (1975).
7. Thomson was Professor of Natural Philosophy there from 1905. His assistants were G. W. C. Kaye and then Francis Aston who won the Nobel prize for his work on isotopes.
8. See M. J. Nye, *Molecular Reality: A Perspective on the Scientific Work of Jean Perrin* (London, 1972).

9. G. W. C. Kaye, *X Rays* (London, 1923), p. xix.
10. L. Badash, 'The Completeness of Ninteenth-Century Science.' *Isis* 63 (1972), 49–58. T. S. Kuhn, *Black-Body Theory and the Quantum Discontinuity*, 1894–1912 (Oxford, 1978). See also S. Schaffer, 'Utopia Limited: On the End of Science.' *Strategies*(4/5) (1991), 151–181.
11. C. H. Gibbs-Smith, *The Great Exhibition of 1851* (London, 1981). J. A. Bennett, *Science at the Great Exhibition* (Cambridge, 1983). J. A. Bennett, *The Divided Circle* (Oxford, 1987). D. Follett, *The Rise of the Science Museum under Henry Lyons* (London, 1978). R. Brain, *Going to the Fair. Readings in the Culture of Nineteenth-Century Exhibitions* (Cambridge, 1993).
12. See S. Forgan and G. Gooday, 'Constructing South Kensington: The Buildings and Politics of T. H. Huxley's Working Environments,' *BJHS* 29 (1996), 435–468.
13. A. J. Meadows, *Science and Controversy: A Biography of Sir Norman Lockyer*, (London, 1972). D. S. L. Cardwell, *The Organization of Science...*, pp. 119–126. *A History of the Cavendish Laboratory 1871–1910* (London, 1910).
14. See *Royal Commission on Scientific Instruction and the Advancement of Science, Fourth Report* (London, HMSO, 1874), p. 23, recommendation IX.
15. *Catalogue of the Special Loan Collection of Scientific Apparatus at the South Kensington Museum* (London, 1876). p. vii.
16. *Catalogue of the Special Loan Collection of Scientific Apparatus at the South Kensington Museum*, (London, 1876).
17. Ibid. *Catalogue of the Special Loan Collection*, 2 vols, 2nd edition (London, 1876), vol 1 p. ix.
18. The countries providing exhibits were the United Kingdom, Austro-Hungarian Empire, France, Germany, Holland, Italy, Norway, Russia, Spain, and Switzerland. That year the United States held the Centennial Exhibition in Philadelphia. At the time the preoccupation of the organisers of the Special Loan Collection with scientific instruments was shared by others. The new physics laboratories then being constructed at universities had to be equipped and James Clerk Maxwell, for one, took great trouble to acquire suitable instruments for the Cavendish Laboratory. Similarly, the physicists who in 1874 founded the Physical Society of London, the first specialist society in Britain for physicists, made a point of having novel demonstration experiments at their meetings. See G. Gooday, 'Precision measurement and the genesis of physics teaching laboratories in Victorian Britain,' *BJHS* (1990), 23: 25–51.
19. These are in the collections of the Deutsches Museum. While they were in South Kensington, copies were made.
20. *Catalogue of the special loan collection of scientific apparatus at the South Kensington Museum* (London, 1876), p. viii. To encourage research, there were conferences held while the Collection was on display. At one, James Clerk Maxwell gave a paper on scientific instruments.
21. See M. E. W. Williams, *The Precision Makers: A History of the Instruments Industry in Britain and France, 1870–1939* (London, 1994).
22. F. M. Turner, 'Public Science in Britain, 1880–1919,' *Isis* 71(1980), 589–608.
23. R. Brain, *Going to the Fair. Readings in the Culture of Nineteenth-Century Exhibitions* (Cambridge, 1993). Tony Bennett, *The Birth of the Museum: History, Theory, Politics* (London, 1995). P. Greenhalgh, *Emphemeral Vistas: A History of the Expositions Universelles, Great Exhibitions and World's Fairs, 1851–1939*, (Manchester, 1988).
24. This was written as Hong Kong was handed over to China.
25. The earlier Paris Exhibition had even more visitors, 44 million.
26. *Engineering Sectional Catalogue British Empire Exhibition* (London, 1924), pp. 14–5.
27. Ibid, p. 13.
28. Ibid., p. 48. The NPL also provided some exhibits for the exhibition on pure science.
29. Royal Society archives, British Empire Exhibition Committee, Box 7 Department of Overseas Trade, File B, Draft for guide book, dated 22 January 1924.
30. The physics exhibits dealing with the atom and radiations from Gamma Rays to Wireless Waves takes up more space in the catalogue than the other sciences, namely Geophysics, Zoology, Botany and Physiology.
31. Royal Society archives, British Empire Exhibition Committee, Box 7 Department of Overseas Trade, File B, Draft for guide book, dated 22 January 1924.
32. Recalling a striking remark made by Sir J. J. Thomson, Oliver Lodge wrote '...though the present century had been extraordinarily prolific in discoveries in Natural Science, especially in the more physical branch thereof, there was very little popular knowledge or understanding thereof.' O. Lodge, *Atoms and Rays*, (New York, 1924), p. v.

33. Royal Society, *Phases of Modern Science* (London, 1925?), p. 34. Of course, working demonstrations had long been used for teaching.
35. Ibid, pp. 161–2.
36. D. Halliday and R. Resnick, *Physics* (note 1).
37. When the Post Office in Britain declined to issue special stamps to mark the electron centenary, preferring instead to issue stamps honouring Enid Blyton, the children's author, some members of the Institute of Physics were incensed. R. Cooter and S. Pumfrey, 'Separate Spheres and Public Places: Reflections on the History of Science Popularization and Science in Popular Culture,' *History of Science* 32 (1994), 237–267. '1947 Jubilee Exhibition: Life, the Universe and the Electron,' Science Museum (1997).
38. See R. A. Millikan, *The Electron* (Chicago, 1963). Millikan's case also illustrates some personal and national characteristics by comparison with Thomson's. Millikan regarded his oil drop apparatus as so much junk once he had finished with it whereas Thomson's tubes have gone to museums. Millikan entered into an arrangement to be buried at Forest Lawn as one of their 'Immortals.' Thomson was buried in Westminster Abbey.
39. See R. B. Leighton, *Principles of Modern Physics*, (New York, 1959), p. 624. See also A. Pais, *Subtle is the Lord: The Science and Life of Albert Einstein*, (Oxford, 1982); T. Arabatzis, 'Rethinking the "Discovery" of the Electron.' *Stud. Hist. Phil. Mod. Phys.* 27(4) (1996), 405–435.
40. Stoney coined the term electron, see J. O'Hara, *George Johnstone Stoney and the Conceptual Discovery of the Electron*, (Dublin, 1993). S. Schaffer, 'Scientific Discoveries and the End of Natural Philosophy,' *Social Studies of Science* 16 (1986), 387–420. W. C. Dampier, *The Recent Development of Physical Science* (London, 1904). E. Hobsbawm, and T. Ranger (eds.) *The Invention of Tradition*, (Cambridge, 1983).
41. Royal Society, *Phases of Modern Science* (London, 1925), p. 146. Thomson wrote this caption himself. See J. J. Thomson to Martin (?), Secretary of the Royal Society British Empire Committee, April 4 1924, Box 3, British Empire Exhibition Committee, Royal Society Archives. In addition Thomson provided a modified Perrin tube he had also used in his experiments. This Thomson had used to repeat an experiment originally performed by Perrin which served to identify that cathode rays carried a negative electric charge. The Perrin tube is in the museum of the Cavendish Laboratory.
42. Apart from the diagram there are few details in the paper which would serve to identify the tube exactly. Thomson's notebooks detailing his experiments in this period are not present in the collections of his papers. Thomson also introduced different gases into his tubes. The idea being that if neither the material of the cathode nor the trace of gas left in the tube made any difference to his measurements of e/m, then his corpuscle was more likely to be a constituent of all matter. Today there are other similar tubes in the Cavendish Laboratory and one in the Deutsches Museum that belonged to Thomson. See I. J. Falconer, *Apparatus from the Cavendish Museum* (Cambridge, 1980).
43. In fact, originally the tube had gone from the Cavendish Laboratory to what was then the Victoria & Albert Museum, Science Collections in 1901. The Museum's annual report for that year described the acquisition as 'Apparatus for measuring the velocity of the cathode rays.' Only in 1909 did the V&A and the Science Museum become separate organisations. J. Physick, *The Victoria and Albert Museum: The History of its Building* (London, 1982), p. 24.
44. The Secretary of the Royal Society's British Empire Exhibition committee to P. M. S. Blackett, 22 December 1923. Royal Society British Empire Exhibition 1924 Box 3 Cambridge file. The word rays has been added in ink to the typescript. Blackett, acting for Rutherford, was responsible for the Cavendish Laboratory's contribution to the exhibition.
45. See File ScM 177.
46. The Science Museum even today has a number of these items on display, a direct legacy of the British Empire Exhibition.
47. He was also one of the first holders of a scholarship established by the Commissioners of the 1851 Exhibition, a scholarship which enabled him to study in Cambridge. A further reason for linking science and empire was that in the 1920s the Department of Scientific and Industrial Research in Britain and its equivalent in Australia, the CSIR, began to coordinate their programmes for research. See C. B. Schedvin, *Shaping Science and Industry: A History of Australia's Council for Scientific and Industrial Research, 1926–49* (Sydney, 1987). J. Morrell and A. Thackray, *Gentlemen of Science: Early Years of the British Association for the Advancement of Science* (Oxford, 1981). The BAAS held meetings in different parts of the empire.

48. 'During the whole of his tenure of the Cavendish chair, Thomson was the active head and inspirer of a great research school. The institution of the status of "advanced student" at Cambridge in 1895 led to a great increase in the numbers of young graduates of other universities who came to work in his laboratory; with the consequence that in a few years nearly all the important chairs of physics in the British Empire were filled by his disciples.' E. T. Whittaker, A *History of the Theories of Aether and Electricity: The Classical Theories* (New York, 1951), p. 366.
49. See A. G. Cock, 'Chauvinism and Internationalism in Science. The International Research Council, 1919–26,' *Notes and Records of the Royal Society* 37 (1983), 249–288. B. Schroeder-Gudehus, 'Nationalism and Internationalism,' in R. C. Olby, G. N. Cantor, et al. (eds.), *Companion to the History of Modern Science* (London, 1990), pp. 909–19.
50. See James Chadwick to Martin, secretary of the Royal Society Committee, 18 November 1924, in Royal Society Archives, Cambridge, British Empire Exhibition 1924, Box 3..
51. See E. Pyatt, *The National Physical Laboratory: A History* (Bristol, 1983).
52. See D. S. L. Cardwell, *The Organization of Science ....* (note 6). I. Varcoe, *Organizing for Science in Britain* (Oxford, 1974).
53. M. G. Ebison, *The Development of the Physics Profession Linked to the Education and Training of Physicists to 1939* (Salford, 1991), p. 334. The new Institute was not a trade union. cf Association of Scientific Workers.
54. Ibid., p. 341. The new Institute soon collaborated with the NPL to produce the *Journal of Scientific Instruments.*
55. See D. S. L.Cardwell, *The Organizaton of Science....* (note 6).
56. L. Rayleigh. *The Life of Sir J. J. Thomson O. M.* (Cambridge, 1942), pp. 198–89.
57. See K. Gottfried and K. G. Wilson, 'Science as a Cultural Construct.' *Nature* 386 (10 April 1997), 545–47, to see an example of how the idea of pure science is still used today.
58. R. Appleyard, *The History of the Institution of Electrical Engineers 1871–1931*(London, 1939).
59. See J. A. Hughes, *The Radioactivists: Community, Controversy and the Rise of Nuclear Physics.* PhD dissertation, Department of History and Philosophy of Science, Cambridge, 1993.
60. Interestingly, some of the growth of physics in Cambridge was the direct outcome of the 1851 exhibition, for a portion of the proceeds of the exhibition was used to fund scholarships. Of the scholarships awarded between 1891–1895, 29 were held by physicists, of whom only two went to Cambridge. However, between 1896 and 1921, 103 physicists had scholarships, of whom 60 went to Cambridge. L. Rayleigh, *The Life of Sir J. J. Thomson.*
61. Interview with James Chadwick reported in *The Times* (Monday, 29 February 1932). A later example comes from an exhibition, 'Atom Tracks,' at the Science Museum in 1936–37 which showed the use of the cloud chamber developed by C. T. R. Wilson.
62. For similar reasons, Dirac argued the public showed great interest in relativity in that period. R. Williamson (ed.), *The Making of Physicists* (Bristol, 1987), p. 6.