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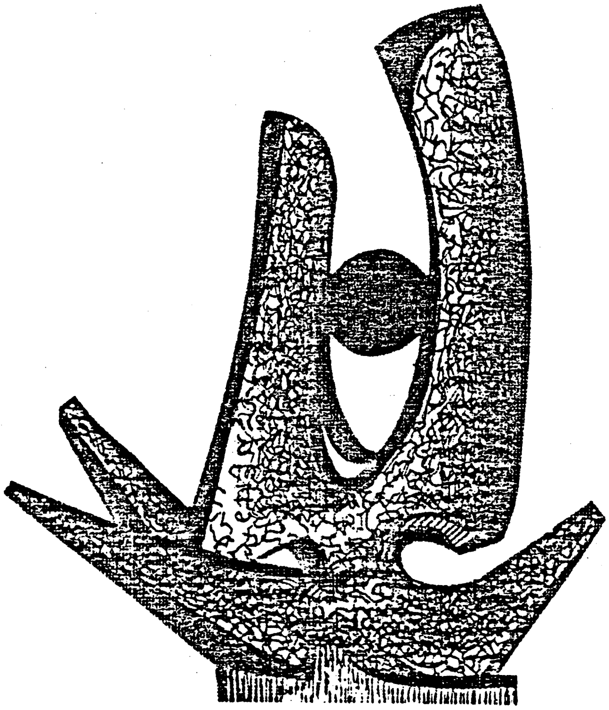

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Pairing Model Predictions for (p,t) Experiments on the Cadmium Isotopes[*]

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ABSTRACT

The even-even cadmium isotopes have been studied by the (p,t) reaction at 42 MeV. A broad resonance-like structure is observed between 6 and 7 MeV excitation energy which has similar properties to the feature observed in (p,t) reactions in the tin isotopes. A second smaller bump at higher excitation energy appears to arise from pickup of two particles from deep orbits.

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The distribution of one-hole strength in a large number of nuclei has been studied both experimentally (see ref. 1 and references therein) and theoretically.[2,3] Recently, a broad resonance has been observed near 8 MeV excitation energy in two particle pickup reactions on the tin isotopes.[4,5] These structures appear to arise from pickup of one neutron from a deep lying orbit ($g_{9/2}$) and one from a valence orbit.[6,7]

In order to gain further insight into these broad structures the (p,t) reaction was carried out on the even-even isotopes of cadmium, viz ^{106}Cd, ^{110}Cd, ^{112}Cd, ^{114}Cd, ^{116}Cd using the 42 MeV proton beam from the MSU K50 cyclotron. The tritons were detected on the focal plane of the Enge split pole spectrograph using a position sensitive proportional counter backed by a plastic scintillator. Triton spectra measured at a laboratory angle of 20° are shown in Fig. 1. Broad structure is observed in all the cadmium isotopes as in the tin case, but there appears to be somewhat more varied and fragmented structure in the cadmium spectra particularly for the higher isotopes.

Another important feature observed in the cadmium spectra is the appearance of a second broad bump at an even higher excitation energy. This second peak is marked with an arrow in the spectra in Fig. 1.

In the ^{104}Cd spectra it is possible to resolve individual levels which have been previously reported.[8] Using the ^{62}Ni(p,t)^{60}Ni reaction and ^{108}Cd(p,t)^{106}Cd reactions (from the ^{108}Cd impurity on the ^{106}Cd target) as calibrations, the Q-value for the ^{106}Cd(p,t)^{104}Cd reaction was measured as -10.802 ± 0.015

MeV. The ground state of ^{104}Cd was bracketed by the ^{60}Ni ground state and first excited states. The resulting mass excess is 83.990±0.021 MeV. This number disagrees significantly with the mass excess of ^{104}Cd recently measured[9] as 83.720±0.030 MeV using the β^+ decay of ^{104}Cd. This most recent measurement also disagrees with an earlier measurement[10] of the decay value by 164 keV even though the error on the earlier measurement was given as ±50 keV. In addition, in as much as the final mass excess obtained in the β^+ decay experiment depends on a much earlier measurement[11] of the decay of ^{104}Ag to an excited state of ^{104}Pd, the final value is obtained by a somewhat indirect route. Nevertheless, an independent measure of the mass excess of ^{104}Cd to resolve the discrepancy between the (p,t) and the β^+ measurement would appear to be useful.

The excitation energies of the enhancement in the cadmium spectra are plotted against the neutron number, N, of the target in Fig. 2 together with the values observed in the tin isotopes. For the cases in which the neutron number for cadmium and tin are the same (N=66 and 70) the value of the excitation energy for the lowest bump in the cadmium isotopes is reasonably close to the value for the tin isotopes. In general, the values of the excitation energies of the lowest energy feature show a smooth trend from cadmium to tin. In contrast, the excitation energy of the higher excited state in the cadmium isotopes increases much more rapidly with N than the lower energy bump.

A qualitative understanding of the energy systematics in the tin isotopes has been obtained using a simple pairing model for the two cases (1) when both neutrons are picked up from deep orbits (the 2d case) and (2) when one neutron is picked up from a valence orbital and one from a deep orbital,

(the v+d case). A detailed discussion has been given previously for the tin isotopes[7], and the applicable formulae are given in Table 1. In the case of the tin isotopes, the conclusion was reached that the broad bump around 8 MeV excitation energy had a dominant component of (v+d) configuration.

The simple pairing model for the excitation energy was also applied to the cadmium isotopes using the same values of V_{dd} (-1.7 MeV) and Δ(1.4 MeV). The (v+d) calculation is shown as a dot-dashed line in Fig. 2 and matches very well the magnitude and the variation with A of the excitation energy of the lowest energy feature. The implication is that this first bump corresponds to the same general configuration as was observed in the tin isotopes with one particle coming from a deep orbit and one from a valence orbit. The (2d) calculation, on the other hand, shown by a dashed line in Fig. 2 is lower by about 1 MeV than the experimental values for the higher energy bump but has a very similar slope. In fact, a choice of V_{dd} of about -0.7 MeV would bring the prediction into good agreement in both magnitude and slope with the measured values. This suggests that the second feature observed in the cadmium isotopes corresponds to picking up two particles from deep orbits.

Angular distributions have been extracted for the two broad features observed in the ^{106}Cd(p,t)^{104}Cd reaction but, as was also noted for the tin case, these distributions do not distinguish different structures. Even though the higher energy feature must contain $\ell=0$ strength if it arises from pickup of particles from the same deep orbit, the $\ell=0$ strength does not dominate the cross section. This feature is illustrated in Fig. 2 of ref. 4 in which calculated angular distributions for individual ℓ-transfers are shown. The angular distributions of both of the features appear to be incoherent mixtures of different ℓ transfers similar to the cases measured in the tin isotopes.

In summary, (p,t) reactions on the even cadmium isotopes show broad features at similar excitation energies and with similar dependence on A as those previously observed in the tin isotopes. In addition, a second smaller bump was observed at higher excitation energy the centroid of which varies more rapidly with A. This more rapid variation is in agreement with predictions of a simple pairing model in which this peak corresponds to pickup of neutrons from deep lying orbits.

Table 1

State	Excitation Energy Formula	Numerical Result for A-118
Single deep hole (1d)	$e_d - e_v \simeq (\varepsilon_F - \varepsilon_d) - \Delta$	5.4 MeV
Deep hole pair (2d)	$2e_d + V_{dd} \simeq 2\,(\varepsilon_F - \varepsilon_d) + V_{dd}$	11.9 MeV
Valence hole plus deep hole (v+d)	$e_d + e_v + V_{dd} \approx (\varepsilon_F - \varepsilon_d) + \Delta$	8.2 MeV

Pairing gap, $\Delta \simeq 1.4$ MeV, from average odd-even mass difference.
Interaction energy between particles in deep orbits, $V_{dd} = 1.7$ MeV from ref. 12.
$\varepsilon_F - \varepsilon_d = 6.8$ MeV, from empirical (1d) energy.

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Figure Captions:

Fig. 1. Triton spectra from the Cd(p,t) reaction at a laboratory angle of 20°. The arrow on each spectrum marks the position of the high excitation energy structure described in the text. The sharp peaks at very high excitation energy are from carbon and oxygen impurities in the cadmium targets.

Fig. 2. Excitation energy of structures observed in (p,t) reactions is plotted versus neutron number N of the target. The dash-dot line (valence plus deep hole calculation) is described in the text.

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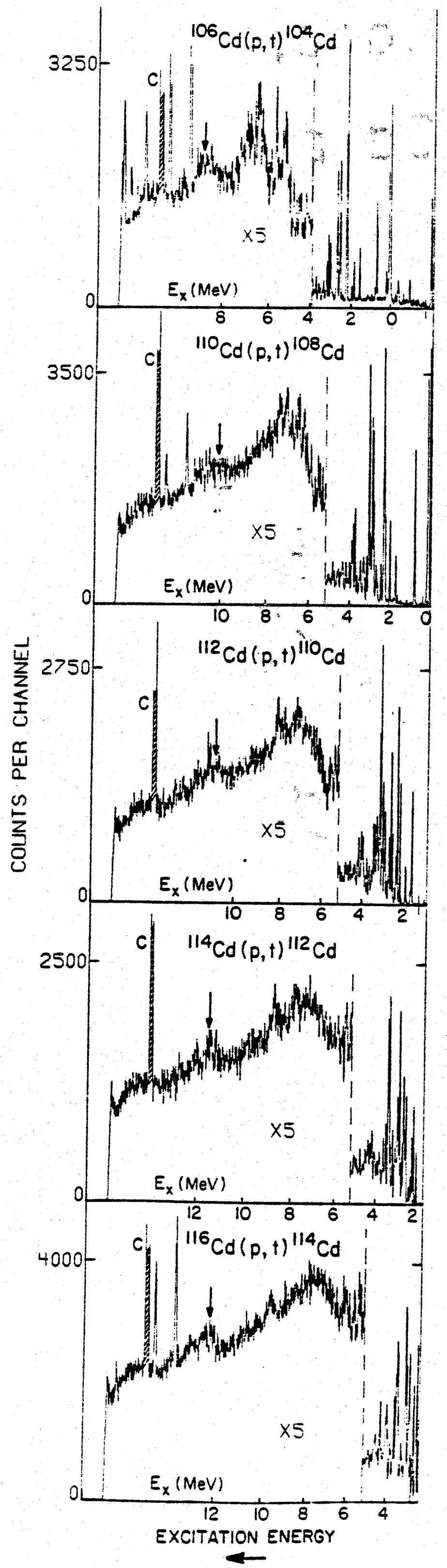
TRITON SPECTRA
$E_p=42$ MeV, $\theta=20°$



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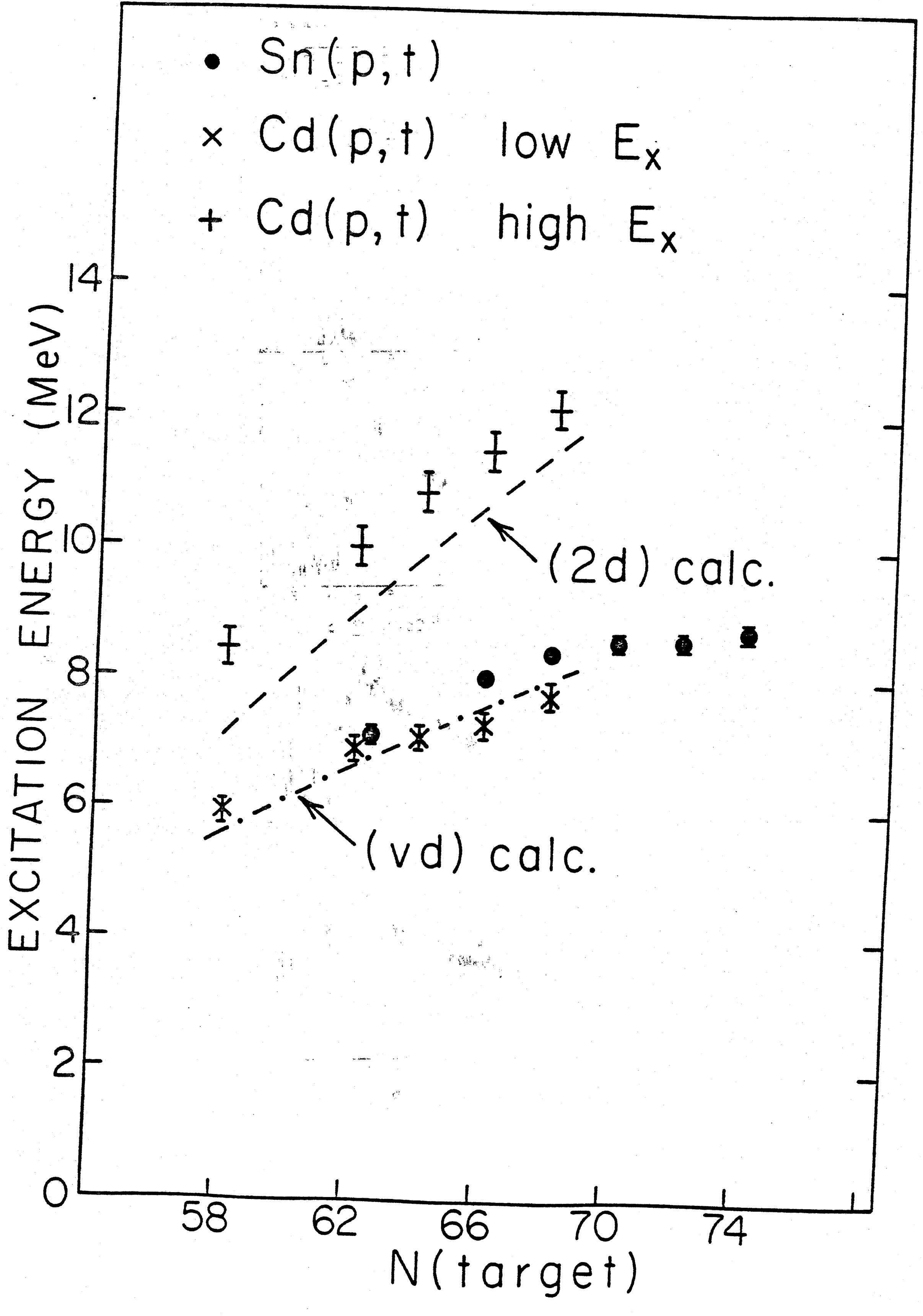

● Sn(p,t)
× Cd(p,t) low E_x
+ Cd(p,t) high E_x
EXCITATION ENERGY (MeV)
0
2
4
6
8
10
12
14
(2d) calc.
(vd) calc.
58
62
66
70
74
N(target)