The Surface Effect of Sodium Iodide Scintillators*

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The response of NaI(Tl) crystals to α-particles originating outside of the crystal was compared to that of α-particles originating within the crystal in order to determine any possible surface effects of the crystal. It was found that any such effect, if present, is too small in magnitude to explain the nonlinearity of response of NaI(Tl) crystals to α-particles of energy less than 8 Mev.

VARIOUS studies[1–3] have been made of the linearity of response of scintillating crystals to heavy charged particles, with particular interest centering on NaI(Tl) crystals. The results available thus far show that the response of such crystals to α-particles as a function of energy is linear above 8 Mev.[1,2] Below this energy, however, the characteristic response shows marked nonlinearity. Since the range of low energy α-particles is so short in a scintillator and the sources of α-particles employed by various workers are external, there exists an uncertainty as to whether the surface condition of a NaI crystal might contribute in some degree to this nonlinearity in its energy response. This is of particular interest since NaI scintillators are widely used for energy determinations and different methods for preparing the crystal surface are used by various workers.

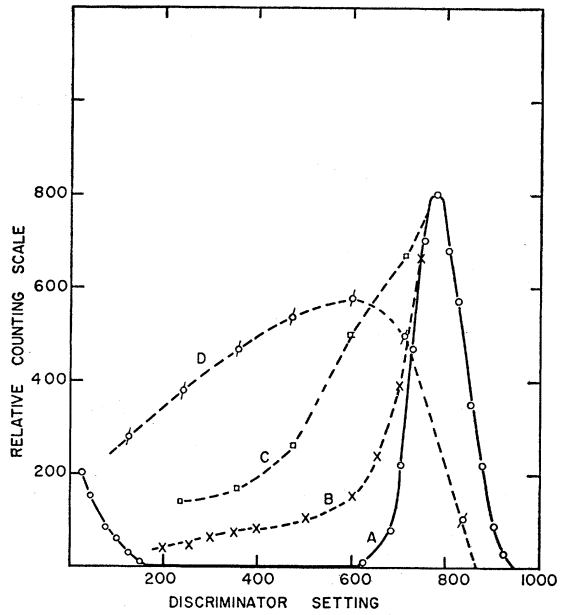

FIG. 1. Response of NaI-Tl crystals to Po^{210} α-particles. Curve A is the spectrum of pulses obtained with a crystal containing an internal source of α-particles. Curves B and C show the response of this same crystal when two different amounts of Po^{210} were deposited on the surface. Curve D shows the pulse distribution from an external Po^{210} source on a standard (inactive) NaI-Tl scintillator. These curves have been normalized.

A technique developed by der Mateosian and Goldhaber[4] of growing NaI crystals containing an internal source of radiations has made it possible to determine the surface effect of a crystal by comparing the scintillations obtained from an internal and an external α-source.

In order to measure the magnitude of a surface effect a comparison was made of the output pulses of an ordinary NaI crystal when exposed first to an external α-source and then to an external gamma-ray source. The crystal was first cleaned in a succession of chemical baths (a cleaning procedure used successfully in this laboratory). A powdered source of polonium was mixed into toluene forming a suspension of finely divided particles. Then a drop of this solution was put directly on the surface of the scintillating crystal and the toluene was allowed to evaporate, thus leaving a thin layer of the polonium source immediately on the surface. The crystal was mounted on top of a 5819 photomultiplier tube followed by an Atomic Instrument Company linear amplifier and pulse analyzer set-up. An external Cs^{137} gamma-ray source (661 kev) was used for energy calibrations. The distribution of the pulses obtained from the external α-source was quite diffused, probably because of particle size of the source, oblique entry into the crystal through a thin oil film, and scattering effects. By comparing the end point of the Po^{210} distribution with that of the Cs^{137} gamma-rays, a pulse-height ratio of 5.1 to 1 was obtained. This is smaller than the nominal ratio (8.03) of the energies of the α-particle and photoelectron.

Next, a specially grown NaI crystal containing an internal Po^{210} α-source was substituted for the above crystal. The pulses arising from this internal source show a well-defined, sharp, energy spectrum. The ratio of the size of the internal Po α-pulses to that of the Cs^{137} conversion electron pulses in this crystal turned out to be 5.3 which agrees within 5 percent with that obtained with the external source. An external Po^{210} source was superposed in the manner described above on the crystal containing the internal α-source and a

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[3] Taylor, Jentschke, Remley, Eby, and Kruger, Phys. Rev. **84**, 1034 (1951).

[4] Scharff-Goldhaber, der Mateosian, Goldhaber, Johnson, and McKeown, Phys. Rev. **83**, 480 (1951); E. der Mateosian and A. Smith, Phys. Rev. **87**, 193 (1952).

direct comparison between these two pulse-height distributions were obtained. Figure 1 shows a superposition of the two spectra measured simultaneously. It can be seen that the difference in the end-point values of the two distributions is less than 5 percent of the α-particle energy.

Since this surface effect is so small, it cannot be responsible for nonlinearity of response of (chemically cleaned) NaI crystals to α-particles. An incidental result is that trace amounts of polonium in a NaI(Tl) crystal do not affect its characteristic performance as a scintillation crystal.

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The Scattering of Slow Neutrons by O_2 Molecules*

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The scattering of slow neutrons by O_2 is due to nuclear interaction as well as magnetic forces arising from two magnetically active electrons. The molecular (nuclear) scattering is subdivided into elastic (coherent and incoherent) transitions and inelastic (mostly hyperelastic) transitions. The magnetic scattering is purely incoherent and essentially elastic. Numerical values are obtained for the integral cross sections of these various scattering processes in dependence upon the wavelength. The case of very long neutron wavelength is of greatest physical interest, since only then can a sizable magnetic effect be expected. The analysis requires careful consideration of the thermal motion of the O_2 molecules, which sometimes influences the order of magnitude of the result. More accurate experiments can be expected to lead to an independent measurement of the distribution of the magnetically active shell of valence electrons.

1. INTRODUCTION

THE present paper contains a detailed theoretical analysis of the scattering of very slow neutrons by O_2 molecules. One of us (O.H.) has announced some time ago, in very brief form, some theoretical estimates.[1] We present here a full quantitative discussion of this problem which will justify previous expectations that more refined experiments may lead to an analysis of the distribution of valence electrons in O_2.

The interaction between a neutron and the O_2 molecule is essentially twofold. There exists first the customary nuclear interaction caused by the two nuclei. In addition to it, the paramagnetic O_2 gives rise to a magnetic type of neutron scattering caused by the interaction between the magnetic moment of the neutron and the molecule.

This magnetic interaction, which has previously been analyzed in great detail,[2] has so far been studied experimentally mostly through observation on the salts of elements of the iron group in polycrystalline form. While very recent experiments[3] seem to lead to a satisfactory agreement between experiment and even finer points of the theory, it must be kept in mind that scattering experiments with solid targets are often accompanied by some disturbing features. The paramagnetic scattering of a neutron by O_2 can be expected to be essentially undisturbed; one can therefore hope to draw conclusions from a comparison of calculation and experiment which will lead to information concerning the distribution of the magnetically active shell.

It is, of course, necessary for this purpose clearly to isolate the magnetic scattering from the purely nuclear scattering. As shown before,[2] the magnetic scattering does not interfere with the nuclear scattering so that the latter may be calculated quite independently and the resulting total cross section can be subtracted from the observed cross section to obtain a value for the paramagnetic cross section.

Since, on the other hand, the earlier theory[2] of paramagnetic scattering leads us to expect that only neutrons of very long wavelength will have sufficiently large a form factor so that a sizable magnetic scattering can be expected, the analysis must be carried out for a range of wavelengths which make the calculations of inelastic transitions somewhat complicated. It will turn out that the change in the neutron energy accompanying inelastic (mostly hyperelastic) transitions will be, in general, large compared with the orignial neutron energy. This fact requires an individual study of all the matrix elements of significance, which are very numerous, since O_2 at room temperature occupies rotational states with quantum numbers 1 to 23 with appreciable frequency. Customary simplifications in the theory of neutron scattering by molecules are, therefore, no longer applicable.

It will also turn out that the thermal velocity of O_2 is comparable with the neutron velocity. The thermal motion of O_2 needs to be taken into account rather accurately in the study of the various contributions.

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