THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

FOR THE PROMOTION OF THE MECHANIC ARTS

Hall of the Institute,
Philadelphia, January 8, 1947.

Report No. 3173.

Investigating The Work of

Enrico Fermi

of Chicago, Illinois.

THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

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Committee on Science and
the Arts Case No. 3173.

The Franklin Institute of the State of Pennsylvania, acting through its Committee on Science and the Arts, has considered carefully the work of those who have contributed greatly to the advancement of science and to the application of physical science to industry, and has selected as the recipients of the two awards of the Franklin Medal for 1947 -

ENRICO FERMI,
of Chicago, Illinois,

and

ROBERT ROBINSON,
of Oxford, England.

Enrico Fermi

Enrico Fermi was born in Rome, Italy, on September 29, 1901. He was a student at the University of Pisa for four years and then served from 1924 to 1926 as Lecturer in Physics at the University of Florence. In 1927 he became Professor of Theoretical Physics at the University of Rome where he remained until 1938, when increasing political tension drove him to seek residence in the United States. Since 1939 he has been Professor of Physics at Columbia University.

Fermi's contributions to Physics fall into three groups, namely, those of a theoretical physicist, those of an experimental physicist, and those of an engineer. The work which he has done in the character of each of these three types of scientist is of the highest merit and shows him to be possessed of extraordinary ability and of such an uncanny physical intuition that it is often said that Fermi's guesses are better than the careful calculations of most physicists.

1. <u>Theoretical.</u> Among Fermi's contributions to theoretical physics are his papers on such subjects as the entropy constant, the theory of hyperfine structure, the theory of the Raman effect, other problems of atomic and molecular spectroscopy, quantum electrodynamics, and the principles of quantum mechanics including the quantum theory of collisions.

At a very early age he evolved simultaneously with, but independent of, Dirac the new system of statistical mechanics, now known as Fermi-Dirac statistics of a gas of identical particles obeying Pauli's principle, namely, an electron gas. This has proved to be the key to the modern theory of metals.

Our current theory of nuclear structure is based upon two assumptions: 1) that every atomic nucleus consists of neutrons and protons only; 2) that the nucleus possesses quantized energy levels the existence of which has been demonstrated experimentally by the line spectrum of gamma rays. Both assumptions are hard to reconcile with the emission of electrons from the nucleus as beta rays, and the fact that the beta ray spectrum is a continuous one. Fermi has proposed to eliminate these difficulties by assuming: 1) that the electron does not exist in the nucleus but is created in the act of its emission, and this process is associated with the transformation of a neutron into a proton; 2) that the energy thereby released is taken away by a hypothetical particle emitted simultaneously. This particle, called the neutrino, is supposed to have zero electric charge, negligible mass, spin one-half, and Fermi-Dirac statistics. Up to the present time unequivocal experimental proof of its existence has been notably lacking. Nevertheless, the quantitative explanation of the puzzling phenomena of beta disintegration which Fermi's theory provides has opened up new avenues of research the end of which is not yet in sight.

2. Experimental. In experimental physics the name of Fermi is connected primarily with the physics of the neutron. It was for his work in this field that he received the Nobel Prize in Physics in 1938.

Prior to 1932 artificial disintegration had been accomplished by bombarding atomic nuclei with alpha particles from naturally radio-active sources, but early in that year the field was widened by the use of protons and deuterons as atomic projectiles. These were accelerated to high speeds by the newly invented atom-smashing machines. In that same year Chadwick's discovery of the neutron provided a new type of projectile ideally adapted to bring about nuclear disintegration. This is because the forces which arise to prevent the approaching neutron from entering a nucleus are so small that even very slow neutrons, that is those with very low energy, have been found extremely effective in producing such disintegrations.

Fermi immediately grasped the significance of the neutron as an atomic projectile, and between 1932 and 1935 he and his associates bombarded some sixty of the chemical elements with neutrons which produced disintegrations that were true transmutations in about forty cases. M. Joliot and his wife, Mme. Irene Curie, have taken cloud-chamber photographs of such a transmutation (Plate I). The manner in which such transmutations may be conceived to occur is indicated in Plate II.

The neutron is first captured by the bombarded atomic nucleus. This combination is unstable and may emit either a proton, an alpha particle, or a gamma ray leaving behind an intermediate nucleus which is frequently radioactive with the emission of a beta ray (electron). Whenever this happens the atomic number of the final stable nucleus is one unit greater than that of the intermediate nucleus. Thus it often happens that bombardment by neutrons may result in transmuting the atoms of a given element into those of the one next higher in the table of atomic weights.

This led Fermi, as early as 1934, to wonder whether bombardment by neutrons of the heaviest known element, uranium of atomic number 92, might result in the formation of a radioactive isotope which would decay by the emission of a beta ray, thereby forming an element of atomic number 93. If by chance this element should also be radioactive and should disintegrate by the same process an element of still higher atomic number would be formed.

Experiments by Fermi and his associates quickly revealed that the bombardment of uranium by neutrons does result in one or more radioactive products which emit beta rays. These products were observed to have several half-life periods which were interpreted as indications of the formation of elements of atomic number 93, 94, 95 and 96. Similar results were obtained from the neutron bombardment of thorium, of atomic number 90.

However, in 1939, while Hahn and Strassmann were working on this same problem, namely the production of transuranic elements, they obtained definite evidence that certain of these products of supposed atomic number higher than 92 were in reality isotopes of barium, with atomic number only 56. This was something entirely new. Never before had there been observed a particle more massive than the alpha particle (helium nucleus) torn from any atomic nucleus. However, in this case the uranium nucleus was found to be split into two parts of nearly equal weight. This is the phenomenon now called fission. Thus although Fermi missed discovering fission himself through an incorrect interpretation of his results, it was his brilliant experimental work that led Hahn and Strassmann to take the final step which resulted in their epoch-making discovery. Since then element 93, called neptunium, and element 94, called plutonium, have both been produced by exactly the method used by Fermi, namely, neutron bombardment of uranium 238 followed by beta ray emission. By a slightly different method elements 95 and 96, called respectively americium and curium, have been produced very recently. Thus Fermi's original concept of the production of transuranic elements has been brilliantly verified.

3. <u>Engineering.</u> Soon after the discovery of fission three other facts were brought to light: 1) that of the three isotopes of uranium it is only the one of atomic weight 235 that disintegrates in this manner under bombardment of slow neutrons; 2) that each fission of a uranium nucleus is accompanied by the

emission of one to three neutrons, each capable of bringing about another fission; 3) that neutron bombardment of plutonium also results in fission plus neutron emission. Hence there is the possibility of setting off a chain reaction, under just the right conditions, causing the sudden release of vast amounts of energy by pyramiding the disintegrations of atoms of either uranium 235 or plutonium 239 (Plate III). Fermi's supervision of the design and the construction of the first nuclear chain-reacting pile, which makes use of this principle, must be regarded as an engineering accomplishment of the highest order; but it is only one of many vital contributions that he made to the atomic energy project.

In recognition of his brilliant contributions to both theoretical and experimental physics, and of his skill in combining theory with experiment so as to open up a vast new field of research in which practical use may be made of the energy stored in the nuclei of certain kinds of very heavy atoms, THE FRANKLIN INSTITUTE awards its FRANKLIN MEDAL to ENRICO FERMI, Institute of Nuclear Research, University of Chicago, Chicago, Illinois.

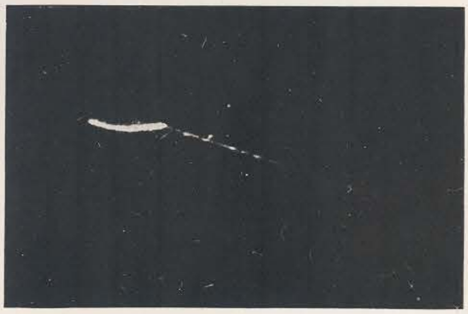
Richard T Nalle
....
President.

Henry B. Allen
....
Secretary.

....
Chairman of the Committee on Science
and the Arts.

(*a*) A neutron entering the chamber from below traverses a plate of paraffin extending across the lower part and ejects from it a proton (H^1) which shoots clear across the chamber.

(*b*) The chamber is here filled with helium. A neutron entering from below collides with a He nucleus four times its own mass and can only impart to it a range of about 5 mm.



(*c*) The neutron here causes the transmutation of a nitrogen nucleus which it enters and by so doing occasions the ejection of an α particle while the heavy short trajectory reveals the recoil of the remainder of the nucleus. The pressure was here low and the magnification large.

FIG. 70.—Photographs of the effects of the collision of neutrons with the atoms of hydrogen (*a*), helium (*b*), and nitrogen (*c*) (after Curie-Joliot).

Plate 1. S. & A. Case No. 3173.

PLATE I.

$${}_1H^1 + {}_0n^1 \rightarrow {}_1H^2 + h\nu \qquad (1)$$

$${}_3Li^6 + {}_0n^1 \rightarrow {}_1H^3 + {}_2He^4 \qquad (2)$$

$${}_1H^3 \rightarrow {}_2He^3 + \beta^- \qquad T = 31 \text{ yr.}$$

$${}_4Be^9 + {}_0n^1 \rightarrow {}_2He^6 + {}_2He^4 \qquad (3)$$

$${}_2He^6 \rightarrow {}_3Li^6 + \beta^- \qquad T = 0.8 \text{ sec.}$$

$${}_5B^{10} + {}_0n^1 \rightarrow {}_3Li^7 + {}_2He^4 \qquad (4)$$

$${}_{11}Na^{23} + {}_0n^1 \rightarrow {}_9F^{20} + {}_2He^4 \qquad (5)$$

$${}_9F^{20} \rightarrow {}_{10}Ne^{20} + \beta^- \qquad T = 12 \text{ sec.}$$

$${}_{12}Mg^{24} + {}_0n^1 \rightarrow {}_{11}Na^{24} + {}_1H^1 \qquad (6)$$

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$${}_{13}Al^{27} + {}_0n^1 \rightarrow {}_{13}Al^{28} + h\nu \qquad (9)$$

$${}_{13}Al^{28} \rightarrow {}_{14}Si^{28} + \beta^- \qquad T = 2.4 \text{ min.}$$

$${}_{19}K^{39} + {}_0n^1 \rightarrow {}_{19}K^{38} + {}_0n^1 + {}_0n^1 \qquad (10)$$

$${}_{19}K^{38} \rightarrow {}_{18}A^{38} + \beta^+ \qquad T = 7.7 \text{ min.}$$

$${}_{29}Cu^{63} + {}_0n^1 \rightarrow {}_{29}Cu^{62} + {}_0n^1 + {}_0n^1 \qquad (11)$$

$${}_{29}Cu^{62} \rightarrow {}_{28}Ni^{62} + \beta^+ \qquad T = 10.5 \text{ min.}$$

$${}_{29}Cu^{65} + {}_0n^1 \rightarrow {}_{29}Cu^{66} + h\nu \qquad (12)$$

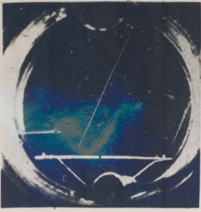
$${}_{29}Cu^{66} \rightarrow {}_{30}Zn^{66} + \beta^- \qquad T = 5 \text{ min.}$$

$${}_{79}Au^{197} + {}_0n^1 \rightarrow {}_{79}Au^{198} + h\nu \qquad (13)$$

$${}_{79}Au^{198} \rightarrow {}_{80}Hg^{198} + \beta^- \qquad T = 2.7 \text{ da.}$$

Plate 2. S. & A. Case No. 3173.

PLATE II.



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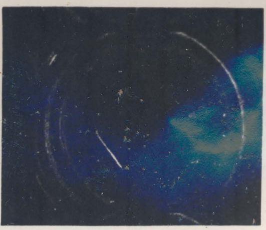

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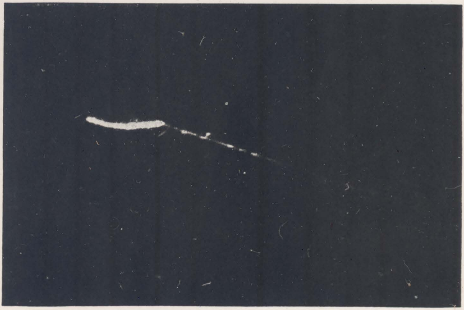

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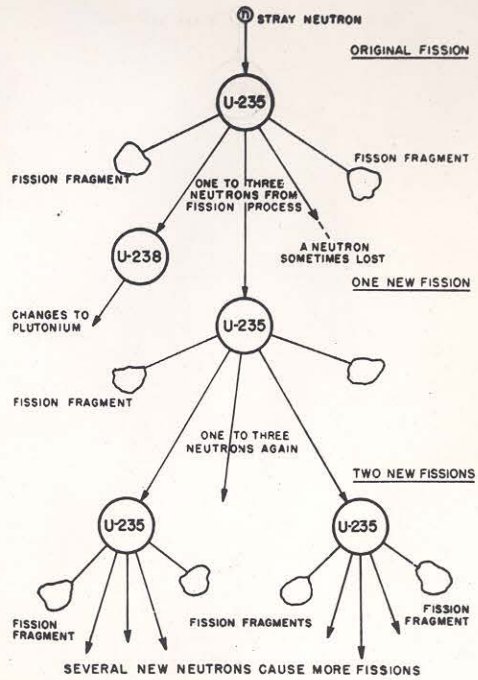
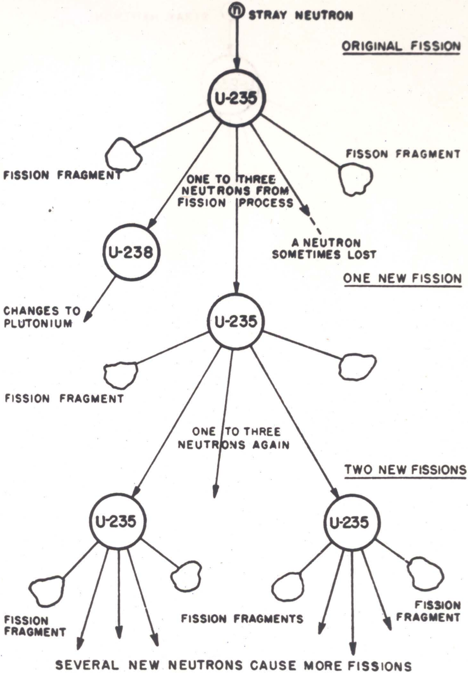


SCHEMATIC DIAGRAM OF CHAIN REACTION FROM FISSION,NEGLECTING EFFECT OF NEUTRON SPEED. IN AN EXPLOSIVE REACTION THE NUMBER OF NEUTRONS MULTIPLIES INDEFINITELY. IN A CONTROLLED REACTION THE NUMBER OF NEUTRONS BUILDS UP TO A CERTAIN LEVEL AND THEN REMAINS CONSTANT.

Plate 3. S. & A. Case No. 3173.

PLATE III.



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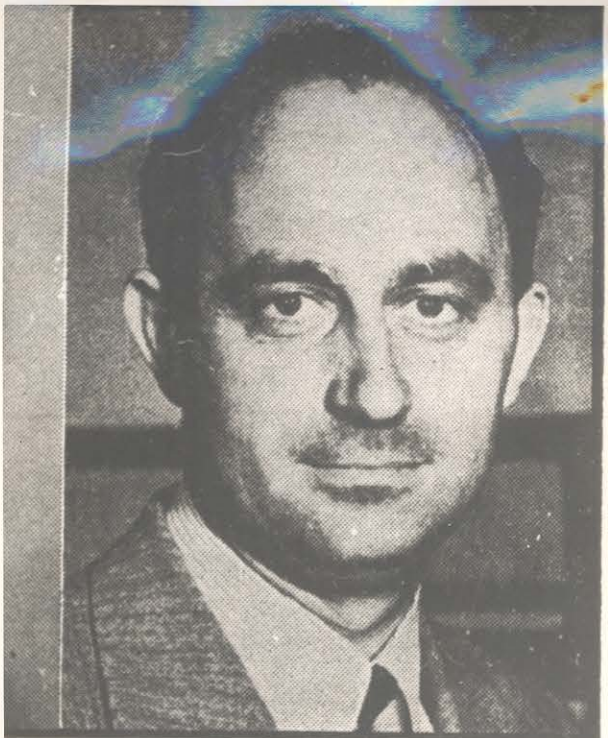

Eric Schaal-Pix, Wide World, Acme
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S. & A. Case No. 3173.

PLATE IV.

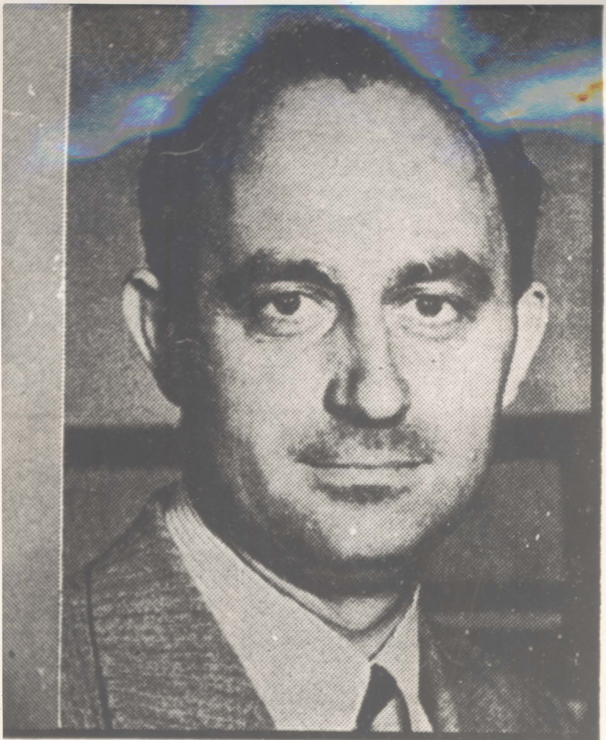

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Plate 2. S. & A. Case No. 3173.

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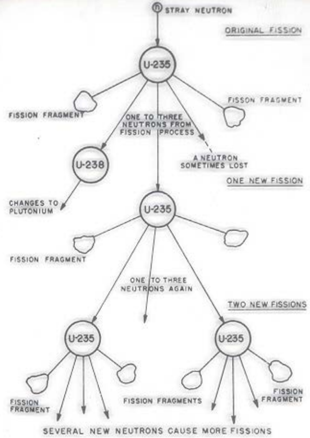

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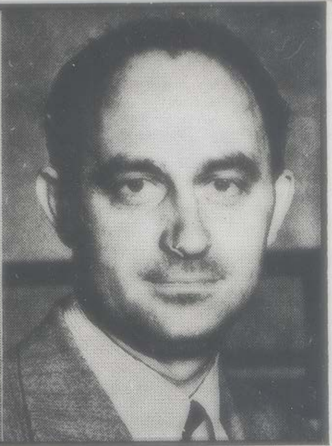

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