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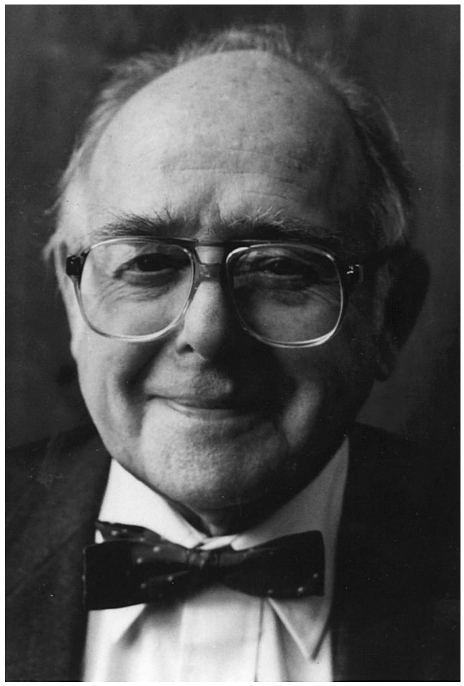
Clifford Glenwood Shull 1915–2001



Clifford G. Shull, a 1994 Nobel Prize winner in Physics for his pioneering work in neutron scattering, died of kidney failure on 31 March 2001 in Lexington, Massachusetts, USA. Born in Pittsburgh, Pennsylvania, on 23 September 1915, Cliff exhibited a strong interest in science in high school. He majored in physics at Carnegie Tech (now Carnegie Mellon University) in Pittsburgh, earning a BS degree in 1937, and then went on to graduate school at New York University (NYU), earning a PhD in physics in 1941. His thesis at NYU under Professor Frank Myers involved the construction of a Van de Graaf accelerator and the scattering of polarized electrons, so his focus was on nuclear physics.

In June 1941, Cliff finished his thesis and accepted a job with the Texas Company (later to become Texaco) in Beacon, New York. With the Texas Company, Cliff's work was on the study and characterization of catalysts used in making high-octane aviation fuel. In this work, he used X-ray diffraction and small-angle-scattering techniques to study powder samples, which gave him valuable experience for his later work with neutrons.

On a visit to Oak Ridge in April 1946, Cliff met Ernie Wollan and learned of Wollan's exploratory work on the diffraction of monochromatic neutrons by powder samples of NaCl and the scattering of neutrons by H_2O and D_2O. Cliff was immediately excited by this work and came to Oak Ridge in June 1946.

Wollan had been a student of Arthur Compton at the University of Chicago and was well versed in the theory and practice of X-ray diffraction. When Shull arrived, Wollan had already assembled a two-axis neutron diffractometer, using a large NaCl crystal as monochromator and moving from Chicago the Compton-designed sample table and counter arm that Wollan had used in his thesis work.

At first, they concentrated on developing a complete understanding of the scattering of neutrons by powder samples. They then used this powder diffraction technique to measure the neutron coherent scattering amplitudes of almost all the elements and many isotopes. For many years, this work served as reference data for interpreting all neutron scattering experiments. They were the first to measure neutron Laue patterns of single crystals from a white beam extracted from the Graphite Reactor.

Early in this work of building a library of neutron scattering amplitudes, Shull and Wollan determined the hydrogen and deuterium amplitudes (both fairly large and opposite in sign) by measuring the diffraction patterns of NaH and NaD. By combining the hydrogen result with the known total cross section, they deduced the nuclear singlet and triplet scattering amplitudes and explained the large total cross section in terms of nuclear spin incoherent scattering. They used the deuterium result in a study of polycrystalline ice that gave the first direct evidence in support of Pauling's double-minimum potential model of hydrogen bonding in ice, as opposed to the Bernal–Fowler model, the Barnes model or the rotating-molecule model. Both Cliff and Ernie have islands named after them in the Crystal Islands between Antarctica and Australia. Levy and Peterson (for their later more precise neutron diffraction studies on single crystals of D_2O ice) and Pauling also have islands in the Crystal Islands named after them. Varying the coherent neutron scattering amplitude of hydrogen by controlled deuteration is now one of the most powerful techniques available in the study of polymers and biological materials.

It was the study of magnetic materials that most excited Shull and Wollan. They had the theory of Halpern and Johnson (of NYU), the first neutron source capable of producing sufficient flux, and the right experimental technique – powder diffraction. They quickly exploited these factors in a series of experiments that established neutron scattering as the key to understanding magnetic materials. The first direct evidence of antiferromagnetism was produced in determining the magnetic structure of MnO, the Néel model of ferrimagnetism was confirmed for Fe_3O_4, the first magnetic form-factor data were obtained by measuring the paramagnetic scattering by Mn compounds, the production of polarized neutrons by Bragg reflection from ferromagnets was demonstrated, the magnetic diffuse scattering was used to determine the distribution of magnetic moments in 3*d* alloys, and the magnetic critical scattering at the Curie point of Fe was measured. For his work on magnetic materials, Cliff was awarded the Buckley Prize by the APS in 1956.

Attracted by a new research reactor being constructed at MIT and by the opportunity to teach, Cliff left Oak Ridge in 1955 to become a Professor of Physics at MIT, where he remained until retiring in 1986. His first experimental work at MIT involved the construction and use of a highly sensitive polarized neutron diffractometer to make extensive and precise measurements of the magnetic form factor in iron. This work revealed the spatial variation of the spin density and the existence of negative spin density in regions of the unit cell far removed from the Fe sites.

With this sensitive polarization technique, Cliff was able to measure the 'Schwinger interaction', that is, the interaction of the neutron's magnetic moment with the electrical charge distribution in the crystal. This scattering amplitude is dependent on the neutron polarization and is about three orders of magnitude smaller than the usual nuclear scattering amplitudes, and the scattering is 90° out of phase. Cliff showed that it is not necessary to have atoms with complex amplitudes to observe anomalous scattering for, in non-centrosymmetric crystals, such as α-quartz, Bijvoet inequalities could be measured for those reflections with complex structure factors. With the advent of very high flux reactors, he suggested that this effect may be of value to crystallographers in determining phases in suitable crystals.

In the 1960's, Cliff began to study dynamical diffraction and the propagation of neutron waves in perfect crystals. This work, requiring imaginative experimental concepts, careful attention to experimental details and thorough understanding of theory, was ideally suited to Cliff's character and he remained active in this field until his retirement.

His success as an educator can be measured by the distinguished careers of many of his graduate students. The MIT physics community held Cliff in high regard as an inspiring colleague, always kind and generous, who maintained high academic standards and high scientific productivity. He was elected to the National Academy of Sciences in 1975.

Cliff was creative in conceiving experiments, careful in their execution and patient in the data-collection process. He was modest and unpretentious with regard to his accomplishments, gentle in his interaction with others (including students), always willing to help by sharing his knowledge and experience, and careful to give credit to others. These scientific and human qualities resulted in universal admiration, respect and affection for Cliff within the neutron scattering community. He was a much-loved father of his field and will be missed by many.

A Clifford Shull Scholarship Fund has been established at Carnegie Mellon University. Contributions may be sent to Carnegie Mellon University, c/o Kristin L. Sullivan, Donor Relations, 5th Floor, Warren Hall, 5000 Forbes Avenue, Pittsburgh, PA 15213, USA.

Note: This is a modified version of the Obituary published in the October 2001 issue of *Physics Today*, p. 86.

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