tials. Band extrema are again determined and the procedure repeated until the conduction-band minimum and the d-band extrema have converged to within 0.005 eV. Calculations using other approximations suggest an uncertainty of $\lesssim 0.3$ eV and $E_{\rm band}$ and $\lesssim 1$ eV in $\epsilon_F - \epsilon_{5f}$.

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Is the Deformation Parameter β Different for Different Kinds of Transitions?

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It is shown on the basis of isospin arguments that the deformation parameter β_2 for 2^+ first excited states is expected to be a function of the external field producing the transition. This is contrary to the usual assumption based on the collective model that β is an intrinsic property of the nucleus and is, therefore, the same for all kinds of transitions. Data available in the literature support the expectation.

It is usually assumed *a priori* for lack of better information that the deformation parameter β for excitation of a collective state is independent of the means of excitation. This idea stems directly from the usual collective model, where the neutron and proton matter distributions are assumed to have the same shape. The purpose of this note is to point out, however, that a systematic difference in the deformation parameter β_2 is expected when the first excited 2^+ collective state of nuclei is excited by different external fields. Several authors[1] have pointed out from the point of view of a microscopic model that (p,p') and (n,n') might be rather different because of a difference between n-n or p-p and n-p forces. Spin-dependent forces are not very effective in exciting the these states, and the spin-independent n-p force is much stronger than the n-n or p-p forces. This fact is taken into account in the optical model of elastic scattering by the Lane potential[2] $\hat{V}_1 T\cdot t/A$, which has the effect of making the nuclear potential deeper for protons than for neutrons in neutron-excess nuclei. However, when the collective model is then applied to inelastic scattering of 2^+ states, the deformed optical potential may fail badly in describing the excitation process.

As an example of the expected failure consider a nucleus like ^{90}Zr, which has the $N=50$ neutron shell closed. In an extreme shell-model picture the 2^+ vibration would involve just the protons filling the 29–50 shell, which would be excited much more strongly by neutrons than by protons. On the other hand the deformed optical potential would inappropriately describe the difference between (n,n') and (p,p') in terms of the neutron excess and would therefore be greater for proton projectiles. In reality both the neutron and proton closed shells participate rather strongly through $\Delta N=2$ transitions, and these transitions give rise to large corrections to the shell-model amplitudes expressed in terms of polarization charges. Because core polarization reduces the isovector amplitude and enhances the isoscalar amplitude, the collective-model picture of the excitation, whose strength is represented by the intrinsic parameter β, is nearly recovered. However, it is expected that some residue of the shell effect will remain, so that the parameter β will be different when measured by different kind kinds of transitions.

A convenient parametrization of the expected differences based on the collective model can be made by use of different deformation parameters

β_0 and β_1 for the $\hat{V}_0$ and $\hat{V}_1$ isoscalar and isovector terms of the deformed optical potential. If it is assumed that the imaginary and real parts of the Lane potential[2] are in the same ratio as the isospin-independent terms,[3] $\hat{W}_1/\hat{V}_1=\hat{W}_0/\hat{V}_0$, it is possible to define an overall deformation parameter β for scattering as the ratio of the interaction to the radius-multiplied derivative of the optical potential:

$$\begin{pmatrix}\beta_{nn'}\\ \beta_{pp'}\end{pmatrix}\approx\beta_0\left[\begin{pmatrix}1\\1\end{pmatrix}+\begin{pmatrix}1\\-1\end{pmatrix}\frac{\hat{V}_1}{\hat{V}_0}\frac{N-Z}{4A}\left(\frac{\beta_1}{\beta_0}-1\right)\right]. \quad (1)$$

Corresponding to Eq. (1) a deformation parameter can also be written down for electromagnetic transitions, under the assumption by analogy with the deformed-Lane-potential model[4] that the isovector operator is effective only on the neutron excess[5]:

$$\beta_{\mathrm{em}}\approx\beta_0\left[1-\frac{N-Z}{A}\left(\frac{\beta_1}{\beta_0}-1\right)\right]. \quad (2)$$

For the special case of single-closed-shell nuclei in which the shell model of the 2^+ vibration involves only neutrons or protons, the ratio of isovector to isoscalar strength as given by the collective-model parameters should be set equal to the ratio of isovector to isoscalar effective strength parameters:

$$\frac{\beta_1}{\beta_0}\frac{N-Z}{A}=\pm\frac{\epsilon_{11}\pm\epsilon_{01}}{\epsilon_{00}\pm\epsilon_{10}}, \quad (3)$$

where the upper signs refer to target n, the lower to target p, and where $\epsilon_{\tau'\tau}$ is an element of a core-polarization matrix ϵ described in another publication.[6] The necessity that the matrix ϵ include nonzero off-diagonal elements arises from the lack of purity of the isoscalar and isovector giant resonances, which are mixed with the shell-model states by the interaction with the core. The index τ' designates whether the polarization parameter $\epsilon_{\tau'\tau}$ is isoscalar or isovector in the shell-model nucleons, and the index τ designates whether it is isoscalar or isovector for the nucleus as a whole. Consideration of several rough nuclear models for the elements of ϵ shows that $\beta_1\neq\beta_0$ and that differences of up to about 20% are expected between $\beta_{pp'}$ and β_{em}, for example, for single-closed-shell nuclei. More details of this development will be given in a separate paper.[7]

On the experimental side we have searched the literature for $\beta_{pp'}$ to compare with Stelson and Grodzins's[8] tabulation of β_{em}. These include ^{44}Ca, ^{50}Ti, ^{52}Cr, ^{54}Fe, isotopes of Ni, ^{88}Sr, ^{90}Zr, ^{92}Mo, and isotopes of Sn. Since $\beta_{pp'}$ involves target neutrons more strongly than protons and vice versa for β_{em}, we expect $\beta_{\mathrm{em}}<\beta_{pp'}$ for proton-closed-shell nuclei and vice versa for neutron-closed-shell nuclei. Data on (n,n') are too scarce for a comparison. For the proton-closed-shell nuclei $\langle\beta_{\mathrm{em}}-\beta_{pp'}\rangle$ is -0.015 with a standard deviation of 0.012 and for neutron-closed-shell nuclei it is $+0.028$ with a standard deviation of 0.020. Although the differences[9] in individual nuclei are about the size of the expected experimental errors, the probability that the difference in the means could occur by chance is 10^{-4}. Furthermore, ratios of the β parameters are in the range expected on theoretical grounds as discussed above. Details of the comparison will also be given in Ref. 7.

The averages given above use $\beta_{pp'}$ parameters determined from data without making a correction for the finite range of the interaction between the projectile and the matter of the nucleus.[10-12] This is probably not a serious problem since it has been shown by Satchler[12] that for quadrupole transitions this correction is essentially canceled by exchange effects. The averages also use[8] β_{em} obtained with the uniform-density model. Downward corrections of 4–10% in β_{em} are indicated by calculations[13,14] of multipole integrals using a diffuse density distribution. However, we do not believe that including these corrections will alter our conclusions since nuclei with neutron vibrations or nuclei with proton vibrations would be affected in the same way. Nevertheless, it is obvious that systematic studies of $\beta_{nn'}$, particularly in single-closed-shell nuclei, would be valuable in confirming the existence of these differences, since the finite-range correction would be essentially the same in both (n,n') and (p,p').

In summary, a difference in the parameter β as measured by electromagnetic and (p,p') transitions both is expected on theoretical grounds and appears to be present in the data available in the literature. We wish to emphasize that, in contrast to the assumption commonly made in practice, there is an *a priori* reason to expect β's obtained from different kinds of measurements to be different even after the finite-range and realistic nuclear-density corrections have been made.

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Tangential Friction in Deep-Inelastic Scattering of ^{16}O from Nickel

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Bombarding Ni targets with 96-MeV ^{16}O ions, we have observed deep-inelastic groups of mass-16 and -12 reaction products with Q values centered at -30 to -35 MeV. From the multiplicity of the coincident γ de-excitation, total fragment spins and hence, using a classical model, orbital angular momentum transfers of $12\hbar$ to $15\hbar$ are deduced. These, and at least 50% of the energy dissipation, are ascribed to tangential friction.

Recent studies of collisions induced by heavy projectiles, e.g., ^{40}A and ^{84}Kr, with heavy targets at energies well above the Coulomb barrier have revealed[1] a new type of reaction mechanism. The terms deep-inelastic scattering or transfer, quasi fission, or strongly damped collisions have been used to describe processes which have in common a large dissipation of the entrance-channel kinetic energy. In the attempts to describe these processes by the action of frictional forces, the importance of tangential friction, causing a loss of orbital angular momentum, is widely discussed,[2,5] while no experimental information seems to exist on this point. In this Letter, we first show that deep-inelastic scattering occurs also for the ^{16}O + Ni system at 6 MeV/A which is a much lighter target-projectile system than those for which this process has been observed so far. Second, we present a measurement of the multiplicities of γ rays emitted by the reaction products from which we deduce the fragment spins and hence the energy loss due to of tangential friction.

At the upgraded[6] Heidelberg MP-type Van de Graaff tandem accelerator a beam of 96-MeV ^{16}O was used to study the reactions induced in a 1.3-mg/cm^2 nickel target. The light reaction products were measured at laboratory scattering angles between 25° and 55° with a time-of-flight arm of 80 cm length. The time-start signal was derived from a 0.5-mg/cm^2 scintillator foil, the energy and the time-stop signal from two 300-μm-thick Si detectors of 450 mm^2 area each. Three 3-in.$\times$3-in. NaI(Tl) detectors were placed 15 cm from the target and operated in coincidence with the particle detectors. One of the γ detectors was mounted in the scattering plane at $\theta_\gamma = 135°$ and two at $\theta_\gamma = 90°$ and azimuthal angles of