Letters to the Editor

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Collision Alignment of Molecules, Atoms, and Nuclei

NORMAN F. RAMSEY*

Clarendon Laboratory, Oxford, England, and Harvard University, Cambridge, Massachusetts

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RECENTLY, there have been a number of experiments on the polarization of scattered beams of particles. Such polarization is reasonable in scattering since the axial spin vector of the particle can be associated with the axial angular momentum vector that is related to the angle of scattering. However, in the transmitted beam no simple polarization is expected since there is no axial vector with which the particle spin can be associated. However, it is the purpose of this note to point out that if the particle spin is greater than $\frac{1}{2}$, the orientation properties frequently described as alignment[1,2] can be achieved in the transmitted beam, e.g., the spin orientation states corresponding to $M_I=\pm 1$ relative to the direction of motion may be more occupied than the state $M_I=0$. This alignment of the transmitted beam is related to the more complex orientations achievable in the scattered beam when the spin is greater than $\frac{1}{2}$.[3] However, from an experimental point of view alignment of the transmitted beam instead of a scattered beam has the advantage that the transmitted beam intensity is ordinarily much greater. For particles of spin I, the order k of the degree of orientation[2] of the transmitted beam may include any even number up to $2I$.

With beams of molecules attenuated by a scattering vapor, the geometrical shape of the molecule leads to a considerable dependence of the cross section upon M_J. For example, with beams of linear molecules attenuated by a monatomic scattering vapor whose kinetic velocities are considerably less than those of the molecular beam, factors of two or more in cross section may exist between the $M_J=0$ and $M_J=\pm J$ states. For such a case amounts of molecular alignment can be achieved for an attenuation of the beam by only a factor of two or so. For higher atomic velocities of the attenuating gas the amount of alignment is reduced but is still appreciable. In any specific case the amount of alignment produced depends on the molecular shape, the mean velocity of the incident molecule (no alignment can result from pure S scattering), the mean velocity of the scattering atom, and the mean rotational angular velocity of the molecules.

Atoms in electronic P or higher states similarly should be aligned in atomic beams that have been attenuated by scattering.

In experiments with either atoms or molecules, the existence of collision alignment should be observable in many ways. For example, in molecular beam magnetic resonance experiments with molecular hydrogen,[4] separate nuclear resonances occur for different values of M_J so the relative intensity of these resonances should be modified by attenuation with a scattering gas. Alternatively, observations of the apparent cross section in successive scattering attenuators should indicate the occurrence alignment by a diminution in the apparent cross section in the last attenuator in comparison with the first. In such an experiment, however, care must be taken to distinguish this effect from those corresponding to the changes in molecular velocity distribution by the attenuation.

In addition to its value as a tool for the study of collision phenomena and molecular shapes, collision alignment should be useful in some cases as a replacement for the inhomogeneous deflecting fields in molecular and atomic beam magnetic resonance experiments. For example, if an atomic beam passes through two successive attenuation regions, the total attenuation will be less if the atom retains its orientation than if it is reoriented between the two attenuation regions. Consequently, a diminution in transmitted beam intensity indicates the presence of a resonance reorientation of the atom. An atomic beam magnetic resonance experiment with collision alignment of the atoms possesses the advantage that much broader and more intense beams can be used than with the conventional molecular beam resonance method.

At least in principle, collision alignment of transmitted nuclear particles could be achieved for nuclei of spin greater than $\frac{1}{2}$. However, the significance of collision alignment in nuclear research is diminished by the fact that most high-energy nuclear particles have spins of 0 or $\frac{1}{2}$. Although the deuteron has a spin of 1, nuclear attenuation experiments are made more difficult by its electrical charge and consequent ionization energy losses. However, some alignment of the transmitted beam should occur in high-energy deuteron total cross-section experiments[5] and a slight departure from simple exponential attenuation should arise from alignment. Even with incident nucleons of spin 0 or $\frac{1}{2}$, alignment considerations affect nuclear reaction problems. For example, Bohr and Mottelson[6] find nuclear surface deformations as large as 30 percent for some nuclei while the transit time of an incident high-energy nucleon past a nucleus is small compared to the rotational period of the deformed surface. Consequently, even from purely

geometrical considerations nuclear reactions will take place dominantly with nuclei in preferred states of alignment.

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Saturation of Nuclear Electric Quadrupole Energy Levels by Ultrasonic Excitation*

W. G. Proctor and W. H. Tanttila
Department of Physics, University of Washington, Seattle, Washington
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We have observed the decrease in the population difference between the degenerate $m=\pm\frac{1}{2}$ and the $m=\pm\frac{3}{2}$ quadrupole energy levels of Cl^{35} in $NaClO_3$ following a long pulse of ultrasonic excitation at the transition frequency. The experiment was performed at the temperature of liquid nitrogen, for which the transition frequency is 30.63 Mc/sec and the thermal relaxation time 0.94 sec.

The population difference was measured by the amplitude of the transient nuclear induction signal following a short (50 μsec) pulse of radio-frequency magnetic flux at the transition frequency.[1] In our experiment, the signals were induced in a second coil, a receiver coil, perpendicular to the exciting or transmitter coil, as suggested by Dean.[2] The sodium chlorate crystal, about 1 cm^3 in volume, located between the above coils, received ultrasonic energy in the (1,0,0) direction across a polished face in contact with the polished face of a long, narrow halite crystal. The latter was joined similarly to a second halite crystal, joined in turn to an X-cut quartz crystal, used as an ultrasonic transducer. Rubber-vaseline vacuum grease was used as an interface medium. The halite crystals, about 1 cm^2 in cross section, were each about 4 cm long, separating the quartz transducer from the $NaClO_3$ sample by about 8 cm. The transducer was excited by a second transmitter of variable frequency; current reached the transducer through a coaxial cable, of which the outer, grounded conductor was flared out at the end to enclose the quartz transducer completely and make contact with the silver coating of its outside face, thus preventing magnetic fields from originating from the transducer to a great extent.

The ultrasonic pulse was 0.3 second in duration; the rf power supplied to the transducer was about 5 watts. After a delay of about 0.03 second, the population difference was examined. The cycle was repeated at 1-second intervals. Depending upon a number of variables, it was observed that the amplitude of the transient was diminished to 20 percent or less of its equilibrium amplitude only when the transducer was excited at the transition frequency. To separate the ultrasonically induced quadrupole transitions from a spurious effect which would be obtained by dipole transitions caused by magnetic flux leaking into the sample region, the resonant transmitter and receiver coils were short-circuited by relays during the ultrasonic excitation period. Further, after a small gap ($\sim\frac{1}{2}$ mm) was introduced between the sample crystal and its neighboring halite crystal, interrupting the path of ultrasonic energy while providing a geometry and transducer loading for which one would expect almost identical leakage fluxes, no attenuation was discernable. A further possible spurious effect, due to the generation of a temperature gradient in the sample crystal, is not likely since the transducer heating should not be frequency-dependent; the transducer, driven at the third harmonic, tuned broadly when loaded.

Quantitative measurements are now under way. The experiment was performed in order to be able to measure the direct and Raman process contributions to the thermal relaxation time.[3]

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Experimental Evidence for Thermal Spikes in Radiation Damage*

W. Primak
Chemistry Division, Argonne National Laboratory, Lemont, Illinois
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Theoretical work[1–3] and experimental measurements of stopping power indicate that toward the ends of their ranges in solids, energetic atoms lose $\sim 10^4$ ev to the lattice at a rate of about 10^9–10^{10} ev/cm. Brooks[4] discussed the resultant temperature fluctuations (termed thermal spikes). He showed that the thermal spikes in the electronic system are small, behave nearly independently, and cannot produce marked structural effects. For the lattice, the temperature distribution would be between cylindrical and spherical

$$T\sim 3(10^{-21})(q/c)(x^2t)^{-1}\exp(-r^2/4x^2t) \quad \text{or}$$
$$10^{-21}(Q/c)(x^2t)^{-\frac{3}{2}}\exp(-r^2/4x^2t),$$