

The Two Ernests—II

Sir Mark continues his personal recollections of Ernest Rutherford and Ernest Lawrence. By 1935 precise mass determinations with nuclear reactions were being made at Cavendish. In the following years Rutherford was arranging for new facilities at the laboratory. Meanwhile Lawrence began to use the cyclotron for medical research, learned to extract a beam from the accelerator and found a lot of unexpected radiation. Two years after Rutherford's death, the discovery of fission opened a new era.

by Mark L. Oliphant



BOTH ERNEST RUTHERFORD and Ernest Lawrence led great laboratories and inspired the physicists who worked in them. Rutherford was personally involved in almost all of the work at the Cavendish Laboratory, dominating the laboratory by his sheer greatness as a physicist and providing for his colleagues only the barest minimum of equipment. Lawrence, on the other hand, created at the Radiation Laboratory, the first of the very large laboratories in which massive and expensive equipment was designed, built and used for investigations into basic problems in physics in which he played little part, personally. After the discovery and successful development of the cyclotron at his laboratory, Lawrence enthusiastically offered his assistance in the construction of cyclotrons at laboratories elsewhere.

The two men did not meet until the Seventh Solvay Congress, October 1933. At the meeting, Lawrence defended his hypothesis that the "deuton" (deuteron) was unstable, breaking up in nuclear collisions into a proton and neutron. By May of the following year, however, Lawrence was convinced by

experiments in the Cavendish Laboratory that what he had actually observed were reactions of deuterons with deuterons. From that time onward, the contributions of Lawrence's laboratory were above reproach and of rapidly increasing importance as the energy and intensity of the beams available from the cyclotron increased.

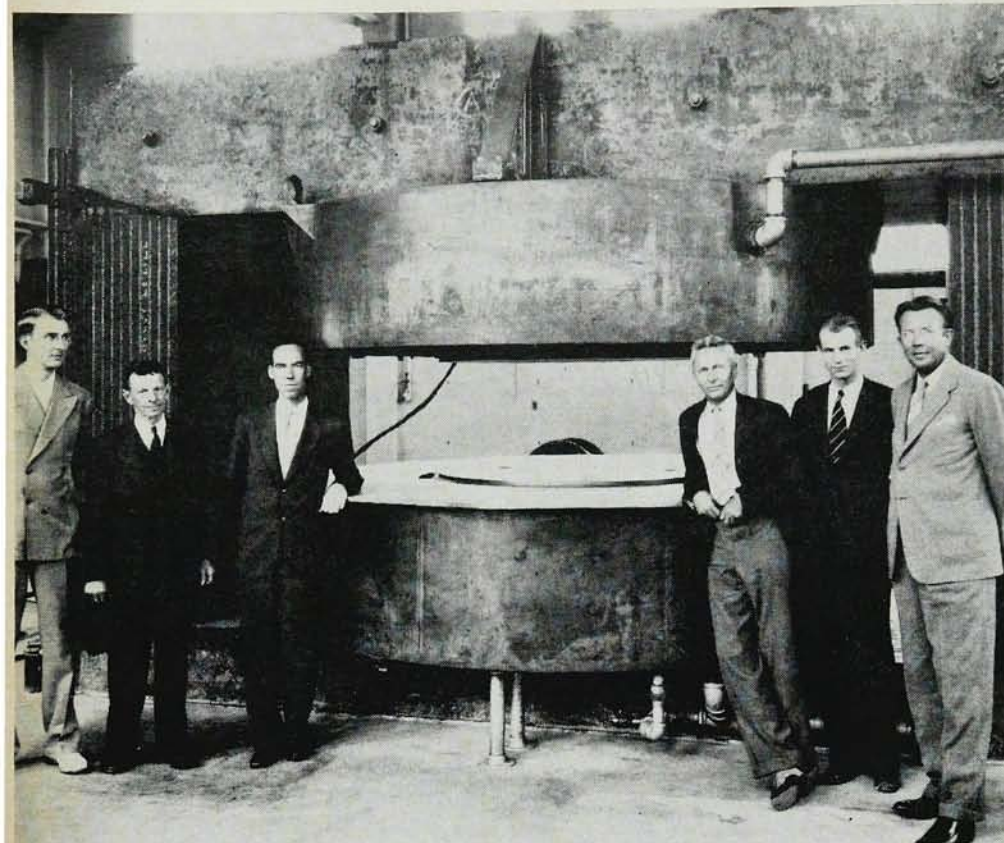
Accurate mass measurements

One of the early results of more accurate observations of the energies released in nuclear reactions involving the light elements was realization that the relative masses of the atoms, as given by the mass spectrograph, were not sufficiently reliable to give consistent agreement. In the Cavendish Laboratory, we naturally used the mass determinations made there by Francis W. Aston, whose improved mass spectrometer was then in operation. We came to the conclusion that there was an appreciable error in Aston's value for the mass ratio of hydrogen to helium, a basic determination upon which many of his other mass values depended. Aston was a touchy person and reacted with characteristic violence

to the suggestion that there were systematic errors in his list of isotopic masses. On 4 May 1935, Rutherford wrote to Lawrence:

"You will no doubt have heard from Cockcroft and others about what is going on here. We have given a complete account of our beryllium results in the P.R.S. [*Proceedings of the Royal Society*] which appears this month, and you will see that we have put forward a scheme of masses to fit in—practically along the same lines that [Hans] Bethe has independently suggested in your country. At first, Aston took a high line about the accuracy of his results, and the impossibility of any serious error between helium and oxygen, but when I told

Sir Mark was assistant director of research at Cavendish until 1937, when he became director of the physics department at Univ. of Birmingham. In 1950 he became director of the Research School of Physical Sciences, Australian National University, Canberra. He served for three years as president of the Australian Academy of Sciences.



KEY FIGURES in development and early use of the 60-in. Crocker cyclotron stand beside the machine during construction. Only the magnet yoke and the coils have been completed. Left to right: Luis Alvarez, William Coolidge (who was visiting), William Brobeck, Donald Cooksey, Edwin McMillan and Ernest Lawrence.

him that if he did not get to work, I was going to put forward the correct mass scheme, he rapidly started in, and found that he had dropped one or two bricks of reasonable magnitude! I am not quite sure he is right yet, but no doubt he may amend his results later. As a matter of fact, it is obviously very difficult for mass-spectrographic methods to give the same accuracy as from transformations when we are sure of the reaction."

In his reply, Lawrence wrote:

"Your very much appreciated letter was forwarded to me in New Haven, Connecticut, late in May: I was in the East about two months, engaged in my annual task of raising money for the support of our work in the radiation laboratory. I rather expected considerable difficulty in raising needed funds this year, and indeed was rather worried that we might have to restrict our work a great deal, but fortunately matters turned out otherwise. In this country

medical research receives generous support, and it was the possible medical applications of the artificial radioactive substances and neutron radiation that made it possible for me to obtain adequate financial support. We are now able to produce several millicuries activity of radiosodium. We are devoting a good deal of attention to the further development of the magnetic resonance accelerator for considerably larger currents and also higher voltages. It is reasonable to expect that it will not be very long before we will be producing ten times as much radioactive substance as at present. However, according to the medical people, at the present time we can provide enough radiosodium for beginning clinical investigations, and we have agreed to begin supplying the University Hospital here early this fall.

"We have lately been making various tests of the performance of our apparatus with a view to the con-

struction of an improved design. Perhaps the most interesting result is that the focusing action of the electric and magnetic fields is so nearly perfect that we can get just as large current of deuterons at 4.5 MV as at 2.5 MV. At the present time the apparatus delivers several microamperes of deuterons having a range of 16.7 centimeters (about 4.5 MV). We have bombarded several substances, using these energetic deuterons, and it appears that almost the whole periodic table can be activated, the type of nuclear reaction involved being that in which the neutron of the deuteron is captured by the bombarded nucleus. We have found that gold can be activated in this way, a result which is very surprising. We shall do a good deal more work yet on these things before we can have confidence in the experimental results and theoretical interpretations.

"We were all very much surprised to hear that Chadwick is leaving you to be professor at Liverpool. I suppose it is a promotion for him, but I am sure that if I were he I would be very loathe to leave you and the Cavendish Laboratory."

Cyclotrons for medical research

This letter mentions again Lawrence's readiness to develop the medical applications of the cyclotron and its products in order to obtain the funds required for the work of his laboratory. However, his interest in possible medical applications was not only financial. His early ambition to become a doctor and the fact that his younger brother, John, had qualified in medicine and had become an instructor at Yale Medical School had kept his genuine interest in the healing art. In the summer of 1935, John, who had broken his leg, went to California to stay with Ernest while he recuperated. He did some experiments while there, with the aid of Paul Aebersold, a young colleague of Ernest. They exposed rats to neutrons and gamma rays from the cyclotron. On 13 Aug. 1935 Lawrence wrote a letter to Rutherford that I quote in full:

"Dear Professor Rutherford:

"I am very, very grateful to you for the photograph of yourself which

I shall always treasure very highly. In asking Cockcroft to get a photograph of yourself for me and ask you to autograph it, I had in mind that he could purchase one in a bookstore and perhaps persuade you to write your signature on it. I appreciate very much your kindness in sending me the portrait.

"Work is going along quite satisfactorily in our laboratory, although at the moment we are bothered with cathode ray punctures of the insulators of the magnetic resonance accelerator, the result of increasing the voltage and current output. My brother, who is on the faculty of the Yale Medical School, is vacationing here, and I persuaded him to undertake a preliminary investigation of the biological effect of neutrons. He has been exposing rats to neutrons for periods of time from ten minutes to three hours, and has been observing the changes produced in the blood of the rats. The first rat was exposed for a period of three hours, and as a result died, and subsequent experiments indicate that neutron rays are considerably more lethal biologically than x rays. The immediate result is that we are taking rather greater precautions in the matter of exposing ourselves in the course of our work in the laboratory.

"I am very glad to hear that you are well, and again I want to thank you ever so much for your picture.

"With best wishes and highest personal esteem, I am

Respectfully yours,"

John tells me that in fact the rat died of suffocation, being too completely confined! However, an important result was that much more stringent precautions against neutron and gamma radiation were then instituted in the Radiation Laboratory. From then till 1937, John Lawrence visited Berkeley regularly, at intervals of about three months, taking with him biological experiments to be carried out with the aid of the cyclotron. In 1937 he moved to Berkeley permanently to take charge of the medical work with a 60-in. cyclotron provided through the generosity of Crocker. Direct treatment of patients with the neutron beam from the cyclotron began in 1938, in collaboration

with Robert Stone of the University of California Medical School in San Francisco. Lawrence had encouraged Sloan to design, and get into operation, an x-ray equipment for about 1 MV, using a resonant transformer in a vacuum, and Stone was using this in the hospital. The mother of Ernest and John was treated for a malignant growth with this equipment by Stone in 1937, and the treatment was so successful that it reinforced the faith of the brothers in the possibility of developing still more effective uses of radiation in the treatment of cancer.

New equipment at Cavendish

A letter from Rutherford to Lawrence, of 22 Feb. 1936, contains the following passages:

"I was delighted to get your letter and to hear how your work is going on. I congratulate you on your success with your apparatus in getting high voltages and intense beams. The neutron photographs you sent me were certainly very impressive, and I can roughly estimate the strength of your artificial source of neutrons in terms of radium emanation.

"I was exceedingly interested to hear also that you [this work was done by John Livingood, under Lawrence's general direction] have been successful in producing radium E from bismuth—a great triumph for the new apparatus. I have a personal interest in this artificial product; for I do not know whether you know that I worked out the changes radium D-E-F long ago in Montreal, and showed that as the β rays decayed an α -ray product grew. The apparatus I used is now preserved in the Physical Laboratory in McGill. I shall be interested to hear the details of your experiments and how much radium E you manage to produce.

"I note what you say about the present stage of your apparatus. At present we are very busy transferring the apparatus from the Royal Society Mond Laboratory, and getting duplicates, and keeping the cryogenic work going as usual. We do not intend to get a duplicate of the big generator for producing

strong magnetic fields, but have in view instead the installation of a large magnet for general purposes, and also probably for use as a cyclotron. We have not had time as yet to go into the matter, but I think probably Cockcroft will be writing to you soon to see whether you can give him any information of the best design of magnet to be used for the latter purpose.

"At present we are just beginning the new building for our high tension D.C. plant, and we hope with luck to reach 2 million volts positive and negative, and possibly higher, but no doubt we will find plenty of trouble before it is in working operation. We shall, of course, build up the component parts of the apparatus ourselves so as to keep down the expense.

"Aston will shortly be publishing the new values of the masses of the light elements obtained with his improved spectrograph, and these new values fit in very satisfactorily with transformation data, so that difficulty is removed. I have also heard from several sources that Bainbridge has also done very much the same thing with his new spectrograph, and it will be interesting to see how far these two independent sets of measurements agree. It will be an ultimate test of the accuracy of these two systems."

The reference to the Royal Society Mond Laboratory concerns equipment that had been provided for the work of Peter Kapitza, the Russian engineer-physicist who had joined the Cavendish Laboratory in 1921. He was in the habit of visiting Russia during the summer to see his old mother. In 1935 the Soviet government refused to allow him to return to Cambridge, but offered to buy his equipment from the university in order that he might continue his researches in Russia. With the able help of Cockcroft and others, Rutherford proved himself a better man of business than expected, and negotiated a good price for the equipment. Meanwhile, Rutherford's resistance to the idea of as complex a piece of apparatus as a cyclotron in the Cavendish Laboratory had been worn down, and he was willing to devote part of

the sum received from Russia to the acquisition of a large magnet which could be used, inter alia, for a cyclotron.

The reply by Lawrence was characteristic of his generosity towards all who wished to build a cyclotron:

"Thank you ever so much for your good letter. I should have known that you were responsible for the radium D-E-F, but I must confess that I didn't. As regards the yields of radium E by bombarding bismuth with five-million-volt deuterons, I must say that they are quite small. If I remember correctly, several hours bombardment with several microamperes gives, after a few weeks, something like thirty alpha-particles count per minute when the bismuth target is placed near the ionization chamber of the linear amplifier. Measurements on the range distribution of the alpha particles from the bismuth indicate that the transmutation function is exceedingly steep (for nearly all of the alpha particles have very near the full polonium alpha-particle range). It is probable, therefore, that at six million volts, which is the voltage we are now using, the radium E and polonium yield should be very much greater; and doubtless in the near future Dr. Livingood will continue experiments at this higher voltage.

"We have recently made some alterations of the cyclotron which have made it possible to withdraw the beam completely from the vacuum chamber through a thin platinum window out into the air, and I assure you that we have got quite a thrill out of seeing the beam of six-million-volt deuterons making a blue streak through the air for a distance of more than twenty-eight centimeters. Our purpose in bringing the beam out and away from the cyclotron chamber is twofold: partly to make it convenient to carry on scattering experiments, and partly to bring the beam to a target at a considerable distance from the vacuum chamber in order to get rid of the annoying neutron background produced by the circulating ions in the chamber striking various parts of the ac-

celerating system. With this latest improvement in the design of the cyclotron, I think now we have an apparatus which closely approximates one's desires.

"I believe in my last letter I mentioned that we have been carrying on experiments on the biological action of neutron rays. During the past two months such biological matters have taken a good share of my attention, because I feel that such matters, as well as nuclear physics, are of great importance. My brother, Dr. John H. Lawrence of the medical faculty of Yale University, has been out here studying the effects of neutrons on a certain malignant tumor called 'mouse sarcoma 180.' He has compared the lethal effect of neutrons and x rays on the tumor and on healthy mice and has very impressive evidence that this malignant tumor is relatively much more sensitive to neutron radiation than to x-radiation. If this is generally true for malignant tumors, we have here a very important possibility for cancer therapy. I am sure that it will not be long before neutrons will be used in the treatment of human cancer. . . .

"I was interested to hear that you are beginning the new building for your two-million volt D.C. plant and that you are undertaking the construction of a large magnet.

"I received the letter from Cockcroft and in the next few days will be sending him detailed information.

"Several days ago I received an invitation to attend the meeting in September of the British Association for the Advancement of Science and I have written a tentative acceptance and I can arrange to be away from the laboratory at that time. I should like very much to come to England to spend two weeks. In the event that you should decide to build a cyclotron, it is possible that I could be helpful by going over in detail with you matters of design."

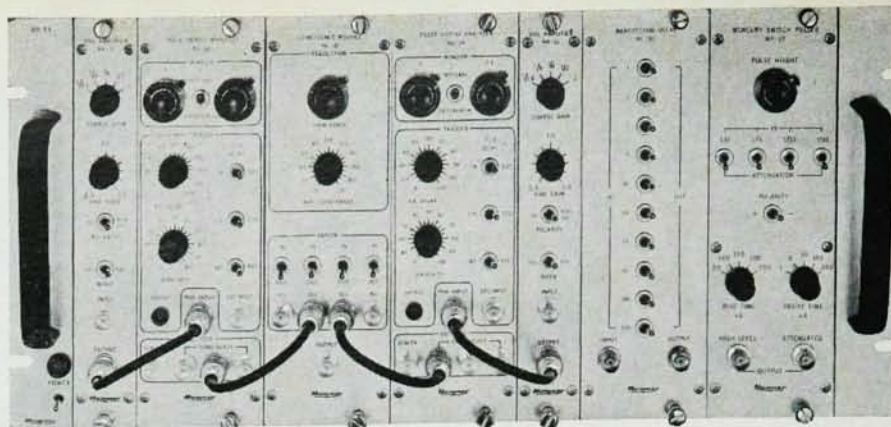
Unfortunately, the design of the cyclotron for the Cavendish Laboratory, and its brother for Chadwick, in Liverpool, did not follow the lines



JOHN LAWRENCE who used cyclotron for medical research, with Ernest, 1927.



ERNEST RUTHERFORD, by Birley.



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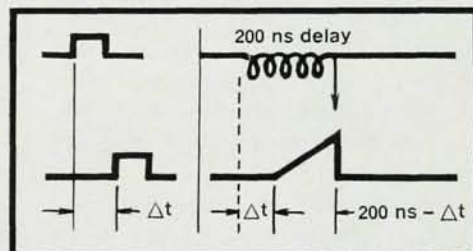
Hamner has developed a fast coincidence system capable of recovering reproducible data over a wide range of nuclear particle experiments. Typical of these are multi-particle breakup studies to determine whether breakup proceeds sequentially or simultaneously. Others include particle identification coupled with general angular correlation and simultaneous energy and momentum determinations. Here are four reasons why this system is eminently suited to any application requiring fast coincidence/anti-coincidence logic:

over timing may be preferred. With slow rise detectors such as NaI, leading edge timing may be advantageous. The system may be further optimized by means of its time pick-off sensitivity control. This unique Hamner feature permits control of triggering sensitivity to suit the characteristic pulse shape of the detector.

in time symmetrically spanning the coincidence pulse. Other systems either do not provide anti-coincidence or, if they do, provide a blanking time which follows the anti-coincidence input rather than including it. The symmetry of the Hamner blanking gate makes possible anti-coincidence gate widths as small as 10 nanoseconds.

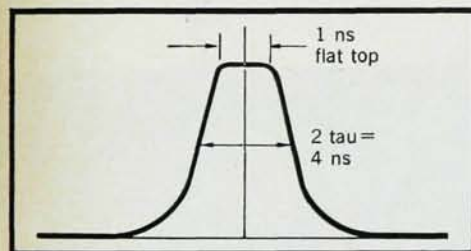
All components of the Hamner Fast Coincidence System conform to the new A.E.C. National Laboratory Standards (TID-20893).

For more information, contact your nearest Hamner field engineering office or use the coupon below.



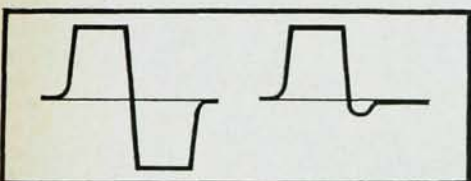
Multiple coincidence measurements without degradation of time accuracy

The Hamner system uses an exclusive fast ramp principle which operates independently of pulse width and provides increased accuracy at smaller time intervals. It delays the first of a pair of pulses by 200 ns and uses the second pulse to trigger a linear ramp voltage. The ramp is then called back by the leading edge of the delayed first pulse. Ramp amplitude is therefore proportional to $(200 \text{ ns} - \Delta t)$. The amplitude of the ramp is then discriminated to obtain highly linear, drift-free and accurate time resolution equivalents. Also, in the Hamner system, pulse width is not critical since only the leading edges are considered.



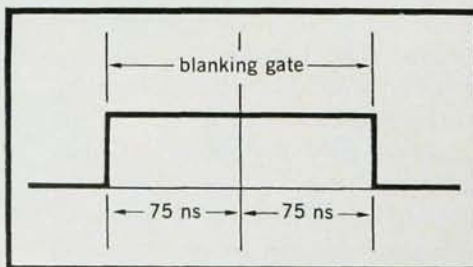
Minimum coincidence resolving time of one nanosecond

Using a pulse generator and a switchable delay as input, the Hamner system yields a reproducible cable curve with a one nanosecond flat top and 4 nanosecond 2τ . Under experimental conditions therefore, the rate of chance or false coincidence counts is limited only by the resolution of the detector.



Optimization of coincidence system with detector

The double delay line clipped pulses produced in the Hamner system may be timed from either their leading edges or their zero crossover points. This permits optimization of system operation based on the characteristics of the detector. For example, with plastic scintillators or other fast-rise detectors, cross-



Anti-coincidence gate opens symmetrically about zero point

The blanking gate for the anti-coincidence input of the Hamner system opens



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developed in Berkeley. It was entrusted to a large electrical engineering firm, with no previous experience, while funds were too restricted to enable the magnets to be as large as was desirable. Much trouble was experienced with them, and they never performed as efficiently as the virtual copy of the 60-in. Crocker cyclotron built by us in Birmingham. However, they did useful work, and established the technique in Britain.

Biology and beam extraction

Lawrence wrote to Rutherford on 24 Nov. 1936:

"I had intended writing you some time ago regarding Dr. R. [Ryokichi] Sagane, who has been with us the past year and desired to spend this year in the Cavendish Laboratory. I am afraid that he has arrived, and therefore words in his behalf now are a bit late. However, I should like to say that we liked Sagane very much; he proved to be a self-reliant and competent experimenter and a congenial personality. I do hope that you will find him an agreeable person to have as a visitor in the Laboratory, for I know that he is very anxious to be with you and will profit a great deal by such a sojourn.

"All of us here are very busy with a number of things. In addition to the nuclear work, we are devoting a lot of attention to biological problems, as I feel that there is important work to be done in this direction as well as in nuclear physics. We are supplying various artificial radioactive substances to the chemists for investigations of chemical problems and to biologists, particularly physiologists, for use as tracers in biological processes. I do hope that in this way we shall be able to contribute to the elucidation of some biological questions. We are also investigating quite extensively the biological effects produced by neutrons. I think we can say pretty definitely now that neutrons do not parallel x rays in their biological action. Studies of the comparative effects of x rays and neutrons will doubtless shed light on the mechanisms whereby ionization produces effects in bi-



NEWS OF HIS NOBEL PRIZE brings joy to Ernest Lawrence, 9 November 1939.

ological systems, and of course also there are the possibilities of effective medical therapy with neutrons.

"In some preliminary experiments on a mouse sarcoma, we got indications that neutrons had a greater selective action in killing this tumor than x rays. Under separate cover I am sending you a reprint of this work. This fall, similar experiments have been carried out upon a mouse mammary carcinoma with similar indications. In these more recent experiments, many more tumors and mice were irradiated with neutrons and x rays than in the first experiments on the sarcoma, and the new data also indicate a greater selective action of the neutrons on tumor tissue. It seems to me quite probable that neutrons will prove to be valuable in the treatment of cancer.

"We are this year undertaking the establishment of a new laboratory, which might be called a laboratory of medical physics. The organization and planning of the new laboratory is taking a good share of my time this year, but of course I am glad to do it, although I regret I cannot spend full days in the laboratory. Friends of the University have given funds for a new building and equipment, and I hope that by late next fall, experimental work in the new building will get under way. The architects have practically finished the building plans and we are engaged in designing the new cyclotron. Many of us are

having pleasure in planning the new apparatus; although doubtless we are deluding ourselves into thinking that the new outfit will be all that a good cyclotron should be.

"For certain experiments in progress we recently further modified our present cyclotron to bring the beam entirely out of the magnetic field, and we are finding the new arrangement one of great convenience for many experiments. I am enclosing a photograph of six microamperes of six million volt deuterons emerging into the air through a platinum window at the end of a tube six feet long. The beam is quite parallel and can be brought out considerably farther if so desired without undue loss of intensity.

"I have heard from several sources that you are very well and very busy—and in view of the latter, I can hardly expect a letter from you, although, needless to say, I should be greatly delighted if you should find time to write a few lines.

"Professor and Mrs. Bohr are coming to Berkeley in March and we all are looking forward to their visit. I wish it were possible to persuade you to visit America also."

Rutherford replied with characteristic enthusiasm for Lawrence's success:

"I got your letter a few days ago, and was very interested to hear of your latest developments in getting a beam of fast particles well out-

side the chamber. I congratulate you on your success in this difficult task, and I gather you are hopeful to get even stronger beams in this way. The photograph you have sent me is a beautiful one, and I would be very grateful if you would allow me to reproduce it in a lecture I am just publishing called 'Modern Alchemy,' which is an expansion of the Sidgwick Memorial Lecture I gave in Cambridge a few weeks ago. Unless I hear from you to the contrary, I will assume that you agree to this.

"Dr. Sagane visited us this term and he then decided to go for a short tour to Germany and Copenhagen, and is returning here in the New Year to begin some work. He seems a pleasant fellow, but he writes to me that he is finding a difficulty in seeing some of the German laboratories, as it is necessary to get a special permit from the Government to do so. This state of affairs in Nazi-land is rather amusing, and when some of our men from the Cavendish wished to visit Berlin to see Debye's laboratory, he wrote to Cockcroft that official permission would have to be granted by the Government before he could admit them!

"As to our own work, we are going ahead as usual. The new High Tension Laboratory is nearly completed and we hope to get a D.C. potential of 2 million volts going. We are also making arrangements to run one of your cyclotrons in due course.

"We celebrated J. J. Thomson's 80th birthday on December 18th by giving him a dinner and presentation in Trinity and also an address with signatures from many of the Cavendish people. He is still very alert intellectually, and he was much moved by our little homely address.

"I wish you good luck in the development of your new laboratory and success in your experiments."

Cyclotron radiations

It was on 11 Feb. 1937 that Lawrence wrote again to Rutherford:

"I greatly appreciate your very interesting letter received some time

ago. I know that you are extremely busy and it is very kind of you to write at such length.

"Your account of the state of affairs in Germany is almost unbelievable. One would think with such a scientific tradition the German people could not adopt such an absurd course of action in scientific affairs.

"The dinner to J.J. Thomson must have been a very nice occasion. It is certainly fine that he has such vigor at his ripe old age.

"I am glad to hear that your new high tension laboratory is coming along nicely and that you are also constructing a cyclotron. As I have written Cockcroft, if we can be of assistance in any way we should be only too glad. I have just heard that he is coming over for some lectures at Harvard and I have written him a letter inviting him to come out to see us. I do hope it will be possible for him to do so. I think it is possible that he might be saved some unnecessary beginning troubles by spending a few days in our laboratory operating our cyclotron. Also, in a month or so we shall have our new cyclotron chamber for the present magnet practically completed in the shop. This new outfit has quite a few improvements which Cockcroft would probably want to consider in his design.

"During the past few weeks we have been bombarding with 11 million volt alpha particles, studying the radioactivities produced. In addition to those already reported we have been finding many new activities, especially on up the periodic table. Also we have been making some absorption measurements of the radiation from the cyclotron and find that there is a very penetrating component. We do not know what it is yet, but the indications are that the penetrating radiation consists simply of very energetic neutrons. A 7 inch thickness of lead does not cut it to half. According to Oppenheimer theoretical considerations indicate that the mean free paths of neutrons vary as their energy. Hence it may be that the 14 MV neutrons from

Be + 5 MV D² have mean free paths of more than 50 cms—something like the penetration of the radiation observed. We are continuing with the experiments with the endeavor to get the experimental facts as clear-cut and definite as possible, and I am sure when this is done we shall understand what is going on. Under separate cover I am sending you several reprints."

He followed this with a further letter of 24 Feb., having received some reprints of lectures given by Rutherford:

"Thank you very much for the reprints of the lectures, which I have already read with much pleasure and profit. The history that you tell about is certainly absorbing. Your discussion of the essential role played by the development of new methods and techniques in the advance of science appealed to me very much, as I have always held similar views, and of course your mention of the cyclotron in this connection was to me the highest compliment. Your lectures, which I regard as models for us younger men, have a quality in common with your great experimental works, that is to say, they go to the heart of the matter and bring out the essential points with beautiful simplicity. . . .

"We have been pursuing the investigation of the radiations from the cyclotron, and have pretty well satisfied ourselves that there is nothing extraordinary about the radiations excepting that it is an extremely difficult matter to screen out all the neutrons and the gamma rays from any particular region. We have now quite a lot of water around most of the cyclotron, but in spite of that Professor Lewis in the Chemistry building next door is not able to carry on his experiments with his sources of neutrons consisting of a mixture of beryllium with 200 milligrams of radium, and we find that at a distance of 300 feet from the cyclotron the mixture of neutrons and gamma rays from the cyclotron produce an easily detectable ionization. We are now planning to have the cyclotron in the new laboratory in a

basement room rather than at ground level in order to cut down the amount of radiation getting out into surrounding laboratories. I am afraid that you will find your new cyclotron something of a nuisance in this regard also."

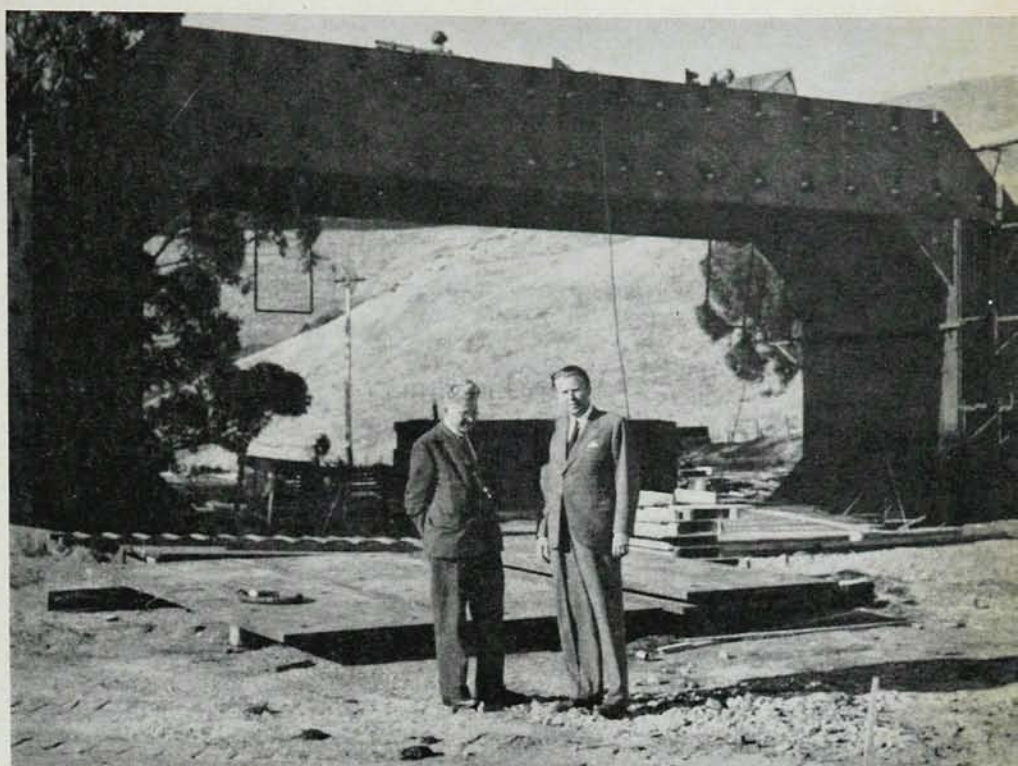
It is clear that these two enthusiastic men were developing a considerable understanding and respect for one another. Lawrence absorbed more than he realized of the spirit of the father of nuclear physics, and he was able to pass this on to others. The center of gravity of the study of the nucleus was already moving across the Atlantic to the United States, a move which was to become almost complete by the end of the second world war. Rutherford was to write only once more, in reply to the following invitation from Lawrence:

Invitation to Charter Day

"I have just been talking with the President of the University, who has asked me to write you informally as to whether there would be any possibility that you might be willing to come over here to give a Charter Day address next March or a year later.

"Charter Day here is regarded as a very important occasion and the speaker at the exercise is always someone of great distinction. President [Robert] Sproul is aware that you may be very reluctant to come, but is most anxious to persuade you to do so, since he appreciates your eminence, not only with respect to your scientific contributions but also with respect to your general scientific statesmanship and world-wide good influence. I do hope you will entertain thoughts of coming over, as quite aside from the Charter Day exercises, all of us in the laboratory would gain so much from your visit, even though it were very brief. Needless to say we would do everything we could to make your stay with us pleasant.

"The President is anxious to know whether there is a possibility that you will come, and so if it is not too much trouble, I should appreciate a note from you at your early convenience. In case you should



MARK OLIPHANT AND ERNEST LAWRENCE stand before 184-in. cyclotron, 1941.

consider coming, it would be helpful if you would give me some informal indication of a suitable financial arrangement which I could transmit to President Sproul, as I know it is customary to provide a proper honorarium. . . .

"We enjoyed very much Cockcroft's visit, brief though it was. I need not describe here what we did when he was with us, as doubtless he has given you a complete report. . . .

"Hoping to hear from you soon and again hoping that you will actually entertain thoughts of coming over next March, and with highest personal esteem, I am

Respectfully yours,"

Rutherford answered:

"I have just received your letter, asking me whether I could visit California next March, in order to be present at your Charter Day Exercises.

"Please convey my thanks to your President for his very kind suggestion and invitation. I write, however, to let you know at once that there is no possibility of a visit next year, as I have already arranged



SKETCH of Ernest Rutherford in 1928.

to go to India in November and preside over a joint meeting of the British Association and the Indian Association of Science, in January, 1938. I shall not return until February, and I shall find great arrears of work to attend to. At this stage, I cannot make any promises about the following year. I have so many calls on my time, that it is difficult for me to make arrangements too far ahead. At the same time, I greatly appreciate the very kind invitation of the University and yourself. I should personally like to have the opportunity of visiting California again, and in particular of seeing something of the work of your laboratory. Cockcroft told me about his visit, and how kind you had been in helping him.

"We are now preparing the foundations for the cyclotron, which we hope will be ready for transmission to Cambridge in July.

"I am glad you were interested in the little book and the lectures I sent you.

With best wishes,

Yours sincerely,"

Lawrence was naturally disappointed that Rutherford could not accept the invitation to Berkeley, but wrote saying that he was glad that the possibility of a visit in the following year was not ruled out.

Rutherford had looked forward with keen anticipation to the meeting in India. He believed implicitly in the British Commonwealth, and his political liberalism led to his welcoming the development of responsible self-government in India. He had had many Indian students and had known well that remarkable mathematical genius, Srinivasa Ramanujan, also a Fellow of Trinity College, who had died so young, leaving behind a series of intuitive mathematical theorems that intrigued the world of mathematics for the succeeding generation. He spent much time in preparing his presidential address for the occasion. This address contains two passages that are significant in the present context:

"It is imperative that the universities of India should be in a position not only to give sound theoretical and practical instruction in the various branches of science but,

what is more difficult, to select from the main body of scientific students those who are to be trained in the methods of research. It is from this relatively small group that we may expect to obtain the future leaders of research both for the universities and for the general research organisations. . . . This is a case where quality is more important than quantity, for experience has shown that the progress of science depends in no small degree on the emergence of men of outstanding capacity for scientific investigation and for stimulating and directing the work of others along fruitful lines. Leaders of this type are rare, but are essential for the success of research organisation. With inefficient leadership, it is as easy to waste money in research as in other branches of human activity. . . ."

Speaking of artificial radioactivity:

"As Fermi and his colleagues have shown, neutrons and particularly slow neutrons are extraordinarily effective in the formation of such radioactive bodies. On account of the absence of charge, the neutron enters freely into the nuclear structure of even the heaviest element and in many cases causes its transmutation. For example, a number of these radio-elements are produced when the heaviest two elements, uranium and thorium, are bombarded by slow neutrons. In the case of uranium, as Hahn and Meitner have shown, the radioactive bodies so formed break up in a succession of stages like the natural radioactive bodies, and give rise to a number of transuranic elements of higher atomic number than uranium (92). These radioactive elements have the chemical properties to be expected from the higher homologues of rhenium, osmium and iridium of atomic numbers 93, 94 and 95."

Rutherford's death

Rutherford was not destined to go to India. He had suffered for years from an umbilical hernia, to relieve which he wore a truss. On 14 Oct. 1937 he became unwell, and was sick enough in the night to be removed from his

home to a hospital next afternoon. An operation for Richter's hernia was performed at once, and the outlook appeared good. However, normal bowel movement was never reestablished, and despite the efforts of his physicians, he died of intestinal paralysis and intoxication on 19 Oct. His great wish at the onset of his illness was to be well in time to fulfil his presidential task in India.

Cockcroft and I were in Italy, at the Galvani Celebrations when news of Rutherford's death reached us. We were very upset and sad. At the morning meeting on 20 Oct., before we left to return to England, Bohr, Rutherford's older student and colleague, who loved Rutherford as we did, spoke movingly of the great man. Afterwards, on 20 Dec., he wrote to Lawrence thanking him for the many kindnesses shown him, Mrs Bohr, and their son, on his recent visit to the Radiation Laboratory, and for his great help in the construction of the cyclotron in Copenhagen. His letter ended:

"When in spite of all this I have not written long before, it has, however, not least been due to the very sudden death of Rutherford which has caused, as you understand, so great upset among his friends. Only a few weeks before I attended his unforgettable dignified funeral in Westminster Abbey, I had visited him in Cambridge where he was as cheerful and enthusiastic over his work as ever. In some way it was the most beautiful end of his marvellous life, but at the same time it makes the feeling of loss ever so acute. Still, I know that the thought of Rutherford will be to you as to myself a lasting source of encouragement and inspiration and will be a close bond between all of us who admired and loved him."

To this Lawrence replied:

"Lord Rutherford's sudden passing . . . was a great shock and your remarks in your letter, which I appreciated so much, are very true. It is sad that Lord Rutherford could not have lived longer, but on the other hand we may rejoice in the memory of his great life. . . ."

"These tragic events remind one that life is short and uncertain and that time is not to be wasted. I often think that, (perhaps more so now because of my mother's serious illness) that we know really so little about the biological processes, and we physicists should not pass by any opportunities to be of help in biological research, although perhaps our first inclination would be to devote ourselves to fundamental physical problems."

What happened to the neutron

Rutherford had predicted the existence of the neutron in his Bakerian Lecture to the Royal Society in June 1920. During the following years, sometimes with the aid of research students, he and Chadwick searched diligently for the particle which both were convinced was essential in the structure of the nucleus. Many experiments were made, and James Chadwick has given a charming personal account of these.² The elusive neutral particle was discovered by Chadwick in 1932, and its effectiveness as an agent producing nuclear transformations was established soon afterwards by Fermi and others. Rutherford was intrigued by the properties of the neutron, and in his last lecture, read posthumously by James Jeans at the joint congress in India, the passage that I have quoted shows how interested he was in the production by neutrons, in collision with uranium, of the transuranic elements of higher atomic number than any existing naturally on earth. He did not live to experience the excitement created by the discovery by Hahn and Strassmann in 1938, of the fission process, or the beautiful work of Otto Frisch and Lise Meitner, which established clearly that the uranium nucleus could indeed split into two parts when it absorbed a neutron. On 9 Feb. 1939 Lawrence wrote to Cockcroft: "We are having right now a considerable flurry of excitement following Hahn's announcement of the splitting of uranium."

He went on to say that within a day of reading about it in the newspapers, they had observed the heavy ionizing fragments produced in the fission of uranium, and had identified

several radioactive species among them by chemical methods.

"We are trying to find out whether neutrons are generally given off in the splitting of uranium, and if so, prospects for useful nuclear energy become very real."

Lawrence was one of the few in the United States who rapidly appreciated the profound significance of the discovery of the fission process. In England the possibility that it had military significance was more quickly realized in particular by Frisch and Rudolf Peierls, and by Chadwick, who showed independently that a fast-neutron fission chain process in the uranium isotope of mass 235, leading to a super-explosion, was possible. In 1941 when I visited Lawrence again, the magnet for his giant cyclotron was being erected on the new site on a hillside above the campus of the university. We discussed the general problem, and in particular the methods that we had been considering in Britain for the separation of the isotopes of uranium. He was deeply impressed by the serious view of scientists in England that nuclear weapons were not only almost certainly possible, but that Germany might be working on the problem. Soon afterwards, he began his experiments upon the separation of the uranium isotope by means of the CALUTRON, a technique which we began to develop independently in my laboratory in Birmingham, using the magnet of the 60-in cyclotron, which was being built with the aid of information generously supplied by Lawrence during and after my visit to Berkeley in 1938. In 1943 this minor effort by us was abandoned in favor of coöperation with Lawrence, and under the arrangements for a joint attack on the problem of nuclear energy, made between the governments of our countries, we moved to Berkeley.

This is not the place to discuss subsequent events, in which Rutherford and his Cavendish Laboratory played no part. If he had lived, he would have rejoiced in the subsequent triumphs of Lawrence and his colleagues in the Radiation Laboratory. But he would have regretted that his nuclear atom had become of such practical importance that the main

motives for the financial support of such work, in all countries, became other than the advance of knowledge of nature.

It was a great privilege to be the pupil and colleague of Rutherford, and to have known, and worked with that other Ernest who so ably took over the torch of nuclear physics from him, and carried it to further heights of achievement. Rutherford, the greater scientist, laid the foundations of modern physics. Lawrence, with his greater flair for technology and organization, showed how to build, on those foundations, the massive edifice of physics today. All who knew and worked with these great men shared deep respect for their genius. But they inspired more than that. The warmth of their natures, their generosity, and their simple, unassuming personalities, generated an abiding love that made our lives fuller and happier.

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The sketch of Rutherford by R. Schwabe is from a copy presented to the author by Lord Rutherford.

The portion of Birge's history of the Berkeley physics department covering the period 1868 to 1932 will be available in mimeograph form (in limited number) within the next few months.

(This is the second of two articles on Ernest Rutherford and Ernest Lawrence. The first appeared in the last issue.)

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Reference

2. J. Chadwick, *Ithaca* 26 VIII, 2 IX (1962).