dent proton energies ranging from 12.35 to 12.95 MeV in steps of approximately 120 keV. As the proton bombarding energy was increased, all elastic and inelastic peaks moved to higher channels. This can be seen in the spectrum of Fig. 2(b) taken at incident proton energy of 12.95 MeV. In contrast, the position of the $\tilde{p}$ peak did not change, thus proving that the $\tilde{p}$ proton results from a proton transition between two states. The six spectra were added to accentuate any proton group with energy largely independent of the incident proton energy, and their sum is shown in Fig. 2(c). As expected, this procedure extensively broadened all prominent peaks with the exception of the $\tilde{p}$ peak.

The total observed energy of the $\tilde{p}$ decay was 4.74 ± 0.03 MeV. From this, using recently reported Q values,[7] the Coulomb displacement energy is found to be 11.94 ± 0.03 MeV, which is in reasonable agreement with the value 11.75 ± 0.15 MeV measured by Anderson, Wong, and McClure[2] for Zr. Assuming isotropic distribution of the observed $\tilde{p}$ from the decay of Nb^{91*}, the integrated cross section for the reaction is approximately 5 mb. Further measurements of this type are in progress using other targets for which the analog state is proton unstable.

In conclusion we point out that the $(p, n\tilde{p})$ reaction, when feasible, has the advantage of the large cross section of the (p,n) reaction,[1] while at the same time bypassing the difficulties of neutron spectroscopy. Exact knowledge of the incoming proton energy is not needed, and a small energy spread in the incident beam is not required. In fact the larger the spread the more accentuated is the $\tilde{p}$ peak.

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DISCREPANCIES IN PROTON-TRANSFER REACTIONS TO STATES WITH DIFFERENT ISOBARIC SPIN*

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It is widely accepted that the direct reactions (d,n) and (He^3,d) are analogous processes involving proton transfer and that they should therefore yield the same reduced widths (spectroscopic factors). We have compared the relative spectroscopic factors from (He^3,d) reactions with those from (d,n) reactions to the low $T=0$ and $T=1$ states in the odd-odd nuclei B^{10}, N^{14}, and Al^{26}. In contrast to expectation, we find that in each case a smaller value of the relative spectroscopic factor for the $T=1$ states is deduced from the (d,n) reaction than from the (He^3,d) reaction, the spectroscopic factors being normalized to the $T=0$ ground states for the two reactions.

The (He^3,d) reactions leading to B^{10} and Al^{26} at $E(\mathrm{He}^3) = 17$ MeV and to N^{14} at 13 and 17 MeV were studied at the Argonne tandem Van de Graaff with a counter telescope. The (d,n) reactions leading to N^{14} and Al^{26} were measured at $E(d) = 5.5$ MeV at the Hahn Meitner Institut with a pulsed-beam time-of-flight spectrometer. Both sets of observations were at forward angles. Relative spectroscopic factors were obtained from the reactions studied, as well as from other data,[1-8] by means of distorted-wave Born-approximation (DWBA) theory with reasonable distortion parameters. Since the lowest $T=1$ state in an odd-odd $T_z=0$ light nucleus is bracketed by $T=0$ states with little difference in excitation energy, the relative spectroscopic factors are rather insensitive to the choice of the distortion parameters. Furthermore, all final states within one nucleus for which the spectroscopic factors are compared are formed by proton capture with the same orbital-angular-momentum transfer ($l=1$ for B^{10} and N^{14}; $l=2$ for Al^{26}).

It can be seen from Tables I-III that the relative spectroscopic factors for the $T=0$ states are approximately the same for the (He^3, d) and the (d,n) data, whereas for the $T=1$ transitions the values from the (d,n) reaction are less than those from the (He^3, d) reaction. This effect exists at all the energies studied, although the magnitude of the effect may exhibit a slight energy dependence. In the reaction $Be^9(d,n)B^{10}$, the relative spectroscopic factor for the $T=1$ transition is smaller than in the corresponding (He^3, d) reaction by roughly a factor of 3; in the reactions leading to the $T=1$ states in N^{14} and Al^{26}, this factor is approximately 1.6 to 1.8. For B^{10} a comparison of the reactions leading to the 3.57-MeV state is not shown (although this state is also formed by $l=1$ proton transfer) since the angular distribution of the (d,n) reaction[1,3,9] leading to this state shows anomalous behavior. For N^{14}, the relative (d, n) and (He^3, d) spectroscopic factors for the $T=0$ states differ somewhat. In addition, the relative spectroscopic factors for Al^{26} from the (d,n) reaction should be taken with some caution. At 3 MeV, the (d,n) angular distributions show evidence of some compound-nucleus reaction which may still be present at 5.5 MeV. Despite these qualifying remarks, the effect that consistently shows up in Tables I-III is that involving the $T=1$ states.

Table I. Relative spectroscopic factors of B^{10} from the reactions $Be^9(d,n)B^{10}$ and $Be^9(He^3,d)B^{10}$ and from theory.

E_x (MeV)	J^π	T	$Be^9(d,n)B^{10}$ $E_d=2.8$ MeV[a]	4.0 MeV[b]	7.0 MeV[c]	$Be^9(He^3,d)B^{10}$ $E_{He^3}=10$ MeV[d]	17 MeV	25 MeV[e]	S (Theor.)[f]
0	3^+	0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
0.72	1^+	0	2.24	2.2	2.3	2.0	1.8	1.94	1.38
1.74	0^+	1	0.85	1.1	1.0	3.35	2.6	2.7	1.96
2.15	1^+	0	0.60	0.4	0.41	0.57	0.55	0.55	0.42

[a] Ref. 3. [b] Ref. 2. [c] Ref. 1. [d] Ref. 6. [e] Ref. 4 [f] Ref. 10.

Table II. Relative spectroscopic factors of N^{14} from the reactions $C^{13}(d,n)N^{14}$ and $C^{13}(He^3,d)N^{14}$ and from theory.

E_x (MeV)	J^π	T	$C^{13}(d,n)N^{14}$ $E_d=3.9$ MeV[a]	5.5 MeV	$C^{13}(He^3,d)N^{14}$ $E_{He^3}=13$ MeV	$E_{He^3}=17$ MeV	S (Theor.)[b]
0.0	1^+	0	1.0	1.0	1.0	1.0	1.0
2.31	0^+	1	0.97	1.1	1.93	1.6	1.25
3.91	1^+	0	0.72	0.8	0.52	0.5	0.25

[a] Ref. 5. [b] Ref. 10.

Table III. Relative spectroscopic factors of Al^{26} from the reactions $Mg^{25}(d,n)Al^{26}$ and $Mg^{25}(He^3,d)Al^{26}$.

E_x (MeV)	J^π	T	$Mg^{25}(d,n)Al^{26}$ $E_d=3.0$ MeV[a]	5.5 MeV	$Mg^{25}(He^3,d)Al^{26}$ $E_{He^3}=17$ MeV	$E_{He^3}=22$ MeV[b]
0	5^+	0	1.0	1.0	1.0	1.0
0.23	0^+	1	2.0	1.8	3.27	2.8
1.06	1^+	0	2.8	1.55	1.6	1.6

[a] Ref. 7. [b] Ref. 8.

Also included in Tables I and II are relative spectroscopic factors as predicted by the intermediate-coupling model,[10] the normalization again being to the $T=0$ ground states. The theoretical spectroscopic factors for the $T=1$ states are larger than those from the (d,n) reaction and in better agreement with the spectroscopic factors from the (He^3,d) reaction. For N^{14}, discrepancies also exist between the theoretical and experimental spectroscopic factors for the $T=0$ states.

In Table IV, absolute spectroscopic factors for B^{10} and the ground state of Be^{10} are compared with the theoretical[10] spectroscopic factors. In contrast to the relative spectroscopic factors, these numbers do sensitively depend on the distortion parameters chosen and are therefore less certain. Absolute spectroscopic factors have been calculated from the differential cross sections by use of the usual expression

$$\frac{d\sigma}{d\Omega}=\frac{2J_f+1}{2J_i+1}NC^2S\sigma_{\text{DWBA}}(\theta),$$

where N is equal to 1.5 for the (d,n) and the (d,p) reaction and 3.8 for the (He^3,d) reaction. C is the isobaric-spin coupling factor. The absolute spectroscopic factors derived from the reaction $Be^9(He^3,d)B^{10}$ agree remarkably well with those predicted by the intermediate-coupling model. Those for the $T=0$ states from the (d,n) reaction agree moderately well. The major disagreement with theory is that the (d,n) reaction gives a low value for the spectroscopic factor of the $T=1$ state. The spectroscopic factor for the ground state of Be^{10} as deduced from the (d,p) reaction[11] is also low but in good agreement with the spectroscopic factor of the first $T=1$ level in B^{10} as deduced from the (d,n) reaction. The latter result confirms that obtained by Calvert, Jaffe, and Maslin[12] and is expected as a direct consequence of charge symmetry.

The difference between the relative yields of the transitions to the $T=1$ states in the (d,n) and the (He^3,d) reactions is not understood. Originally it was thought that exchange or cluster effects present in the (d,n) reaction might be responsible for the observed difference. If exchange stripping in the (d,n) reaction involves only the low-lying $T=0$ states of the core as intermediate parent states, then this mechanism is not expected[2,13] to contribute to the $T=1$ final state. If exchange effects are that important in the (d,n) reaction, however, we would also expect that the relative spectroscopic factors from the (d,n) and the (He^3,d) reactions to the various $T=0$ states should differ markedly since the spectroscopic amplitudes from the direct and the exchange terms are unrelated. This is in contradiction to observation. For the same reason, the angular distributions of the two reactions to individual states would be expected to differ markedly.

Table IV. Absolute spectroscopic factors from (d,p), (d,n), and (He^3,d) reactions on Be^9.

E_x	J^π	T	S $(d,p)^a$	 $(d,n)^b$	 $(He^3,d)^c$	 (Theor.)^d
0	3^+	0		1.0	0.92	1.20
0.72	1^+	0		2.24	1.78	1.64
1.74	0^+	1	1.30	1.0	2.52	2.36
2.15	1^+	0		0.40	0.51	0.51

[a] Ref. 11 (ground state of Be^{10}).
[b] Ref. 1.
[c] Ref. 4.
[d] Ref. 10.

A comparison of the angular distributions of the reaction $Be^9(d,n)$ at 7 MeV with that of the reaction $Be^9(He^3,d)$ at 17 MeV (Fig. 1) shows a striking similarity in their general shapes for transitions to the same final states. A deep minimum is observed for the transitions to the ground state and the first two excited states of B^{10} in both reactions, whereas the minimum is not as deep for the transition to the 2.15-MeV level. The striking similarity in the angular distributions of the (d,n) and the (He^3,d) reactions strongly suggests that both processes proceed mainly via the same reaction mechanism, namely single-proton transfer. This observation thus is further evidence against explaining the observed differences between the spectroscopic factors from the (d,n) and the (He^3,d) reactions by introducing an additional reaction mechanism.

Another explanation of the observed differences in spectroscopic factors is that the distorting potentials of the exit channel may depend on the configuration of the final state. Similarly, the form of radial wave function of the captured proton may depend on whether it is captured into a $T=0$ or a $T=1$ state. Because of the strong absorption of the He^3 particle, the (He^3, d) reaction is expected to be more localized on the nuclear surface than the (d,n) reaction; changes in the tail of the bound-state wave function will therefore have a greater effect on the (He^3, d) reaction. The use of a $2p$ wave function instead of the $1p$ wave function in a DWBA calculation to produce such a change indeed shows that the change in cross section for the (He^3, d) process is twice that for the (d,n) reaction. A $2p$ wave function was used because it was the most convenient way of introducing a drastic change in the tail of the bound-state wave function without changing the l value. Although there may be some theoretical justification for expecting the wave function for the $T = 1$ state to be different from that of the corresponding $T = 0$ state, a large difference would be required to reproduce the observed discrepancies between the (d,n) and the (He^3, d) reactions. Furthermore, this discussion implies that it is the (He^3, d) reaction which should exhibit the anomalous behavior. In contrast, the comparison of the theoretical and experimental spectroscopic factors in Table IV show that it is the (d,n) reaction to the $T = 1$ state [and of necessity the (d,p) reaction, from charge symmetry] that yields a spectroscopic factor smaller than expected. This result is puzzling, not only for an explanation of the present anomaly but also in view of the general belief that the (d,n) and (d,p) reactions are well described and that the intermediate-coupling wave functions for the low-lying levels of nuclei in the $1p$ shell are reasonably correct.

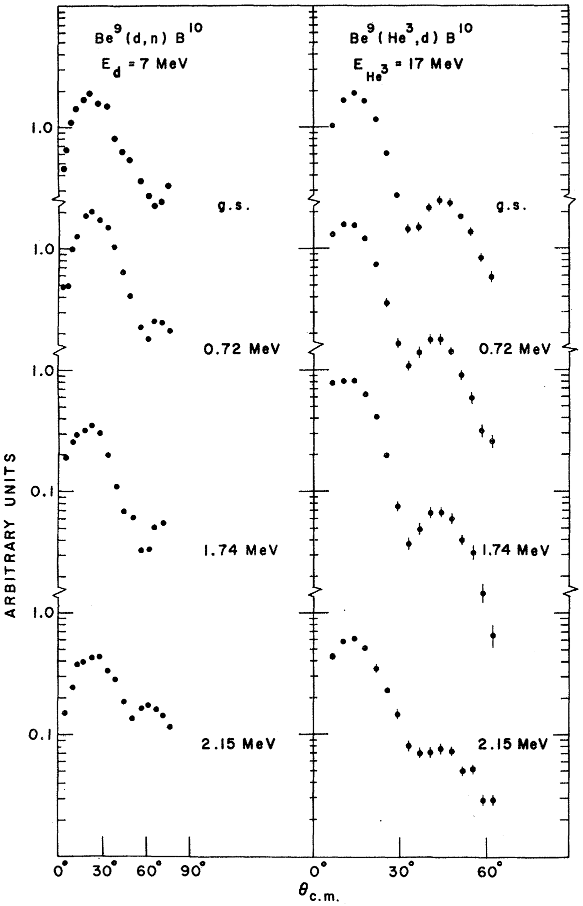

FIG. 1. Angular distributions for reactions Be^9(d, n)B^{10} and Be^9(He^3, d)B^{10} to the indicated levels. The Be^9(d,n)B^{10} data are taken from Ref. 1. The choice of angular scales results in angular distributions plotted against approximately the same momentum transfer of the captured proton in the two reactions. The cross-section scale is arbitrary, but relative cross sections for one type of reaction may be obtained from the scale.

In an attempt to determine whether the effect exists for nuclei of higher A, we have compared the existing data for the (d,p)[14] and (He^3, d)[15] reactions on K^{39} to the $T = 1$ analog states. In this case, the absolute spectroscopic factors deduced from the two reactions agree very well with each other and with theory. However, this result may not be relevant to the present discussion since, in contrast to the odd-odd final nuclei considered above, the Ca^{40} is even-even. We have also examined whether similar discrepancies are exhibited in other reactions. Triton spectra from the (α, t) reaction on Be^9 and other light nuclei bear little resemblance to those observed in the (d,n) or (He^3, d) reactions.[16] This suggests that there is no simple connection between the anomalous behavior observed in the present reactions to the $T = 1$ states and the behavior of the (α, t) reaction. A dependence on isobaric spin was found in a comparison of the (d, t) with the (p, d) reaction on Li^7. The ratio of the relative spectroscopic factors to the $T = 1$ state of Li^6 to that of the ground-state transition deduced from the reaction[17] Li^7(p, d) was about the same as that predicted from theory but was approximately twice the value deduced from the reaction Li^7(d, t).[18]

In conclusion, we have shown that there are serious discrepancies between (d,n) and (He^3, d) spectroscopic factors and that these seem to be correlated with isobaric spin. At present it is not known whether or not they are a peculiarity of direct reactions on light nuclei.

The present results show that for light nuclei even the relative spectroscopic factors extracted from direct-reaction theories must be taken with caution until a detailed explanation of the observed effects can be given.

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REFRACTION OF ELECTRON BEAMS BY INTENSE ELECTROMAGNETIC WAVES*

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It has long been known that electromagnetic waves are refracted by passing through a cloud of electrons. In a previous paper[1] it was suggested that the predicted intensity-dependent frequency shift in high-intensity Compton scattering[2] might be regarded as an example of the complementary effect, the refraction of a beam of electrons passing through an electromagnetic wave.

Here we shall show that this is a very general phenomenon. In particular, in an electromagnetic wave whose intensity is independent of time, the electron has an effective potential energy $\frac{1}{2}m\mu^2c^2$, where μ^2 is the intensity parameter [Eq. (5) below], and so the wave appears like a medium of refractive index $[1-\mu^2c^2/v^2]^{1/2}$.

Both the "field-gradient force" which has been shown by Phillips and Sanderson[3] to lead to significant effects on the experiment proposed to measure the frequency shift, and the $\vec{v}\times\vec{B}$ force which provides the acceleration mechanism responsible for this shift[1] are specific examples of a general force proportional to the spatial or temporal gradient of the field intensity, and leading to secular changes in the electron momentum or energy. (This is quite separate from the effect of radiation pressure,[4] though it might be regarded as due to the pressure gradient, if the electron were assigned an effective volume $r_0\lambda^2/\pi$.)

Let us consider an electron moving in an oscillating electromagnetic field whose amplitude is a slowly varying function of space and time. We wish to investigate the averaged motion of the electron, the analog of the guiding-center drift of a particle in a magnetic field. It is convenient to choose a frame of reference in which near $t=0$ the electron is, on the average, at rest at the origin. Then generalizing