LIVERPOOL AND BERKELEY: THE CHADWICK–LAWRENCE LETTERS

Having met at a Solvay conference in 1933, the discoverer of the neutron and the inventor of the cyclotron carried on a lively correspondence in the late 1930s. The next time they met was in 1943, on the Manhattan Project.

Andrew P. Brown

Research procedures at Cambridge University's famous Cavendish Laboratory underwent some visible changes in the 1920s. An influx of men with electrical engineering backgrounds, such as John Cockcroft, T. E. Allibone and Ernest Walton, led to work on prototype particle accelerators. The goal was to attack the atomic nucleus with something other than Lord Rutherford's beloved alpha particles.

In many ways, however, the Cavendish in the early 1930s still functioned according to its traditional customs. Cockcroft was struck by the contrast he found when visiting Ernest Lawrence's Berkeley laboratory in the summer of 1933. There he saw equipment of industrial size and researchers organized into teams. At Cambridge, researchers worked on their own or, at most, in pairs.

Just a few months after his Berkeley visit, Cockcroft was able to introduce Lawrence to Rutherford and his assistant, James Chadwick, at the Seventh Solvay Conference in Brussels. Lawrence, surprisingly, was the only American at the conference, and he made a favorable impression on the British contingent, even though they did not agree with some of his reported results. (See "The Two Ernests" by Mark Oliphant, in PHYSICS TODAY, September and October 1966.) Rutherford commented to Chadwick: "Lawrence reminds me of my young days. He's just like I was at his age,"[1] and there were indeed some close parallels. Two years earlier, at age 30, Lawrence had become the youngest professor ever appointed at the University of California. Rutherford had been just 27 when when he took up his first chair, at McGill University in Montreal. Both men had grown up in frontier agricultural communities: Lawrence in South Dakota, Rutherford on the South Island of New Zealand.

Chadwick's own relationship with Rutherford stretched back a quarter of a century to when Chadwick was a physics undergraduate at Manchester University. Apart from the 1914–18 war, he had worked with Rutherford continuously since his undergraduate days. He had gone to Berlin in 1913 to work with Hans Geiger at the Reichsanstalt, and made a brilliant start there, publishing the first accurate observation of the continuous beta spectrum.

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Prisoner of war

Still in Berlin at the outbreak of war in August 1914, Chadwick was interned in a camp near Berlin, where conditions were primitive. Through ingenuity, the generosity of German colleagues and bribery, he was able to build himself a makeshift laboratory. Chadwick returned to England in broken health at the end of 1918, and Rutherford took him to the Cavendish Laboratory.

At the Cavendish, Chadwick started as a doctoral research student, and he also took on some responsibility for the Radium Room. He joined Rutherford in a long series of alpha scattering experiments, which involved many hours of sitting together alone in a darkened room to count scintillation pulses. It was during these sessions that he and Rutherford would discuss ideas about nuclear structure and Chadwick first became fired with up the quest for the putative neutron.

Over the years Rutherford became deeply impressed with Chadwick's knowledge and ability as an experimenter. He also found himself relying increasingly on the younger man's shrewd judgement and powers of organization, so that Chadwick rose by imperceptible steps to become, *de facto*, the working director of the Laboratory. His scientific career was, of course, crowned by the discovery of the neutron in February 1932. That was a solo effort, accomplished with bench-top apparatus and a polonium source prepared by himself.

By the mid-1930's, Chadwick felt that "it was becoming very difficult to push on without some new equipment . . . and it was quite clear to me, as it was no doubt to others, that we needed a means of accelerating protons or other particles. . . . But that meant more space, particularly more money, and particularly engineering. It meant complicated equipment, and Rutherford had a horror of complicated equipment."[1]

In many ways, Chadwick was a natural deputy, and he was certainly regarded in that light by Rutherford. But in 1935 he left Cambridge to become the head of his own department at Liverpool. That port city, hit hard by

SOLVAY CONFERENCE, Brussels 1933. Ernest Lawrence (standing, second from right) was the only participant from the US. Seated (left to right) are Schrödinger, Irène Joliot-Curie, Bohr, Joffé, Marie Curie, Richardson, Langevin, Rutherford, De Donder, Maurice de Broglie, Louis de Broglie, Meitner and Chadwick. Standing (left to right) are Henriot, Perrin, Frédéric Joliot-Curie, Heisenberg, Kramers, Stahel, Fermi, Walton, Dirac, Debye, Mott, Cabrera, Gamow, Bothe, Blackett, Rosenblum, Erra, Bauer, Pauli, Verschaffelt in front of Cosyns, Herzen, Cockcroft, Ellis, Peierls, Piccard, Lawrence and Rosenfeld. (Courtesy of AIP Emilio Segrè Visual Archives.)

the prolonged slump in world trade, was experiencing endemic unemployment. Liverpool Unversity's physics department itself was languishing and attracted only a few, local students. The majority of undergraduates settled for an ordinary degree, and only two or three were chosen to take the third-year honors course. The department's George Holt Laboratory had hardly changed since it was first opened 30 years earlier. Its electricity supply was still dc and the few machines in the workshop were operated by belts driven from an overhead shaft. But there was plenty of unused space, and in his mind's eye, Chadwick could already see a cyclotron standing in the basement.

The prize

Almost as soon as he arrived at Liverpool University to take up his post in the autumn of 1935, Chadwick received a telegram from Stockholm to say that he had been awarded the Nobel Prize in Physics. Among several letters of congratulation was one from Lawrence,[2] dated November 27.

> Dear Professor Chadwick,
>
> My heartiest congratulations on the Nobel prize, a recognition that you should have had long ago. Although your neutron work alone justifies the award, it might well have been made in recognition of your many important earlier contributions.
>
> Dr. Fleming, of the Metropolitan Vickers, and his son were here not long ago and discussed the possibility of building a magnetic resonance accelerator for you. I told him that I should be very glad to help with the project in any way possible and doubtless we could be helpful in the way of sending detailed recommendations, drawings and specifications. Our present outfit is running smoothly these days, delivering more than 10 microamperes of 5 MV deuterons. We

JAMES CHADWICK (1891–1974) at about the time of his appointment to the Lyons Jones Chair of Physics at Liverpool in 1935. (Photo courtesy of AIP Emilio Segrè Visual Archives.)

BOERTZELLS ESSELTE

can produce an amount of radio-sodium having gamma-ray activity equal to that of several hundred milligrams of radium; and the neutron yield from a beryllium target is prodigious—something like 10^{10} neutrons per second. Among the various nuclear reactions we have been studying, perhaps the most interesting is that of platinum. We find that deuterons of energies between 3 and 5 MV produce radioactivity in platinum (presumably neutron capture reactions). There are indications of resonance penetration, as the transmutation function shows several sharp maxima.

Doubtless everyone in the Cavendish Laboratory is missing you a great deal. From that standpoint it is regrettable that you left. On the other hand, I think this is compensated by the fact that your going to Liverpool means that there is to be another great center of nuclear physics in England. I imagine that you are having your problems of an administrative character in assembling needed equipment and help, and here is wishing you the best of luck.

With kindest regards and good wishes, and again my warmest felicitations, I am

Sincerely,
Ernest O. Lawrence

Arthur Fleming, the research director of the British electrical engineering firm Metropolitan Vickers, was well known to Chadwick. The reply to Lawrence's effusive message was typically modest and down to earth:

George Holt Physics Laboratory
The University of Liverpool
29th December, 1935

Dear Professor Lawrence,

Many thanks for your kind letter of congratulations, which I appreciate very much. I feel rather lucky to get a Nobel prize. It is certainly difficult to look and feel as if one deserved it, but I am glad to make such a good beginning in a new place.

I am exceedingly pleased to hear from you that Fleming of Metropolitan Vickers is thinking of helping me to build your magnetic resonance accelerator, which ranks with the expansion [cloud] chamber as the most beautiful piece of apparatus I know. As a matter of fact I have been turning such a project over in my mind for some time, but I had to see what the laboratory really needs before thinking of my own wishes. I was indeed just about to write to ask if you would mind my embarking on such a scheme. It is very good of you to offer to help with drawings and specifications, and, I hope, with your advice. Although the method is so beautifully simple in principle I am sure there must be many troubles before one can get it to work smoothly.

I am very interested to hear that you get such enormous ion currents, and also in the resonance effect you mention. There must be many examples of resonance to be found, though they may not all be so striking as in platinum. I got indications with low velocity neutrons but the effects were small.

In connection with the accelerator there was a further matter I wanted to mention. [Bernard] Kinsey is obliged to return to England at the end of the year. I was thinking it might be possible to offer him a temporary post here to help with the accelerator. As things are at present I cannot ask the University for money to create a post. I shall probably have a small studentship or fellowship to offer and the rest I may have to provide myself. Do you think Kinsey has sufficient technique? He was only a beginner when he came to you but he seems to have developed well, and I like him personally. I should be very glad to have your opinion on Kinsey.

If I see any real prospect of getting an accelerator I shall go for it strongly. It would help me very much if you would give me a rough idea of the total cost, running expenses, and size of room to house it. It may sound rather absurd

Chadwick was cautious, but he gave the impression that there was now some progress towards installing a machine at the Cavendish as well. Rutherford had negotiated with the Soviets in October 1935 to transfer equipment from Cambridge to Peter Kapitza's new laboratory in Moscow in exchange for £30 000 and he was, with some misgivings, allowing Cockcroft to plan for a cyclotron.

> George Holt Physics Laboratory
> The University of Liverpool
> 11th May 1936
>
> Dear Professor Lawrence,
> I was very interested to hear of your experiment with a malignant tumor. I think there are very great possibilities in the biological application of neutrons and of the artificially produced active elements. I am myself more particularly interested in the chemical applications than in the direct effects, although the latter may be of more immediate importance, and I do not intend to neglect them.
> We have not proceeded very far with the design of the magnet for the cyclotron. There are, at the moment, three magnets to be considered, one for the Cavendish, one for Fleming and one for me. The Cavendish will have a very large magnet indeed. They have plenty of money from the sale of Kapitza's apparatus. Their magnet will be built so as to be suitable for magnetic work as well as for the cyclotron. Fleming intends to build a small cyclotron for Metro–Vick.

That same month came a windfall that transformed the finances of the Cavendish beyond recognition. Sir Herbert Austin, the motor car magnate, agreed to make the staggering bequest of £250 000. Chadwick sent a note of congratulations to Rutherford.[4]

> Everybody will be pleased that the Cavendish should receive such a magnificent gift. It is far more appropriate than having to collect a large number of small contributions, and it certainly must be a relief to you, as well as a pleasure to have this done properly.
> Begging, like swindling, is only respectable on a big scale.

Not in my laboratory!

It was now impossible for Rutherford to resist the pressure from Cockcroft for a cyclotron. Cockcroft was designing the electromagnet, and he and Chadwick were hoping to proceed in tandem. Chadwick told Rutherford that he would wait until the end of June 1936 before placing orders for parts with Metropolitan Vickers, but no longer. Rutherford still harbored misgivings, and told Chadwick petulantly: "I won't have a cyclotron in my laboratory."[5]

Kinsey returned from Berkeley in the late summer of 1936 to oversee the Liverpool cyclotron project. He found the rate of progress rather pedestrian compared with what he had been used to in Lawrence's laboratory. Chadwick was frustrated too when he wrote to Lawrence on 7 August 1937, after a hiatus of over a year.

> We have not got very far with our cyclotron. The steel blocks for the magnet have been finished for some time but are not yet here. We expect them in September with the coils, cooling boxes etc. from Metropolitan Vickers and we hope the complete magnet will be erected then. Kinsey is building the oscillator system here, and it is nearly ready. We could not afford to buy it from Metro–Vick. Although we are making quite a lot of the general apparatus ourselves, I am sure the cost of the complete outfit will be over £5000. However, we can just manage it. I hope everything will be here shortly and I think we shall have the cyclotron in full blast before Christmas. I am very pleased with Kinsey. He has taken nearly all the cyclotron work off my hands. I think he has found the responsibility rather heavy at times but I am sure it has been good for him.

Chadwick was about to acquire another English researcher from Lawrence, Harold Walke, who had been at Berkeley for two years. Lawrence recommended him warmly and Chadwick thought he could "fix him up for one year, but prospects after that are rather vague."

There were other discernible improvements in Liverpool. The honors physics school was expanding, and the best students were staying on to undertake research. Chadwick had the good fortune and judgement to recruit E. J. Williams from Manchester. Although Williams stayed for only eighteen months, he made impressive advances in cosmic ray research and was one of the first to find evidence for mesons. As Lawrence had predicted, Liverpool under Chadwick was becoming the second center for nuclear physics in England, and Rutherford, for one, was clearly stimulated by the development. One week before his untimely death in October 1937, Rutherford wrote Chadwick an exuberant letter,[6] in which he had come to accept a cyclotron as a *fait accompli*:

> I was rather amused by Walke. Cockcroft and I received strong letters from Lawrence, more or less asking us to do whatever we could to find a place for Walke in the Laboratory, and apparently at the same time he had been writing to you and others. I am glad, however, that you were able to get Walke's services. He ought to be helpful to you in getting the cyclotron going. I presume that we are in the same stage as yourself with regard to getting the magnet etc. going. The parts are all waiting in the Laboratory, and we are hoping to get them erected shortly. I have long since recognised that the cyclotron is a costly toy in this country, and I hope you will manage to get through without exhausting your funds.


LAWRENCE BERKELEY NATIONAL LABORATORY

LORD RUTHERFORD (1871–1937). (Courtesy of AIP Emilio Segrè Visual Archives.)

By this time, Lawrence was exerting a great influence in several European laboratories by sending acolytes to help design cyclotrons. This happened both in Frédéric Joliot-Curie's department at Ivry and Niels Bohr's institute in Copenhagen. Liverpool continued to benefit from the California connection through the presence of two Englishmen trained by Lawrence. Walke brought back, by rail and sea, some new isotopes with long halflives, produced at Berkeley so that their properties could be investigated in Liverpool.

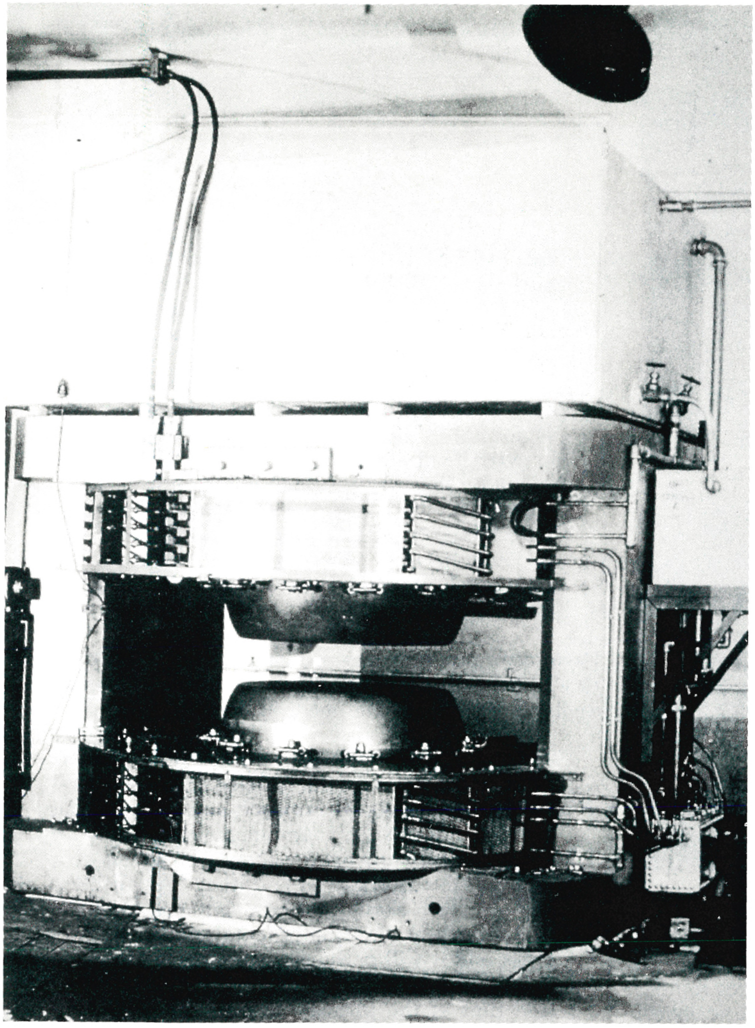
Luis Alvarez of Lawrence's team had just described K-electron capture, a novel form of radioactive decay. John Holt, a young Liverpool graduate who had stayed on to do research, used a homemade Geiger counter to find an isotope, vanadium-47, "which [as Holt recalls[7]] emitted only soft X-radiation, the first example of a K-capture decay with no accompanying nuclear radiation. It was very convincing evidence for the new process. The matter was clinched by some absorption measurements which I was able to make with a counter having a window of Cellophane, which showed that the X-rays were characteristic of the daughter element titanium." Cellophane, rather than the usual mica, was very transparent to the soft X-rays in question.

Chadwick continued his regular correspondence with Lawrence, writing on 16 April 1938:

> I hope your new apparatus is really big. I feel that one ought to make a serious attempt to get up to 60 or 70 million volts (i.e. $\approx$137 mc^2) — perhaps not just yet but one ought to prepare for it. I feel sure that with such particles we should begin to learn the true mechanics of the nucleus. Of course nature provides us with such particles in the cosmic rays but in most niggardly fashion. I think the phenomena in the cosmic rays point the way to us.
>
> I am afraid there is very little chance of being able to build a big cyclotron in this country for some time to come. We have had endless trouble in getting our small one. Even now we have not yet got the tank [vacuum chamber] from Metrovick. It is now a year since the drawings were finally completed and handed to them. For various reasons I cannot quarrel with them but I am sorely tempted to do so. Kinsey's patience was long ago exhausted.

Lawrence's program was forging ahead, and in his reply to Chadwick on 30 April 1938 he could not contain his excitement at a possible medical breakthrough:

> There can be no question at all as to the importance of the artificial radioactive substances and neutrons for medical research and therapy and I should think that your biophysical friends in London would undertake the construction of a cyclotron for this line of endeavor. As an illustration which should not be mentioned in public in as much as the experiments are still in progress and it will perhaps be another year before definite publications will be made, I would mention that at the present time my brother, John Lawrence, is treating with radio-phosphorus a patient suffering from myelogenous leukemia, with remarkable results. Recently he had been studying leukemia in mice and found that radio-phosphorus is selectively taken up by not only the bones and lymphatic tissue but also, to an extraordinary degree by the diseased white blood cells. For example, he found that in the spleen of the diseased animal the uptake of radio-phosphorus is something like 5 times as great per gram of tissue as in the spleen of a normal animal. This suggested the clinical possibility of treating the human disease, and beginning early in January he gave, over a period of about two months, a patient suffering from myelogenous leukemia a total of 70 millicuries of radio-phosphorus. At the beginning the patient's white blood count was 600,000 while the red cells were 2.5 million. Shortly after the beginning of the administration of the radio-phosphorus the white blood count steadily dropped, the myeloblasts falling much more rapidly than the other cells, while the red count steadily went up to normal. Several weeks ago the patient's blood picture had got to the point where it was not far from normal, the total white blood count being about 8,000, while the red count was 5 million, with less than half of one per cent of the white cells being diagnosable as diseased cells. The



THE 37-INCH LIVERPOOL CYCLOTRON, completed in 1939. (Courtesy of the University of Liverpool physics department.)

radio-phosphorus treatment has been stopped and now the patient is being watched to see what will happen next. Dr. John and all of the medical people feel that this patient's response to radio-phosphorus has been remarkable but they feel on the other hand that there is no evidence that the phosphorus has cured the disease, and I am afraid that if my brother knew that I had mentioned it to you he would scold me.

How closely Ernest Lawrence followed his brother's medical research! It wouldn't take much effort to turn this passage into a report for a medical journal.

First beam and then second war

In July 1939 the Liverpool cyclotron finally produced its first beam of accelerated particles. The 50-ton electromagnet from Metropolitan Vickers had cost £3123 and the total cost of the project (excluding salaries) amounted to £5184.[8] That exceeded the funds obtained from the University and the Royal Society. The balance was provided by Chadwick from his Nobel Prize money.

Kinsey, with assistance from Walke, had provided the day to day supervision of the work. Many of the engineering problems had been solved by Michael Moore, an Irishman in his early twenties, who had come to the department in 1937 after completing an apprenticeship with Metropolitan Vickers. A talented Polish physicist, Joseph Rotblat, had also been attracted to Liverpool to learn about commissioning a cyclotron. He had ambitions to build one in his native Warsaw. (See the news story on Rotblat's Nobel Peace Prize in the December 1995 PHYSICS TODAY, page 61.)

With promising research work being undertaken by Holt, Rotblat and Gerry Pickavance, Chadwick had every reason for quiet satisfaction. He looked forward to an exciting era of advances in nuclear physics, radiobiology and medicine. Two months later all these hopes were dashed. Britain was at war with Germany again, Kinsey was assigned to radar research and Walke was accidentally electrocuted while working on the cyclotron in December 1939.

At about this time, Chadwick and Rotblat reached the conclusion, independently of Otto Frisch and Rudolf Peierls, that a uranium bomb might be feasible with fast neutrons. By 1940 they were using the Liverpool cyclotron to measure neutron cross sections in uranium.

Chadwick and Lawrence, who had become firm friends through their letters, renewed their acquaintance on the Manhattan Project, ten years after their first meeting.

The Chadwick–Lawrence letters are quoted through the courtesy of The Bancroft Library at the University of California, Berkeley, owners of the Ernest O. Lawrence papers, and with the permission of the daughters of Sir James Chadwick.

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