the Mössbauer effect be used to check the gravitational red shift and (ii) that iron-57, along with zinc-67, should furnish even sharper lines than Mössbauer's iridium-191. Shortly before this, one member of the Argonne group, J. P. Schiffer, went as a John Simon Guggenheim fellow to the British Atomic Energy Research Establishment at Harwell, and in the 15 December issue of *Physical Review Letters* two letters appeared, both received on 23 November, one from Schiffer and W. Marshall at Harwell and the other, a new note from Pound and Rebka. Both letters discussed experiments with iron-57, and Pound and Rebka produced actual curves showing the line width (Fig. 2) and the hyperfine structure. The 15 January issue also had two notes describing work on iron-57; one, by the University of Illinois group, included a hyperfine structure curve matching Pound and Rebka's, and the other, by the Argonne group, demonstrated polarization of the gamma radiation.

In the 15 February issue, Cranshaw, Shiffer, and Whitehead of Harwell published their conclusions on the gravitational red shift, with the rather large uncertainty of 0.96 ± 0.45 times the expected red shift. Another Harwell group reported in the same issue their measurements of the red shift in an accelerated system. The race, if one could call it that, appeared to be over, with Harwell (and Schiffer) the uncontested winner, when, to everyone's consternation, the 15 March issue appeared carrying the letter by Pound and Rebka which pointed out the strong frequency dependence on temperature of the iron-57 rays, as determined by theory and experiment. This letter had been submitted before the Cranshaw letter appeared in print, so no comment was made on the Harwell results. The reader, however, could readily recognize the importance of this parameter, and the Harwell letter was thereby placed under a cloud. Did the gravitational effect really exist or did it not?

What is probably the final chapter was the publication of Pound and Rebka's gravitational results in the 1 April issue of *Physical Review Letters* (*6*). It removed all doubt concerning the existence and extent of the gravitational red shift, the results matching the theoretical expectations by a factor of 1.05 ± 0.10. Fortuitously, a letter from B. D. Josephson at Trinity College, Cambridge, in the same issue (referring to the Harwell letter and to Pound and Rebka's earlier suggestions) pointed out the definite necessity of taking into account the dependence of frequency on temperature in such experiments.

The Future

Apparently one important relativity question is now settled, and scientists will be searching for other experiments which can capitalize on this very precisely defined electromagnetic frequency. Surely there will soon be practical applications of this narrow line. Pound and Rebka pointed out that at 10 cycles per second, the 0.017 cm/sec velocity which was equivalent to a half-line width corresponds to a peak-to-peak amplitude of 0.0009 centimeters. Were the source to be vibrated at, say, 1 megacycle per second, a velocity of 0.017 centimeter per second would correspond to a peak-to-peak amplitude of 9×10^{-9} centimeter (less than twice the radius of the hydrogen atom). Velocity- and distance-measuring methods of the future may well be based on this interesting new discovery.

Whether the actual electromagnetic frequency itself can be used as a stable source of frequency for subharmonic scaling circuits or for comparison with quartz clock oscillators remains an open question. Suffice it to say that much thought will be given to finding ways of utilizing the remarkable stability of the Mössbauer radiation in this way.

Nuclear experiments in this field will also continue, and through the results of these experiments more will be learned about the properties of matter and the solid state (*7*). Unquestionably, the Mössbauer effect has provided the experimental physicist with a powerful tool for the exploration of many of the remaining secrets of atomic physics (*8*).

References and Notes

1. R. L. Mössbauer, *Z. Physik* **151**, 124 (1958). In this article Mössbauer credits H. Maier-Leibnitz with having suggested the original experiment.
2. R. V. Pound and G. A. Rebka, Jr., *Phys. Rev. Letters* **3**, 554 (1959).
3. I am indebted to Dr. Pound for this quoted interpretation (personal communication).
4. R. V. Pound and G. A. Rebka, Jr., *Phys. Rev. Letters* **3**, 439 (1959).
5. T. E. Cranshaw, J. P. Schiffer, A. B. Whitehead, *ibid.* **4**, 163 (1960).
6. R. V. Pound and G. A. Rebka, Jr., *ibid.* **4**, 337 (1960).
7. Five additional letters on the Mössbauer effect appeared in the 15 April issue of *Physical Review Letters*, after this article was written.
8. I am indebted to Dr. Pound and to Dr. S. A. Goudsmit for helpful discussions on this subject.

Donald J. Hughes, Nuclear Physicist

Donald J. Hughes, who died on 12 April at the age of 45, was a scientist who had played a unique role in the development of the field of neutron physics. Not only have his own researches yielded results of first importance and opened up new avenues of endeavor toward a basic understanding of many aspects of nuclear physics, but as a central driving force Donald Hughes had been the main factor responsible for the collation and unification of most of the information related to the interactions of neutrons with matter. In his extensive contacts with practically all of the neutron scientists of the world he had been instrumental in stimulating a tremendous amount of vital new research; furthermore, he had been one of the main U.S. scientific ambassadors responsible for our fruitful international relationships in the field of neutron physics and nuclear science in general. A most significant aspect of Hughes' work has been the fact that many of his various researches in fundamental neutron physics have led to almost immediate practical uses and are of major significance to reactor technology. Hughes was an eminent and respected member of the scientific community. He showed a deep interest in the broader implications of his science. He was one of the signers of the famous Franck report, through which it was hoped to prevent the use of the first atomic bomb, and in 1955 to 1956 he was chairman of the Federation of American Scientists. The following chronological account of Hughes' accomplishments, while not complete, will give some idea of his various and important contributions to "the broad field of atomic endeavor."

Born in Chicago in 1915, Donald J. Hughes studied at the University of Chicago and obtained his Ph.D. in physics from the same institution in 1940. His Ph.D. research was in the field of cosmic rays, and as a result he became a member of a cosmic ray expedition led by A. H. Compton to South America in 1941. He remained at Chicago as an instructor in the physics department until the U.S. Navy called him to direct a section on underwater ordnance research at the Naval Ordnance Laboratory in Washington in 1942. Until 1943 he remained at the Naval Ordnance Laboratory, working with mine and torpedo detectors, except for a period spent with the British ordnance at Edinburgh, Scotland.

Early in 1943 Hughes joined the Manhattan Project at the University of Chicago at the time the first pile was starting operation. He performed classified pile neutron research, spending one year (1944) at Hanford, Washington, at the time when the large chain-reacting piles for production of plutonium were put in operation.

In 1945 he returned to Chicago and became director of the Nuclear Physics Division of Argonne National Laboratory. Here Hughes and his collaborators developed a method for measuring fast neutron cross sections that became the basis of G. Gamow's theory of the origin of the elements and that was also applied to the design of fast neutron breeder reactors, such as the experimental breeder reactor now in operation at Arco, Idaho.

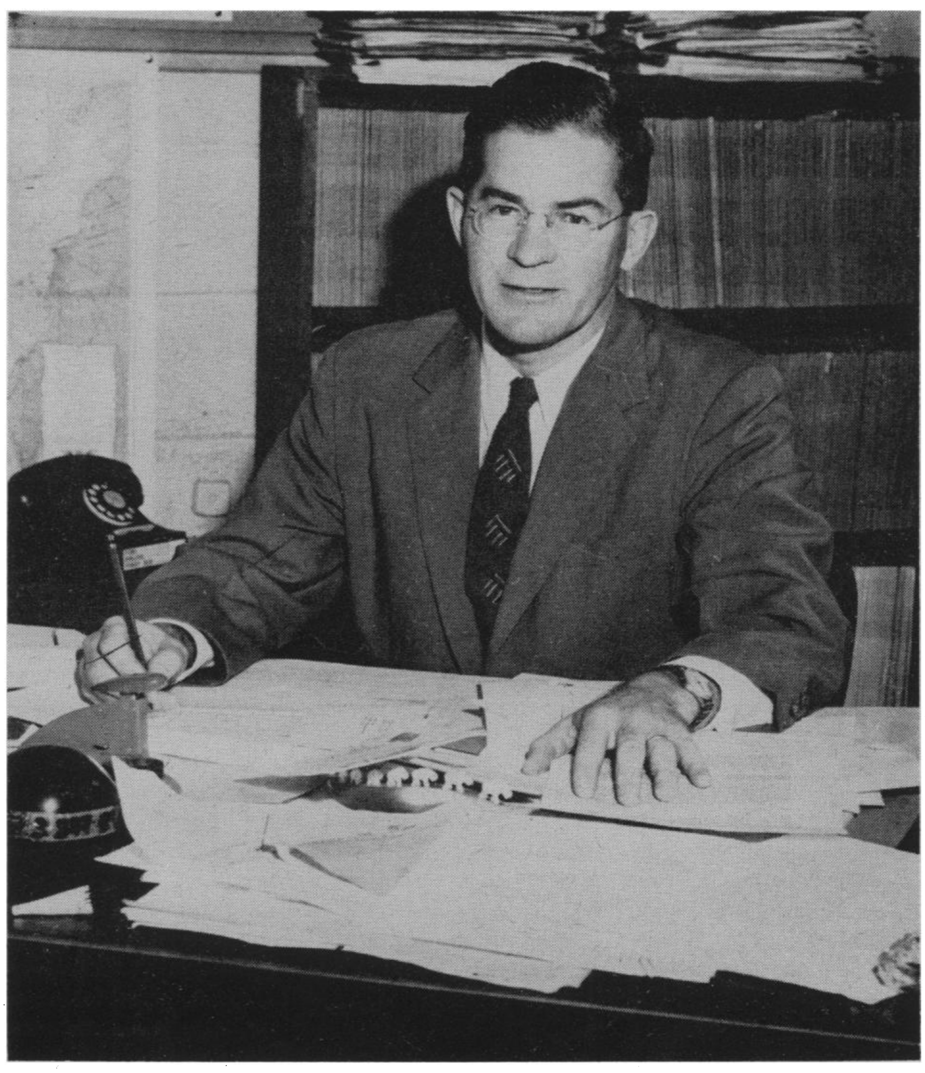
Hughes left Argonne in 1949 to become a senior physicist in charge of a pile neutron research group at Brookhaven National Laboratory. Here he and his group developed several new techniques which made possible extensive new studies in the field of neutron physics. One of these developments was the use of neutron "mirrors." This mirror reflection of neutrons was used by Hughes to make very significant studies of the character of the neutron-electron interaction, which had important bearing on modern meson theory. His group also developed the "fast chopper" device which greatly extended the energy range of accurate neutron cross section measurements. In addition to being effectively used by Hughes' group at Brookhaven, the fast chopper technique has now been adopted by most reactor neutron physics laboratories throughout the world.

His more recent work involved the utilization of "cold" neutrons to obtain information about the motions of atoms in crystals, which had hitherto been impossible to detect with available techniques.

At a very early stage in his neutron studies Hughes realized the importance of collating and unifying information on nuclear cross sections. His systematic collation of this type of data was started in Brookhaven around 1950. This collation of data, which has grown in magnitude with the years, has been the standard source of information for both basic research and many aspects of applied reactor technology. A published version of the cross section compilation, called *Neutron Cross Sections*, was distributed at the first atoms-for-peace conference in Geneva in August 1955. The second, completely revised, edition of this work was completed by 1958 and has received wide international distribution. In connection with his extensive interest in and knowledge of nuclear cross sections, Hughes served as a member and chairman of the Nuclear Cross Section Advisory Committee of the Atomic Energy Commission.

As one of the foremost experts in neutron physics, Hughes traveled widely to contact research groups in various parts of the world. Much of this travel was in connection with the neutron cross section compilation. Furthermore, he served as a lecturer for the U.S. Information Service during the period 1954 to 1956. In this capacity he lectured in Denmark, England, Finland, Germany, and the Netherlands.

He was one of the two American



Donald J. Hughes, at his desk at Brookhaven National Laboratory.

members appointed by the International Council of Scientific Unions to the Committee to Consider the Complications of Contamination of the Moon and Planets by Extraterrestrial Exploration (CETEX). Hughes participated in both the 1955 and the 1958 International Conferences on the Peaceful Uses of Atomic Energy as one of the representatives from the United States. Upon request of the secretary general of the conference, he presented papers reviewing the most recent worldwide nuclear data of technical importance.

In all of these international activities, Hughes established important contacts in many countries and was instrumental in developing a free flow of information between the United States and the rest of the international scientific community.

Hughes had been active as a teacher and a writer. He was a Fulbright professor at Oxford University in England from 1953 to 1954. He was the author of a number of books which have become standard works in the field of neutron physics. These include *Pile Neutron Research* (Addison-Wesley, 1953), *Neutron Optics* (Interscience, 1954), *Neutron Cross Sections* (Pergamon, 1957), and *On Nuclear Energy* (Harvard Univ. Press, 1957). An indication of the scientific value of these books is the fact that *Pile Neutron Research, Neutron Optics*, and *Neutron Cross Sections* have all been translated into Russian by the U.S.S.R. Hughes was also managing editor for a series of books entitled *Progress in Nuclear Energy*, which are published by Pergamon Press in London, and he was a highly valued member of the editorial board of *Science*. His latest book was *The Neutron Story*, which was intended for high school students and the interested general public. During his lifetime Hughes published some 115 papers in scientific journals concerning research with which he was associated.

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Science in the News

Oceanographic Research: Organizing Support for a Fragmented Program

A bill was reported by the Senate Commerce Committee last week authorizing an extensive 10-year program in support of oceanographic research. Hearings on a similar bill are being held in the House. As it happens, many of the agencies interested in oceanography have come out against the form of this particular legislation. Even its sponsors concede that it has no chance of passing this year, although some of the specific proposals may be passed in separate bills. Yet the bills have been the center of considerable interest, if only as symbols of the extent to which this very important but rather obscure branch of science has been brought to the attention of policy-makers in Washington. As a result, even without any formal legislation, spending in this area has been roughly doubled in the past 2 years, and further increases are expected.

When the organized effort to increase federal support for oceanography began about 3 years ago the science faced two especially important obstacles: it was popularly regarded as a field about as far removed from practical affairs as astronomy, and it faced a peculiar organizational problem in that the various elements of oceanographic research were fragmented among a dozen or so different government bureaus and agencies. As a result, although a growing number of people began to recognize that it was in the national interest to develop much enlarged support for the science, the fragments of the program scattered through the Navy, Interior, Commerce, and other departments and agencies tended to be little noticed in the over-all functions of the agencies and in their budget making.

A committee was formed by the National Academy of Sciences–National Research Council to report on the state of the science and to develop a national oceanographic program. This report was issued in mid-1958 and led directly to the formation of a special committee on oceanography in the House, and the formation of an interagency council on oceanography in the executive office of the President. (This council functions under the Federal Council on Science and Technology, which is headed by George Kistiakowsky, the President's science adviser.)

Much use was made of the perhaps illogical but nevertheless quite effective argument these days that the Russians are spending about three times as much on oceanographic research as we are. Press support was sought and gained, such as the fairly recent major article in *Fortune* and the cover story in *Time*. Even the techniques of Madison Avenue came into play, and oceanography began to be described as the exploration of "inner space," a term which may not be quite analogous to what is meant by outer space but which nevertheless sticks in the mind.

Possibilities of Research

In general, a fairly successful effort was made to acquaint Congress and the budget-makers with the sort of results that an expanded program could be expected to achieve.

There are, of course, a great many interesting problems in basic research, rare forms of life that have gone virtually unchanged for hundreds of thousands of years, crevices the size of the Grand Canyon, and mountains nearly as high as Everest protected from the erosion which tends to obscure some of the information that might be gleaned from these formations on land. There are "rivers" deep under the sea several thousand miles long and carrying currents several times greater than the Mississippi, and scientists are far from clear on the mechanism that causes them to exist.

But interesting as these questions