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This Week's Citation Classic®

Bleaney B. Hyperfine structure in paramagnetic salts and nuclear alignment. *Phil. Mag.* 42:441-58, 1951.
[Clarendon Laboratory, University of Oxford, England]

This paper combined two subjects: detailed formulae for electron spin resonance measurements and a novel method of nuclear alignment, in which lower temperatures could be reached by magnetic cooling to zero field. This initiated the first successful experiment, carried out in the Clarendon Laboratory. [The *SCI®* indicates that this paper has been cited in over 540 publications.]

Hyperfine Structure and Nuclear Alignment

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The experimental problems in producing oriented nuclei had been discussed in the 1930s, but the combination of high magnetic fields and very low temperatures appeared to be formidable. Then, in 1948-1949, suggestions of using hyperfine interactions were published by C.J. Gorter[1] and by M.E. Rose;[2] these required demagnetisation to a small residual field to produce nuclear polarisation. In 1950 preparations at the Clarendon Laboratory, University of Oxford, for such experiments were well advanced, and a discussion meeting was held by Professor F.E. Simon. There I put forward a proposal to use the anisotropic hyperfine structure that my group had found in electron paramagnetic resonance experiments. This would not produce nuclear polarisation, with a net excess of nuclear spins pointing in one direction, but nuclear alignment, where the spins occupy equal and opposite senses but in a preferred direction in a paramagnetic crystal. Such alignment is sufficient to produce spatial anisotropy in the emission of gamma rays from a radioactive nucleus, as pointed out to me in 1949 at Harvard University by Robert V. Pound,[3] who proposed the use of a nuclear electric quadrupole interaction.

At the meeting Simon asked Maurice Pryce, Wykeham Professor of Theoretical Physics, about the suggestion, and Pryce confirmed its validity. Our resonance experiments had revealed that salts of divalent cobalt, such as the double sulphates, or Tutton salts,[4] were particularly suitable. J.M. Daniels, M.A. Grace, and N.F.H. Robinson[5] used a mixed crystal of (1 percent Co, 12 percent Cu, 87 percent Zn)Rb_2 $(SO_4)_2$, $6H_2O$, containing a small amount of radioactive ^{60}Co, half-life 5.3 years. Their first experiment in the autumn of 1951 was successful; an anisotropy amounting to 1.44:1 in the spatial emission of gamma rays was observed.

Interest in nuclear orientation has diminished, though experiments are still in progress in a number of laboratories. The paper continues to be quoted because of the extensive formulae for the energy levels and allowed transitions in electron paramagnetic resonance. They assume anisotropy (with axial symmetry), both in the electronic g-factor and in the hyperfine structure; an external magnetic field is applied at an angle to the symmetry axis. A small nuclear electric quadrupole interaction is also included. These formulae have been applied to problems on the borderlines of physics, chemistry, and biology.[6]

1. **Gorter C J.** A new suggestion for aligning certain atomic nuclei. *Physica* 14:504, 1948. (Cited 80 times.)
2. **Rose M E.** On the production of nuclear polarization. *Phys. Rev.* 75:213, 1949. (Cited 85 times.)
3. **Pound R V.** On the spatial alignment of nuclei. *Phys. Rev.* 76:1410-1, 1949. (Cited 50 times.)
4. **Bleaney B & Ingram D J E.** Paramagnetic resonance and hyperfine structure in four cobalt salts. *Proc. Roy. Soc. London Ser. A* 208:143-58, 1951. (Cited 115 times.)
5. **Daniels J M, Grace M A & Robinson N F H.** An experiment on nuclear alignment: the anisotropy of gamma-radiation from oriented cobalt-60 nuclei. *Nature* 168:780-2, 1951. (Cited 25 times.)
6. **Dougherty G, Pilbrow J R, Skorobogarty A & Smith T D.** Electron spin resonance spectroscopic and spectrophotometric investigations of the binding of tetracationic porphyrines and porphyrazines with calf thymus DNA. *J. Chem. Soc. Faraday Trans. II* 81:1739-59, 1985. (Cited 20 times.)

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