site for that purpose. Or can we envision storage in the ocean depths, with the possibility of an overturn of even stable waters sufficient to contaminate marine plant and animal life, and thus eventually all that of the lands adjoining the sea? The very bulk of these long-lived fission products will be so enormous that containment within corrosion-proof vessels, even for 30 to 50 years, will be virtually impossible.

Moreover, the occurrence of accidents, such as an occasional explosion of a reactor or the wreckage in transit of vehicles carrying radioactive materials, cannot be dismissed as too improbable. Atomic power developed on a large scale cannot be immune to accident, any more than any other kind of human enterprise. If even 1 percent of the long-lived fission products produced at a 20,000 megawatt annual level of atomic power were to be released by leakage and accident, the effect would be equivalent to the radiation from 100 bombs of the Hiroshima size.

The threat to mankind of exposure to radiation arising from the peaceful development of atomic energy may thus far outstrip not only that from current exposures due to weapons testing and fallout but even that from the exposures necessary for medical and dental diagnosis. The only immediately obvious escape from so dire an outcome may lie in the rapid development of the hydrogen fusion process as a source of energy.

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W. Bothe, Experimental Nuclear Physicist

Most of today's nuclear physicists are too young to have known the time in which the foundation of their science was laid. The death of Walter Bothe (8 January 1891–8 February 1957) reminds us of the years in which a handful of gifted researchers made one basic discovery after another with very primitive experimental facilities. Their method of working can no longer be imitated today. The field has become too large, the experimental techniques are too involved. However, their way of thinking, the method they employed in choosing, from many possible problems, the important ones, and the way in which they focused their attention on the physical result in spite of great emphasis on experimental technique can be a lesson for us, particularly today when the extension of the experimental method and its problems can all too easily veil the real goal of physical understanding.

Bothe was a student of Max Planck. He therefore started his career as a theoretical physicist. For his Ph.D. thesis he developed the theory of optical refraction and reflection from the scattering of light by single molecules. Max Planck stressed independence in the work of his students. Bothe liked to tell that Planck only twice made a comment on the calculations that were submitted to him. In the first, he said, "This is still insufficient"; in the second, "Now you may finish."

In 1920, after an interruption of nearly 6 years, caused by World War I and long imprisonment in Siberia, Bothe started, with Geiger, his experimental career in physics at the Physikalisch-Technische Bundesanstalt (the German Bureau of Standards). Even from routine measurements in the laboratory he was able to gain new insight which led to publications. However, he soon turned, fully supported by Geiger, to the fascinating problems which the rapidly developing quantum theory set for experimentalists. Geiger's work with alpha rays was carried on in Rutherford's laboratory. Bothe turned his attention to the behavior of beta rays. With the cloud chamber he examined their tracks and, by means of theory, was able to classify the complicated phenomena. His articles on beta rays in the well-known *Handbuch der Physik* are classic examples of the way in which a confused picture may be clarified by theoretical treatment and appear, finally, quite simple.

That was one of the great periods of physics, marked by the penetration of the concept of quanta into "classical" considerations. A large circle of famous physicists was gathered in Berlin, of whom I shall name only Planck, Einstein, v. Laue, and Nernst. The extensive exchange of ideas between them found visible expression in their joint seminars. There, innumerable problems which arose from the new point of view were discussed. Bothe's entrance into this circle resulted in stimulation for experimental investigations, which he then also performed. The best-known result of these endeavors is his work with Geiger, in which it was shown that, in the scattering of light quanta on electrons (Compton-effect), the law of conservation of energy is valid not only on the average but also for the single elementary process. This was one of the important foundations for the further development in quantum theory.

The investigation on the Compton effect consisted in exploring the simultaneous appearance of scattered light quanta and ejected electrons. The detection of single electrons and x-ray quanta had been made possible a short time earlier with the help of Geiger's point-counter (a forerunner of today's counter tube), which was in such an imperfect form that students, nowadays, would refuse to use it. In each such point-counter the recoil electrons, or the scattered quanta, produced a current impulse; the coincidence of these impulses was determined by registering, on the same moving film, the deflections of two electrometers that were connected to the point-counters. By illumination of both electrometer-threads with the same intermittent light source, the coincidence was established within 1/1000 second.

With this work, a new research tool was established—the coincidence method —which since then has found innumerable applications. At first this new method was developed only as far as was necessary to achieve the physical goal. This is typical of Bothe's working method. The apparatus that he used was thought through completely, but it was built as primitively as possible. He used to say, "a good apparatus has to collapse after the last measurement." Nothing made him as angry as a "work-saving" installation which required more work for its development than it saved. He himself developed the first "coincidence amplifier" as a replacement for the tedious photographic evaluation method and has described its theory completely, but he was openly skeptical about the large expansion in the development of electronic circuits.

The coincidence method soon yielded another fundamental result. Together with Kohlhörster, Bothe succeeded in proving that the mysterious cosmic ultra-radiation consists of very penetrating particles which, in their experiment, made each of two counter tubes, one of which was located above and the other below a large lead block, respond.

This insight, decisive for their field, at once gave the two researchers the idea that, because of the earth's magnetic field, the radiation should be greater at the poles than at the equator. A trip to Spitzbergen failed to confirm this because the increase toward the north is already terminated in our latitudes. However, the travels of other researchers toward the south confirmed the original supposition.

Bothe had turned, in the meantime, to another field in which fundamental findings could still be expected—to the physics of the atomic nuclei. At the start, he used a tool that had not yet been applied in this field, which was then governed by the Rutherford school—namely, the point-counter and the Geiger-Müller counter tube. He was thinking, apparently, of something which, later, he was the first to call "nuclear spectroscopy"— that is, that nuclear transformations are characterized by the type and the energy of the nuclei involved. If nuclei of the same type but of different energies appear, then transitions must be possible which correspond to the emission of light, and this light emission must be coupled in timing with the corresponding particles that arise from transformation. He first investigated, therefore, (with Fränz) the particle energies that appear in certain transformations. He then discovered (with Becker) the gamma radiation that occurs in such transformations. And, thereby, something completely new was discovered. Gamma radiation occurred in the bombardment of elements where previously no particles resulting from transformation had been observed. The quantum energy of the gamma radiation which he was able to determine with a new coincidence method was greater than that of the bombarding particles; it could therefore not be simply a matter of the excitation of an atomic nucleus. To solve this puzzle, several laboratories started to work at once on this problem, until Chadwick solved it with the discovery of the neutron.

Since Bothe was now one of the leading experimental physicists, it was inevitable that the fruitful period of pure research with Geiger should be terminated by calls to universities, which brought him to Giessen and, soon afterwards, to Heidelberg. There he finally took over, again, a pure research institute, the Kaiser-Wilhelm-Institut (now Max Planck Institut), which he directed until his death. With a very small group, the work in nuclear physics was continued. A small Van-de-Graaff generator supplemented the previously exclusive use of radium compounds as sources of radiation. The correlation between particle radiation and quantum radiation in nuclear transformation was proved; in transformations produced by fast neutrons, resonance phenomena were discovered which confirmed Bohr's model of the atomic nucleus, established at the same time. Numerous new transformations could be discovered with hard gamma rays, and it was finally possible also to establish the effect of nuclear isomerism (the appearance of nuclei which differ in energy content only), which had remained a mystery for a long time.

This development was interrupted by World War II and the postwar period. Subsequent years were filled mainly with the training of young physicists, a problem to which Bothe dedicated himself with complete devotion and great success. He died before this activity could bear all its fruit.

In a short, unpublished paper which he wrote a few months ago, Bothe identified himself with a working method with which he himself was able to make exceptional contributions to the progress of physics. He talks of the "intensive working method" as an attempt to recognize fundamental problems and to work them out with a minimum expenditure of money and personnel, in contrast to the "extensive," more diffuse, method, which he admits often reaps the fruits of the primary investigations— something he himself experienced.

Those who knew him know that there was more behind his successes than his working method. Bothe was a man of very extraordinary talents in many spheres outside that of science; he was a deeply artistic man, with a nearly consuming intensity in everything he did as well as in his thinking. Since the sphere of our science has so greatly increased, and since most successes, nowadays, are brought about by the cooperation of many, he will remain, for us, a unique example.

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