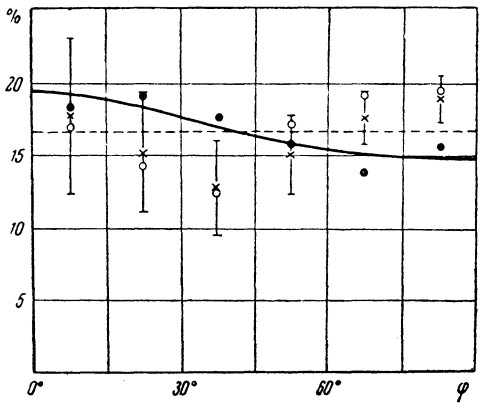
the number of rays produced in the fission of uranium by a neutron beam having a spectrum of the form given in Ref. 7, using at the same time the known relationship for $\sigma_f(E)$.[8] The distribution so computed agrees with that observed. A considerable contribution to the number of single fissions is made here by relatively low-energy neutrons which indeed determine the character of the angular anisotropy. Increasing the energy of the incident neutrons increases the proportion of events corresponding to a higher excitation of the fissioning nucleus, and the parallel anisotropy is replaced by a perpendicular one, in the sense defined above.



Angular distribution of fragments relative to the direction of the incident particle at a 15° angle interval and per unit solid angle: O—proton-induced fission, per Refs. 3 and 4, ●—neutron-induced "single" fissions, ×—neutron-induced "star" fission. The distribution of fragments as per Ref. 1 (solid curve) and the isotropic distribution (dotted line) are shown. The statistical errors are indicated for star fissions. The points corresponding to the proton experiments have errors that are approximately half as large.

We also determined the anisotropy in the angular distribution of the particles that accompany the fission of uranium nuclei, and compared them with the corresponding experimental data on proton-induced fission by protons.[6] The observed directivity of the particles produced in single-ray fissions is high—the forward to backward ratio is 2.0 ± 0.2; this ratio becomes 1.7 ± 0.2 for 2-ray fissions and 1.3 ± 0.2 for multiple-ray fissions. Calculations analogous to those made for the ray distribution, show that these quantities would result from experiments with a proton beam of a similar spectral composition.

One must thus assume that the anisotropy in the escape of fragments, the distribution as obtained from the number of particles accompanying the fragments, and the directivity of these particles are approximately the same whether the uranium nuclei are fissioned by high-energy neutrons or by protons of the same energy.

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On Molecular Neutronoscopy

V. I. GOL'DANSKII
P. N. Lebedev Physical Institute
Academy of Sciences, USSR

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THE use of high-power short monoenergetic neutron pulses makes it possible now to devise a new method, one that can be called "molecular neutronoscopy," for research on the structure and properties of molecules.

The idea in this method is to subject the molecules under investigation to bombardment by short "packets" of monoenergetic neutrons ($E_0 \approx 1$–10 ev) and to determine the binding energy of the molecules, the probability of various molecular conversions induced by the neutrons, and certain other characteristics (mentioned below) from the type of the time-of-flight spectrum and of the angular distribution of the scattered neutrons. The method proposed resembles most closely in its potentialities and means of realization the investigation of Debye levels of crystal lattices with the

aid of "cold" neutrons.[1,2]

When the molecules, bombarded by neutrons of energy E_0, do not break up into two "chips" (atom, radical, or ion) the spectrum of the neutrons scattered at an angle θ consist of a series of lines E_{ni}, whereby

$$\sqrt{E_{ni}} = (A+1)^{-1}[\sqrt{E_0}\cos\theta + \sqrt{E_0(A^2-\sin^2\theta) - Q_i A(A+1)}], \quad (1)$$

where Q_i are the energies of the excited levels and A is the mass number of the molecules. However, if $E_0 > E_b(A+1)/A$, it becomes possible to have inelastic scattering with molecule break up and the spectrum of the scattered neutrons will contain groups with energies between $E_{n\,max}$, as given by (1) (putting $Q_i = E_b$), and $E_{n\,min}$, which vanishes when $E_0 > E_b A/(A-1)$ and given by

$$\sqrt{E_{n\,min}} = (A+1)^{-1}[\sqrt{E_0}\cos\theta - \sqrt{E_0(A^2-\sin^2\theta) - E_{cB} A(A+1)}] \quad (2)$$

at

$$E_b(A+1)/A < E_0 < E_b A/(A-1).$$

Analysis of the position and intensity of the lines and line bands in the neutron spectrum relative to the time of flight $t_i = 72\,l/\sqrt{E_{ni}}$ microseconds (where l is the distance from the scatterer to the detector in meters and the energy is in ev) affords many opportunities for determining the energy of the bonds broken by the neutrons, the probabilities of such breaks, and the excitation levels of the molecules.

Further possibilities of the method proposed are related to the development of theoretical concepts of the scattering of neutrons with excitation of molecules (see, for example, Refs. 3 and 4 for the case of scattering with molecule breakup).

Considerable information on the rotational and oscillation states and on the corresponding wave functions of the molecules is obtained from analysis of the data on the total cross section and angular distribution of the scattering neutrons, and also from the spectrum of the neutrons scattered with molecule breakup at a given angle (typical probelm of pulse approximation).

Let us estimate the practical realizability of the method of molecular neutronoscopy. At the present time it is actually possible to irradiate areas up to 5 cm^2 (for example, 0.7×7 cm) in mechanical monochromators by means of a flux of monoenergetic resonant neutrons on the order of 10^5–10^6 cm^{-2} $sec.^{-1}$. By using as a second scattering or absorbing filter a 5–10 cm diameter rotor with groups of through slots approximately 0.5 millimeters wide, placed 60° apart, it is possible to obtain a 2-microsecond neutron pulse every 100-200 microseconds, provided the linear speed of the rotor edges reaches 250 meters per second (still approximately half the now attainable value). A scatterer of sufficient thickness will scatter in this case 5×10^3 –10^5 neutrons per second. A detector comprising ten counters, filled (to approximately 1 atmos), with $B^{10}F_3$, 2 cm in diameter and 50 cm long (with approximate efficiency of 10%), located one meter from the scatterer, will count from 8.5×10^4 to 1.7×10^6 neutrons during an experiment lasting six hours.

Let us estimate the accuracy of the experiments, using as an actual example the irradiation of water (in the gas phase, with the H–OH binding energy being approximately 5.18 ev) with 7 ev neutrons, the neutron scattering being observed at an angle of 150°. Here the maximum energy of the neutrons scattered upon breakup of the H_2O molecules is approximately 1.1 ev and at $l = 1$ meter we have correspondingly $t_{min} = 70$ microseconds. The maximum time of flight, determined by cutting off the secondary neutrons having $E_n \lesssim 0.3$ ev with a cadmium filter, is approximately 130 microseconds. The relative energy spread of the primary neutrons at the flux value indicated above is approximately 10%. This error—the greatest of all— decreases in proportion to the primary-neutron flux. The width of the neutron pulse is approximately 3% of the minimum time of flight of the scattered neutrons. The effective thickness of the scatterer, equal to the range of the primary neutrons in water, is approximately 0.6 cm, and results in a time-of-flight spread of 2-2.5% (allowing also for the counter diameter, which equals 2 cm). The spread in the velocity of the scattered neutrons due to thermal motion of the molecules in the scatterer is approximately $\sqrt{kT/AE_n}$ and is close to 3.8%. The errors due to the spread in the counter discharge time (approximately 0.1 microseconds) and the angular resolution ($\Delta\theta \approx 1.5°$) are much smaller and can be disregarded. As a result we obtain for this case $\Delta E_b/E_b \approx 13.7\%$, with almost the entire total error (approximately 97%) being due to the spread

in the energy of the primary neutrons. Reducing the primary neutron flux and $\Delta E_0 / E_0$ by 10 times decreases the overall error in the determination of the binding energy to 2.7%.

Molecular neutronoscopy cannot compete with optical methods and with radio spectroscopy whenever the latter methods (which are more accurate) can be used to investigate a substance without a change in its aggregate or chemical state (which may be accompanied by a change in the very properties that are being studied).

However, molecular neutronoscopy does have the advantage of being capable of investigating molecules in specimens in any state, and is consequently capable of studying intermolecular interaction, i.e., the influence of such factors as temperature, pressure, aggregate state, presence of outside admixtures, etc., on the binding energy, and perhaps also other molecular properties mentioned above. In addition, molecular neutronoscopy uncovers still another specific possibility of interest to radiation chemistry and radiation biology, namely, a means of establishing the relative and absolute probability of breaking various molecular bonds by neutron excitation of molecules at different levels.

In conclusion I express my gratitude to F. L. Shapiro and M. I. Pevzner, whose discussions contributed much to establishing the possibility of the method proposed here.

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Excitation Function for the $Si^{28}(d, p)Si^{29}$ Reaction

IU. A. NEMILOV AND V. F. LITVIN

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USING a method described in Ref. 1, we investigated the yields of various groups of protons from the Si^{28} (d,p) Si^{29} reaction, as functions of the fixed detector angle and the primary deuteron energy. In a stripping reaction, the ratios of these yields, called hereinafter "differential excitation functions" for short, should depend in a characteristic manner on the moment of momentum introduced by the neutron in the formation of a finite nucleus in a definite excited state.

However, the stripping mechanism is not unique to the (d, p) reaction and in some cases a substantial contribution to the cross section of the reaction is introduced by the mechanism of the intermediate nucleus. The latter mechanism is of resonant character, corresponding to the formation of excited levels of the intermediate nucleus. The cross section of the (d,p) reaction consists in this case of a contribution from the stripping mechanism, a contribution from the intermediate-nucleus mechanism, and a contribution corresponding to the interference between the stripping mechanisms and the compound nucleus. The presence of such resonances in the differential excitation functions and their interference character were recently established experimentally for light nuclei.[2-9]

We obtained spectra of protons from the Si^{28} (d,p) Si^{29} reaction at an angle $\theta = 109°$ with the direction of the motion of the primary particles for 15 values of deuteron energy ranging from 1.75 to 4.75 mev. A typical Si^{28} (d,p) Si^{29} proton spectrum at $E = 3.45$ mev is shown in Fig. 1. The proton groups p_0, p_1, p_2, p_3, p_4, p_5 correspond to excited levels of Si^{29} at $E_{exc} = 0, 1.28, 2.03, 2.43, 3.07$, and 3.62 mev, respectively. Figure 2 shows the ratios of the differential excitation

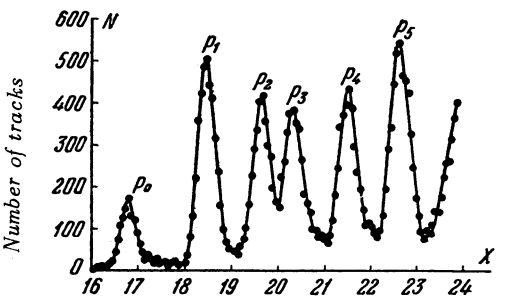

FIG. 1. Distribution of the tracks on a photographic plate. N—number of tracks, X—coordinate along the photographic plate.

functions of various levels of the final Si^{29} nucleus obtained from these spectra.

These relationships disclose 3 resonances at incident-deuteron energies $E_d = 3.26$, 3.75 and