Wetmore, assistant secretary of the Smithsonian Institution, secretary general of the congress and secretary of the organizing committee; Dr. Frank B. Jewett, president, National Academy of Sciences, chairman of the advisory committee; Mr. Roland S. Morris, president, American Philosophical Society, vice-chairman of the advisory committee; Mr. Clarke L. Willard, Division of International Conferences, Department of State, executive secretary of the congress and assistant secretary of the organizing committee; Mr. Michael J. McDermott, chief, Division of Current Information, Department of State, public relations director of the congress; Mr. Henry Charles Spruks, Protocol Division, Department of State, ceremonial officer of the congress; and Dr. André C. Simonpietri, executive assistant to the secretary general.

The congress was adjourned with the same note of uneasiness and apprehension with which it had been opened by President Roosevelt. In his farewell address President Welles said:

You scientists have been free to seek the truth for the sake of that truth. You have been free to use your great powers without hindrance. You have been free to publish the results of your quiet study in your laboratories, or your often hazardous observations, sometimes at the far ends of the earth, without fear that because these results might differ from accepted concepts, you, and even your families, would be subjected to the control and the oppression of the state.

The suppression in some parts of the world to-day of the right of free inquiry, and the endeavor to control the thoughts of men, is therefore of intimate concern, not only to all scientists but likewise to all persons who believe that science has within its grasp the capacity to remedy in great part the ills of our present civilization. We can not but speculate whether, in those parts of the world where free inquiry is no longer possible, there will not be, at least in so far as the things of the mind and the spirit are concerned, a return to the Dark Ages. What hope is there for future generations in countries where the state by fiat has declared that all persons must believe glaring distortions of the truth; where evil is declared to be good; where falsehood is paraded as the truth; and where aggression, pure and simple, is represented as self-defense? . . .

I believe—as firmly as I believe that the sun will rise once more tomorrow—that the present menace to civilization will pass and that the day will come when the now destructive forces of evil which men themselves have created will be vanquished. I believe that mankind will again be afforded opportunity to lay the foundations of a better world—a world in which freedom from fear will be established for all mankind and the right of every person to worship God, to think, to speak, to know the truth and to search for the truth will be made sure.

NUCLEAR FISSION[1]

By Dr. KARL K. DARROW

BELL TELEPHONE LABORATORIES

Some time this summer the art of transmutation will come to its majority; that is to say, twenty-one years will have passed since the day it was born in Rutherford's laboratory. Infancy and adolescence for this art have been marked by more stages than we generally count for human children; I propose to distinguish six. Here follows a table of six great events in the story of transmutation, beginning with birth and ending with fission, which, by the way, bears a name that in biology means a certain sort of birth. Each of them lifted the art to a higher level with a broader scope. It is only the sixth and latest which is my topic, but all the others lead up to it, as I will show immediately with the table for my text.

Table of great events in history of transmutation

1919 First success with helium nuclei (energy of activation derived from radium, etc.).

1932 First success with hydrogen nuclei (energy of activation derived from voltage).

1932 Recognition of the liberated neutron.

1934 Recognition of radioactive bodies resulting from transmutation.

1934 Slow neutrons used to produce transmutation, this resulting in radioactive bodies.

1939 Recognition of fission.

Be it said that in general, transmutation takes place when two nuclei meet and enter into a reaction with each other. They are made to meet by projecting one against the other, and accordingly we speak of one as the projectile and of the other as the target. Transmutation does not occur whenever a projectile comes into the neighborhood of a target nucleus, but only on rare occasions which I will call "lucky hits." There are four principal kinds of projectiles in use for transmutation: helium nuclei—hydrogen nuclei of two sorts, the light and the heavy—and neutrons. Three stages of my chronology have been marked with their names. The phenomena of fission are produced with neutrons as the projectiles and uranium[2] as the target, and they therefore belong in the fifth stage of the chronology. But they also depend on the first and the second stages, for neutrons are always obtained by

[1] Delivered before the National Academy of Sciences at its Washington meeting, April 23, 1940.

[2] The lecture was confined to the fission of uranium by slow neutrons. "Fast" neutrons (of energies amounting to a million or millions of electron-volts) produce fission of a different isotope of uranium, and also of thorium and of protactinium.

bombarding various targets with projectiles of the first three kinds; and of course they depend on the third, because if the neutron had not been recognized it would hardly now be in use as a tool. Moreover, they depend upon the fourth; the phenomena of fission were first detected because the new-born elements resulting from it are radioactive, and to this day they are often though not always observed through this radioactivity. Next it will be noticed that instead of putting fission into the fifth stage, I gave it a line and a stage to itself, and said "recognition of fission" instead of "discovery of fission." This was not in order to compose a three-word poem, but because the phenomena were detected about four years before they were properly analyzed; a strange and interesting story, for which, however, there is not space.

Now I make final use of the table in speaking about energy. Every one has heard so much about the gigantic energies and the huge voltages required for transmutation, that any one may be pardoned for thinking that transmutation is a process which swallows up enormous quantities of energy—which is strongly endothermic, to use the chemical word. Well, there are many transmutations that swallow energy up without restoring it, but many of them give back much more than they receive. I mean by this simply, that whenever a projectile makes a "lucky" hit on a target the total energy of motion of the new-born nuclei is greater than that of the projectile. On balance the experimenter does spend much more energy than is released, because of the amount which he is obliged to squander on projectiles which never make lucky hits; but if one considers only those which do transmute, then their energy may well be smaller and even very much smaller than that which appears on the new-born nuclei. This is what I mean to suggest by using the name "energy of activation" for the energy which hydrogen or helium nuclei must have, in order to make them efficient projectiles. It is, however, the *release of energy* which is one of the spectacular features of fission.

This release of energy is indeed amazing. When the process occurs in any single nucleus *there is released*—in the form of kinetic energy of the new-born particles—*the appalling amount of 175,000,000 electron-volts*. To get a notion of what this figure means, remember that in the synthesis of hydrogen and oxygen into water—perhaps the most terrific explosion of all of chemistry—there is released between two and three electron-volts for each pair of reacting molecules; and in the notorious explosives of industry and war, such as TNT and nitroglycerine, not even so much as that.

Now I have said that fission occurs when a slow neutron impinges on a uranium nucleus, and that an enormous amount of energy is released, and that the resulting new-born elements are radioactive; but I have not yet said what these new-born elements are. This is the second of the astonishing features of fission. All other transmutations have resulted in changing the target element to some other not more than two steps away from it in the Periodic Table of the elements. In this Periodic Table, uranium stands at the ninety-second and last place; but the no fewer than sixteen different elements thus far identified among the "fission-products" (as they are called) stand in places ranging from the thirty-third to the fifty-seventh! What happens in fission is therefore something never before observed—the division of a massive nucleus into two nearly equal fragments. In ordinary transmutations of heavy nuclei, a particle small in both charge and mass pops into a nucleus, and another particle small in charge and mass pops out. In this kind of transmutation a particle of small mass and no charge at all wanders into a uranium nucleus, and the nucleus promptly bursts apart into two pieces not exactly alike indeed but not very different from one another. Fission in biology is the division of a cell into two which are very much alike in size, and this is the source of the name.

As for the fact that fission results in so many different types of nucleus instead of just two, that probably has a double meaning. Many of the radioactive bodies which are observed during and after fission are clearly not the original fragments of the explosions, for after the neutron-influx is suspended they increase for a while in amount instead of diminishing. It is clear that these are descendants of the original fission fragments, and the question as to which are really the original ones is at present a very live one. Theory suggests that the initial fragment-pair need not always be the same. One nucleus, on being entered by a neutron, may burst into barium and krypton, another into xenon and strontium, another perhaps into caesium and rubidium. (Note that the members of these element-pairs are so chosen that their atomic numbers add up to 92, which is a way of saying that the entire positive charge of the uranium nucleus must be found upon the two initial fragments immediately after the explosion.) Whatever the initial fragment-pair may be, one at least of its members must be the parent of a long chain of radioactive bodies, and probably both are. This sufficiently accounts for the fact that the fission-process produces radioactive elements in a profusion and variety beyond any other which is known.

I have saved the most sensational item for the last. Not only is fission caused by slow neutrons, but it produces fresh neutrons among its many products. Could these fresh neutrons produce fission in their turn? Presumably they could; we know of nothing to differentiate them from other neutrons. Could they produce new fissions and these in turn new fissions and so onward in geometrical progression, so that a whole massive piece of uranium might blow up in a sudden explosion of unparalleled fury touched off by so seemingly innocent an event as the entry of a single neutron?

This is perhaps the most important of the unsolved questions of physics. Let us begin by asking after a certain necessary though not sufficient condition. The fissions can not proceed in geometrical progression, the explosion of the whole mass can not occur, unless each fission results (on the average) in more than one free neutron to replace the one neutron which is consumed in producing it. Is this so? Well, the few people whose opinions are worth taking agree that it is. They do not agree well as to how many fresh neutrons there are over and above *one,* but they do agree that there is an excess.

With this as a basis, let us turn the question around. Why has not the great explosion happened as yet, since there are neutrons enough to achieve it?

One reason apparently is, that the fresh neutrons are moving with the wrong speeds when they are released. Fission is performed mainly by very slow neutrons, while the new-born ones are very rapid. But if the piece of uranium were very large, even the fresh neutrons would be slowed down by their repeated collisions with nuclei; and therefore those who are trying to make the explosion, or trying to approach it without quite making it, are heaping up great masses of uranium. If, however, the uranium is mixed with other elements—as in nature it always has been—the neutrons are liable to be captured and rendered harmless by the nuclei of these others. Therefore, the next step is to purify the uranium. This would be easy enough were it not that "purity" in this connection means something more stringent than even chemical purity. Within the last few weeks it has been proved that only one isotope of uranium is sensitive to slow neutrons, and this is a rare one—fortunately, I feel like saying. One must perform a process of isotope-separation in which the two isotopes differ in mass by less than two per cent., and one is more than a hundred times as abundant as the other. Probably this will take a long time in the doing. If and when it is done, shall we find that human artifice has succeeded in removing or relaxing the last brake provided by nature to impede the slide toward catastrophe? Perhaps not even then, for the rare isotope of uranium may have ways of its own for capturing neutrons and rendering them harmless before the most of them achieve fissions. Perhaps on the other hand the brakes are easier to relax than the foregoing words imply. Possibly they can be relaxed just a little without letting go altogether, and then there may be available a potent source of power. But at this point I depart from the traditional detachment of the scientist, and express the fervent hope that the mastery of this process, if ever to be achieved at all, will not be achieved until the world is ready to use it wisely.

SCIENTIFIC EVENTS

EXHIBITS IN THE GEOLOGICAL SCIENCES AT THE CALIFORNIA INSTITUTE OF TECHNOLOGY

Two interesting and important exhibits have recently been given on indefinite loan to the museum of the Division of the Geological Sciences of the California Institute of Technology in Pasadena.

The Kettleman North Dome Association has presented three large models, constructed by Martin Van Couvering, consulting petroleum engineer of Los Angeles. These models[1] served as a part of the exhibit of the defendants, the Kettleman North Dome Association, in one of the most important lawsuits ever tried in the state of California. The trial was concluded in 1938, and subsequently the models were on display at the Golden Gate Exposition of 1939.

One model (about 16 feet long and 6 feet high) shows, on a scale of 500 feet to the inch, all the wells in the Kettleman Hills field by means of steel pegs, on which the different formations encountered are distinctively colored. Another exhibit makes possible the correlation of the areal geologic map (on a scale of 1,000 feet to the inch) with a structural relief model. The third case (also on a scale of 1,000 feet to the inch) consists of a wooden relief model of the dome, in which by the removal of separable segments, subsurface structure can be revealed along various cross-sections.

The other exhibit has been made available by the Metropolitan Water District of Southern California, through F. E. Weymouth, general manager and chief engineer. This consists of three display cases containing some 175 specimens, principally rocks, but including minerals and fossils, assembled largely by L. H. Henderson, resident geologist for the district. Several of the diamond drill cores, taken in connection with the location of the San Jacinto tunnel,[2] are included in the exhibit. The collection constitutes a valuable record of the different lithologic types encountered in the drilling of the ninety-two miles of tunnels of the Metropolitan Water District's Colorado River aqueduct.

1 John H. Maxson, *Am. Asn. Petrol. Geol., Bull.* 24, 740–741, 1940.

2 L. H. Henderson, *Jour. Geol.*, 47: 314–324, 1939.