systems. The ratio is sustained though the magnitude of the cross sections varies by a factor of 20. We thus have evidence that the modes of fragmentation of the ^{14}N nucleus are the same in hydrogen and carbon.

A possible interpretation of this result comes from the theory of multiparticle reactions at high energy.[7] Applicable to single-particle inclusive spectra are the concepts of limiting fragmentation (scaling) and factorization of cross sections. Limiting fragmentation states that, at high energy, the production cross section for the ith fragment is independent of energy.[8] Factorization states that $\sigma_{ab} \propto C_a C_b$, i.e., the total cross section for interaction between a and b can be factored into quantities that are functions of a and b only. A direct consequence of factorization in the region of limiting fragmentation is the prediction that the modes of fragmentation of the projectile (^{14}N in our case) are independent of the target nucleus.

The underlying result of this experiment, then, is the implication that the concepts of limiting fragmentation and factorization are applicable to hadron systems of large baryon number.

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[4] This result may be interpreted by noting that the mass difference $M(^{14}O) - M(^{14}C) = 5.0$ MeV, the production of ^{14}O relative to ^{14}C thereby being inhibited by the requirements for energy conservation.

[5] Although incomplete, data on the $N(\beta_{\parallel})$ distributions for the He isotopes extend to $\beta_{\parallel} \approx 0.1$ to 0.2, corresponding to 5 to 20 MeV/nucleon. Such energies are Coulombic, and suggest that final-state interactions may be an important contributor to the spectra.

[6] R. Silberberg and C. H. Tsao, "Partial Cross-Sections in Hgih Energy Nuclear Reactions for Targets with $Z \leq 28$" (to be published).

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[8] On the basis of existing data, cited in Ref. 6, the total cross sections for fragmentation of heavy nuclei are approximately constant for energies greater than 0.5 GeV/nucleon.

New Approach to Perturbed γ-Ray Angular Distributions from Heavy Nuclei Recoiling into Vacuum*

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Time-differential attenuation coefficients of the γ-ray angular distribution of Coulomb-excited Hf nuclei recoiling into vacuum have been measured using a plunger technique. The data have been interpreted in terms of a new model which assumes a stochastic process with Gaussian probability distribution of the perturbing magnetic field strengths and arbitrary correlation times. Reasonable fits to all existing applicable measurements are obtained with a correlation time considerably larger than previously assumed.

In a first attempt to understand the perturbation of the γ-ray angular distribution in the decay of heavy nuclei recoiling into vacuum, Ben Zvi *et al.*[1] applied the theory of Abragam and Pound[2] (AP) for randomly fluctuating interactions. In a recent investigation[3] we found some evidence that this description of the hyperfine interaction between the nucleus and the highly ionized and excited atomic shell is not entirely adequate. A more complicated time dependence of the attenuation coefficients than the simple exponential dependence, as predicted by the AP theory, appears to be necessary. Furthermore, the very assumptions which underlie the application of this theory have been shown to be not fulfilled. Therefore, we have sought more precise data and also a simple stochastic model that avoids the restrictions of the AP theory, to explain the data.

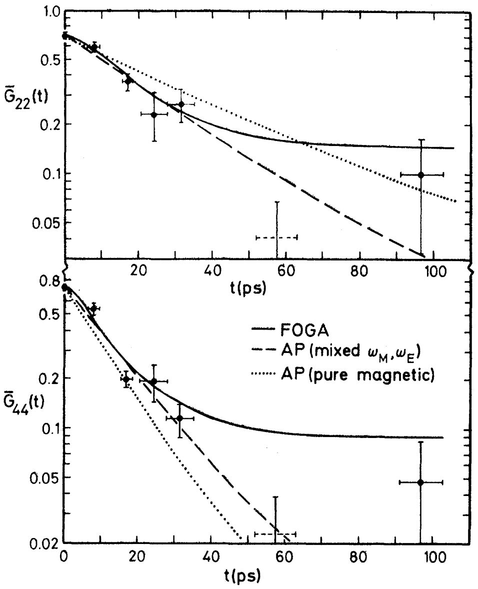

FIG. 1. Least-squares fits of the data for Hf (2^+) recoiling into vacuum using the AP and FOGA models. The FOGA fit shown is for $0 \le t \le 100$ psec.

Time-differential angular-distribution attenuation coefficients for Hf (2^+) nuclei recoiling into vacuum have been measured using the recoil-distance technique. Coulomb excitation with 160°–175° backscattered 33-MeV ^{16}O ions has been used to select head-on recoils of average velocity 3.13×10^8 cm/sec. The γ-ray angular distribution has been measured with three 3-in.×3-in. NaI(Tl) detectors at 0, 45, and 80 deg in coincidence with a particle ring counter. Recoiling Hf ions from a 120-μg/cm^2 target were stopped in a Cu foil, the target-stopper arrangement being at an angle of 30 deg with respect to the beam. The target-stopper distance was varied between 20 and 260 μm.

The measured attenuation coefficients are given by

$$\bar{G}_{kk}(t)=\tau_n^{-1}\int_0^t G_{kk}(t')\exp(-t'/\tau_n)\,dt' + G_{kk}(t)\left[\tau_n^{-1}\int_t^\infty G_{kk}^{\mathrm{Cu}}(t'-t)\exp(-t'/\tau_n)\,dt'\right], \qquad (1)$$

in which the quantity in brackets, by a change of variable, can be replaced by $G_{kk}^{\mathrm{Cu}}(\infty)\exp(-t/\tau_n)$. Here $\tau_n=2.17$ nsec is the average lifetime of the ^{178}Hf and ^{180}Hf 2^+ states. The attenuation coefficients $G_{kk}^{\mathrm{Cu}}(\infty)$ for perturbation in copper have been measured with a target evaporated directly onto the copper foil.

In Fig. 1 the experimental points are given. The horizontal errors stem from the uncertainty in the calibration of the target-stopper distances. For two of the least-squares fits shown, the AP theory has been used with attenuation coefficients[2]

$$G_{kk}(t)=\exp(-\lambda_k t),\quad \lambda_k=\tfrac{1}{3}k(k+1)\tau_c\{\langle\omega_M^2\rangle+\tfrac{9}{5}\langle\omega_E^2\rangle[4I(I+1)-k(k+1)-1]\},$$
$$\langle\omega_M^2\rangle=\frac{g_I^2\mu_n^2\langle H^2\rangle}{\hbar^2},\quad \langle\omega_E^2\rangle=\left(\frac{eQ}{4I(2I-1)\hbar}\right)^2\langle V_{zz}^2\rangle. \qquad (2)$$

In the fit labeled "AP (pure magnetic)" the electric quadrupole interaction $\langle\omega_E^2\rangle$ has been assumed to be zero. The third fitted curve is made with the fixed-orientation Gaussian-approximation (FOGA) model.[4] This model assumes random fluctuations of pure magnetic fields having a Gaussian distribution centered at $H=0$. Essential conditions are that the magnetic field can be regarded semiclassically and that the magnitude of the field can change randomly although the orientation remains fixed. Averaging uniformly over all field directions, the attenuation coefficients are[4]

$$G_{kk}(t)=\frac{1}{2k+1}\sum_{N=-k}^{+k}\exp\left\{-N^2\langle\omega_M^2\rangle\tau_c^2\left[\frac{t}{\tau_c}-1+\exp\left(-\frac{t}{\tau_c}\right)\right]\right\}. \qquad (3)$$

In this model $\langle\omega_M^2\rangle$ is defined as in (2), in which $\langle H^2\rangle$ is now the variance of the magnetic fields with Gaussian probability distribution. Equation (3) applies to any correlation time τ_c, whereas (2) is restricted to $\langle\omega_M^2\rangle\tau_c^2\ll1$ and $\tau_c\ll t$.

The numerical results of the fits are listed in Table I. The following main results should be noted:

TABLE I. Results of least-squares fits of the data presented in Figs. 1 and 2. The row marked "time interval $0 \leq t \leq 35$ psec" is from a separate calculation in which the last two points of $\bar{G}_{22}$ and $\bar{G}_{44}$ in Fig. 1 have been omitted.

	λ_2 (nsec^{-1})	λ_4 (nsec^{-1})	λ_2/λ_4	χ^2/d.f.	χ^2/d.f. (pure magnetic)	τ_c (psec)	$\langle\omega_M^2\rangle$ (10^{21} sec^{-2})	$\langle H^2\rangle^{1/2}$ (MG)	χ^2/d.f.
Hf time interval $0 \leq t \leq 35$ psec						>25	2.8 ± 0.6	30 ± 3	0.56
Hf time interval $0 \leq t \leq 100$ psec	36 ± 5	65 ± 6	0.56 ± 0.09	1.12	2.2	>50	2.8 ± 0.6	30 ± 3	1.45
^{150}Sm[a]	21.6 ± 0.5	42.6 ± 0.9	0.51 ± 0.02	7.5	42	8.6 ± 2.2	2.8 ± 0.5	36 ± 3	1.61

[a]These data are from Polga *et al.* (Ref. 5).

(1) The AP fit assuming a purely magnetic interaction cannot entirely be excluded, but a fit with lower χ^2 per degree of freedom (χ^2/d.f.) is obtained if a mixed magnetic and electric interaction is taken into consideration. (2) With the FOGA model a purely magnetic-interaction fit with approximately equal χ^2/d.f. is obtained. (3) FOGA gives, in contrast to AP, information on both $\langle\omega_M^2\rangle$ and τ_c. The correlation time $\tau_c > 25$ psec is considerably larger than the value $\tau_c = 3 \pm 1$ psec found by Ben Zvi *et al.*[1] in Sm and Nd, obtained by an extrapolation procedure to gas pressure $p \to 0$ from recoil into gas experiments, based on Eq. (2).

We have also fitted the data of Polga *et al.*[5] on ^{150}Sm(2^+, $\tau_n = 70$ psec) recoil into vacuum. The results are given in Fig. 2 and the table. The main points are as follows: (i) A pure magnetic interaction fit with AP is completely excluded. (ii) The ratio λ_2/λ_4 from the best possible AP fit is very close to the result for Hf → vacuum. (iii) The reduced χ^2 decreases from 7.5 for AP to 1.6 for FOGA. (iv) Again τ_c is found to be larger than previously assumed, although not as large as in Hf.

Commenting on the AP fits, the experimental facts presented in Figs. 1 and 2 do not, of course, completely rule out this model. A mixture of magnetic dipole and electric quadrupole interaction, $\langle\omega_E^2\rangle^{1/2}/\langle\omega_M^2\rangle^{1/2} = 0.21$, would be in very rough agreement with the data. There are, however, arguments against the hypothesis of so extensive a quadrupole admixture: (1) The recoil-into-gas data[6] clearly exhibit that the interaction is purely magnetic. It would be surprising if the multipole type were different for recoil into vacuum. (2) The large effective magnetic fields observed can hardly be explained only by orbital contributions. There must also be contributions from unpaired s electrons. Such electrons cannot produce a quadrupole interaction. (3) The average splitting ratio $\langle\omega_E^2\rangle^{1/2}/\langle\omega_M^2\rangle^{1/2} = 0.21$ is equivalent to $B/A \approx 5$, where B and A are the usual hyperfine coupling constants for quadrupole and dipole coupling, respectively. Such a high-average coupling ratio seems to be unrealistic. On the other hand, it appears promising that the FOGA model can explain all data with a purely magnetic interaction.

A few comments have to be added as a justification for the application of the FOGA model. Important is, of course, the result $\tau_c > 25$ psec. This allows one to argue that within our observation time, $t_{max} = 100$ psec, only a few electron transitions occur, following the dipole rule $\Delta m_3 = 0, \pm 1$. Both the large τ_c and the dipole rule favor the approximate preservation of the initial orientation of the axis. Thus, within a sufficiently short time interval, the fixed-orientation approximation should only be slightly violated. The main result of such a violation is expected to be

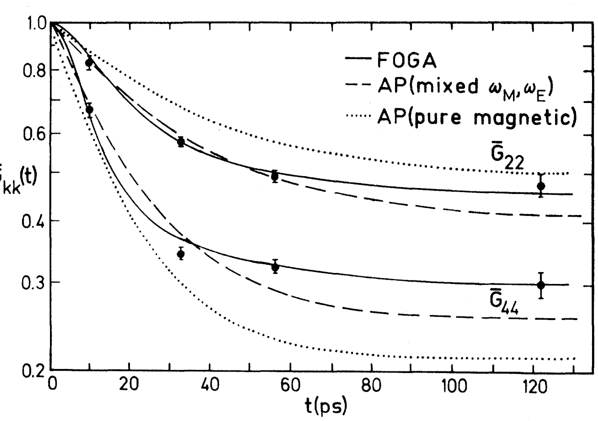

FIG. 2. Same as in Fig. 1, using the data of Polga *et al.* (Ref. 5) for ^{150}Sm (2^+) recoiling into vacuum.

a slight suppression of the hard-core values $(2k+1)^{-1}$. As a test we have a separate FOGA fit excluded the experimental Hf points for $t > 50$ psec which are within the hard-core region. As is seen from the table (time interval $0 \leq t \leq 35$ psec), τ_c becomes smaller. The magnetic field variance $\langle H^2 \rangle$ remains the same. We also note the surprising quality of the FOGA fit to the ^{150}Sm data in view of the fact that the correlation time τ_c turns out to be relatively small. It may be that the dipole rule prevents a drastic violation of the fixed-orientation approximation, even for a relatively small correlation time.

Despite the apparent success of the FOGA model, the approximate nature should be clearly recognized. The assumption of a Gaussian distribution of the perturbing fields is expected to be fulfilled, at least qualitatively, in high-energy heavy-ion recoil, but probably not in very low-energy recoil and certainly not in cases of ions where all electrons except one or two have been stripped off. Furthermore, one has replaced the hyperfine interaction by a semiclassical field. Finally, as a result of the fixed-orientation approximation, the model is applicable only in a limited time interval. It should be clear that for free ions the model becomes meaningless for $t \gg \tau_c$. A stochastic model that avoids some of these limitations is that of Scherer and Blume.[7] However, it is assumed in this model that after a transition all new orientations of the system are equally probable, which is in contradiction with the dipole rule. Nevertheless, results of fits with this model would certainly be interesting, but have not yet been attempted.

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Observation of a Crossover in the Differential Cross Sections for Q-Meson Production*

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A crossover is observed in the differential cross sections for the inelastic processes $K^0p \to Q^0p$ and $\overline{K}^0p \to \overline{Q}^0p$, from $K_L{}^0p$ data in the momentum range from 4 to 12 GeV/c. This phenomenon is evidence that Regge, in addition to Pomeranchukon, exchanges contribute to Q-meson production.

One of the well-known features of elastic scattering is the "crossover" phenomenon where the differential cross sections for the reactions $Xp \to Xp$ and $\overline{X}p \to \overline{X}p$ (X is π^+, K^+, or p) have different forward slopes but become equal in magnitude in the vicinity of $-t \sim 0.2$ GeV^2.[1] The crossover effect recently has been interpreted as a sensitive probe of the Regge exchange contribution to the elastic scattering amplitude.[2]

In this Letter we report the first experimental observation of the crossover phenomenon in inelastic reactions. A $K_L{}^0$ beam (with equal components of K^0 and $\overline{K}^0$ mesons) has been used to obtain a precise comparison of the Q^0 and $\overline{Q}^0$ dif-