The asymptotic value of this integral for large $z$ and for $\alpha z > 1$ is

$$\rho(z) = \frac{1}{8\pi^2}\frac{k_F^{\,2}-\alpha^2}{\alpha}\frac{1}{z^2}. \qquad (7)$$

The usual Ruderman-Kittel terms are included in the nonevanescing waves ($k > \alpha$). The destructive interferences of the oscillating waves, due to the physical irregularities (roughness) of the contact, reduce rapidly to zero the contributions of the nonevanescing waves. On the contrary, the evanescing terms which have a constant sign give a slowly decreasing polarization of spin (+), which appears as a tail in the polarization of (F).

Let us now introduce at $z$ a ferromagnetic probe ($S$) of volume $v$, with the same Hamiltonian as (F). If $v$ is small enough, so as not to create bound states in (N), the coupling energy $W$, with the electrons described in (7), may be obtained by first-order perturbation.

$$W = -\rho(z)(\hbar^2\alpha^2/2m)v\cos\theta. \qquad (8)$$

$\theta$ = angle between the magnetization $\vec{M}v$ in ($S$) with that of (F), with the following numerical values: $\alpha$ = interatomic distance = 3 Å; $v = d^3$; $k_F d = 2$; $z = 30d$; and $E_F = 5$ eV. One obtains

$$W = 10^{-4}(\eta M/E_F)^{1/2}\ \mathrm{eV}. \qquad (9)$$

The ratio between $E_F$ and the exchange energy $\eta M$ is not well-known; with a reasonable estimate $\eta M/E_F \approx 10^{-2}$, one gets $W = 10^{-5}$ eV, which corresponds to the coupling of one Bohr magneton with a field of 2000 Oe.

Of course, the model considered gives the maximum possible interaction. Usually the (−) electrons will also have a tail in (N), whose effect is to oppose that of (+) electrons.

Another way of estimating the strength of this coupling is to fill the space from $z$ to infinity with probes like ($S$) (neglecting the fact, which will be considered elsewhere, that now bound states are associated with the probes). With the same numerical values one obtains $W \approx 0.6$ erg cm$^{-2}$, which is to be compared with the results quoted in references 1-4 which are in the range of $10^{-2}$ to $10^{-1}$ erg cm$^{-2}$.

A final remark: This coupling makes use of electrons of all energies between 0 and $E_F$, and thus should be independent of temperature and mean free path effects.

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# OBSERVATIONS OF FINE STRUCTURE IN ISOBARIC ANALOG RESONANCES*

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Isobaric analog states have been previously identified as resonances of the compound system in proton reactions and scattering.[1] Current theoretical interest in the details of these resonances have led us to remeasure, in very fine detail, two resonances in $Mo^{92}+p$ that are isobaric analogs of the first and second excited states of $Mo^{93}$.[2] The resonances occur at 5.3-MeV and 5.9-MeV proton energy and are $s$ and $d$ wave, respectively. Much of the theoretical interest is concerned with the question of whether or not the isobaric analog resonances characterized by isobaric spin quantum number $T = T_{\mathrm{target}} + \frac{1}{2}$ are effectively spread due to a possible mixing with the more abundant states with $T = T_{\mathrm{target}} - \frac{1}{2}$. The proton resonances selected are particularly well suited for this study since they occur below the neutron threshold and the other possible reactions (e.g., $p,\alpha$ and $p,\gamma$) are comparatively unimportant. Our previous analysis of the 5.3-MeV resonance[3] was based on elastic-scattering data taken at only one angle with a relatively thick target. We have remeasured this resonance and the 5.9-MeV resonance at three angles using thin targets and very fine energy resolution. We find that there is considerable fine structure in the vicinity of the resonance, becoming much less prominent away from resonance. In addition, we are able to fit the observed resonance shape (after averaging the data over 18-keV intervals) assuming a single level formula[4] only by taking the total width, $\Gamma$, to be considerably greater than the proton partial width, $\Gamma_p$.

Very thin targets were prepared by evaporation of enriched $^{92}MoO_3$ onto thin carbon backings which had been prepared previously by evaporation from a high-vacuum carbon arc. Proton beams from the tandem Van de Graaff were held to less than 2 $\mu$amp in order to minimize the dead time losses in the counting system. The beam energy loss in the target is estimated to have been approximately 1 keV for 5.3-MeV protons. In order to ensure that the beam energy spread was minimized, additional electrical filtering of the ion source arc was installed. This had the effect of lessening the beam fluctuations caused by current loading fluctuations. In addition, care was taken to maintain the balance of current on the slits of the analyzing magnet. The image slits of the 90° analyzing magnet were set 0.020 inch apart. The beam at the target chamber Faraday cup was monitored occasionally with a dc coupled oscilloscope in order to determine if there were fluctuations in intensity. With these precautions, the beam energy spread is estimated to be less than 1 keV.

The proton elastic-scattering excitation functions were measured with junction counter detectors placed at 90°, 125°, and 165° to the beam, each detector subtending a solid angle of approximately $6\times10^{-4}$ steradians. The total proton charge collected for each data point was 150 $\mu$C. The data for the $s$-wave resonance in $Mo^{92}(p,p)$ at 5.3 MeV are shown in Fig. 1. A smooth curve has been drawn through the actual data points. The dashed curve is a theoretical single-level formula result assuming $\Gamma_p = 7$ keV and $\Gamma = 27$ keV. Figure 2 is the same data over a smaller energy interval at one angle with the data points shown for three different runs. Similar data for the $d$-wave resonance at 5.9 MeV are shown in Fig. 3.

The observed fine structure is seen to be of the order of 3 keV in width, is most prominent near the isobaric analog resonance energy, and virtually disappears away from resonance. It is not known whether "all" the structure has been observed—a better resolution technique might further subdivide the fine structure observed in this experiment. It is interesting to note that the fluctuations disappear more rapidly on the high-energy side of the resonance than on the

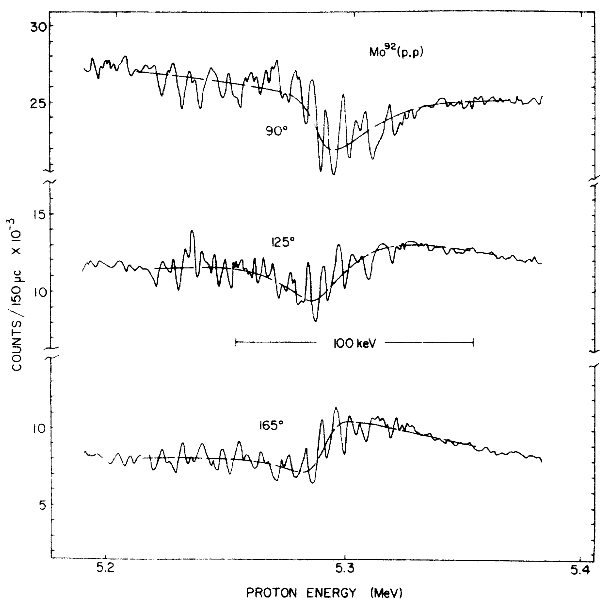


FIG. 1. Proton elastic-scattering yield from $Mo^{92}+p$ measured for $\theta_{lab} = 90°$, 125°, and 165° in the neighborhood of the $s$-wave isobaric analog resonance at $E_p = 5.3$ MeV. A smooth curve has been drawn through the actual data points. The dashed curve is a theoretical isolated level fit assuming $\Gamma_p = 7$ keV, $\Gamma = 27$ keV.

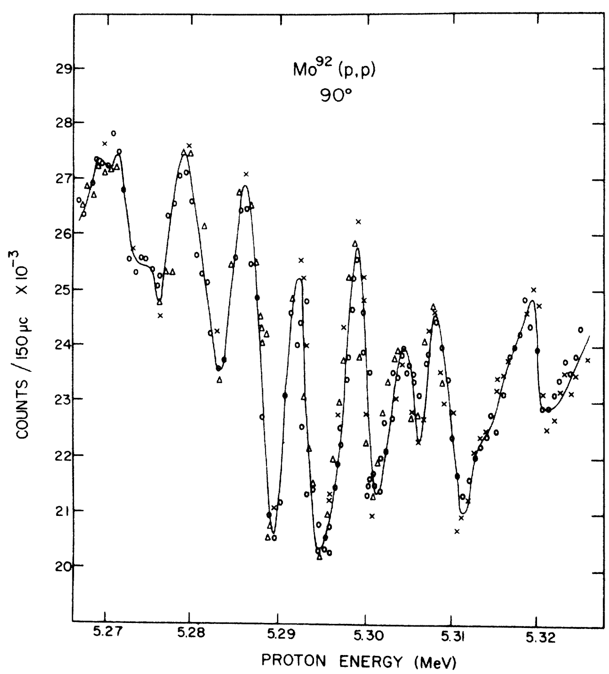


FIG. 2. Proton elastic-scattering yield from $Mo^{92}+p$ measured at $\theta_{lab} = 90°$. Three sets of data points corresponding to different running times are shown in the energy range $E_p = 5.27$ to 5.32 MeV. The smooth curve is drawn to indicate the behavior of the data.

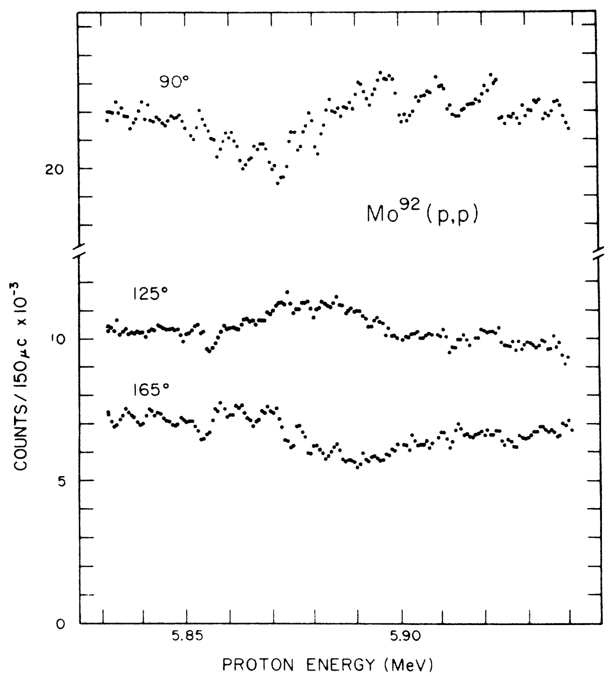


FIG. 3. Proton elastic-scattering yield from $Mo^{92}$ $+p$ measured at $\theta_{lab} = 90°$, 125°, and 165° in the neighborhood of the $d$-wave isobaric analog resonance at $E_p = 5.9$ MeV.

low-energy side. This asymmetry is observed at all three angles in the case of the $s$-wave resonance.

The present results clearly indicate the necessity of a many-level formulation rather than the single isolated-level interpretation which appeared reasonable for the analysis of the "thick" target data.[3] It is interesting to ask what is the nature of the fine structure. Is it, for example, due to the sharing of the strength of the analog state among the many neighboring states characterized ideally by $T = T_{target} - \frac{1}{2}$? Such a "giant resonance" interpretation involves isobaric spin mixing and, in essence, is closely analogous to optical-model giant resonance theory.[4] Some care should be exercised, however, because fine structure may be possible even when the isobaric analog state does not share an appreciable fraction of its strength with neighboring states. It can be shown[5] that the part of the scattering amplitude arising from the presence of these states may be enhanced in the neighborhood of a strongly excited state. Moreover, with this simple picture of one large state and many small states, it is possible to explain the asymmetry in the magnitude of the fluctuations about the resonance energy.

It is interesting to note that these data permit the study of fluctuations due to compound states of one particular spin and parity. Studies of the fine structure observed in the isobaric analog resonance in other nuclei are presently under way.

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