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T=2 STATES IN THE T_Z=0 NUCLEI O^{16}-Ne^{20} AND THE T_Z=1 NUCLEI N^{16}-F^{20}

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T=2 STATES IN THE T_Z=0 NUCLEI O^{16}-Ne^{20} AND THE T_Z=1 NUCLEI N^{16}-F^{20}*

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Both the (p,t) and (p,He^3) reactions when employed on targets with isobaric spin greater than zero can produce states with $T > T_Z$ in the residual nucleus through pickup of the two nucleons in a ^1S, T=1 configuration. The (p,t) reaction on $T=T_Z=1$ targets has been demonstrated[1)] to produce readily observable yields to a T=2, T_Z=0 level in the final nucleus that is the analogue of the ground state of its T=2, T_Z=2 isobar. For example, investigation of the Mg^{26}(p,t)Mg^{24} reaction established the location of the 0+, T=2 state in Mg^{24} which is the isobaric analogue of the Ne^{24} ground state. We wish now to report observations of the two lowest T=2 states in O^{16} and Ne^{20} through the (p,t) reaction on O^{18} and Ne^{22}, respectively. Further, the analogous ability of the (p,He^3) reaction on these targets to locate the same T=2 states in the product T_Z=1 isobars N^{16} and F^{20} is demonstrated.

These (p,t) and (p,He^3) reactions were induced by a beam of 43.7 MeV protons from the Berkeley 88-in. cyclotron. After energy analysis, the protons impinged on a gas target located in the center of a 36-in scattering chamber. A 50 mg/cm^2 dE/dx-780 mg/cm^{2}E counter telescope, which was turned at an angle

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of 25° to the flight path of the scattered particles, fed an improved particle identifier[2]. Complete separation of the tritons and helium-3 ions from deuterons and He^4 was obtained. Total energy pulses were fed into a Nuclear Data analyzer so that the triton and helium-3 spectra were recorded simultaneously, each spectrum in a separate 1024 channel group. Resolutions (FWHM) of 150 keV for tritons and 200 keV for helium-3 were obtained. Since the T=2 states were predicted to lie at high excitations (overall Q-values of ≈ -24 MeV), a wide range of residual particle energies had to be observed. Energy calibrations over the region of interest again[1] utilized the $C^{12}(p,t)C^{10}$ ground state and first excited state transitions (Q = -23.33 and -26.67 MeV, respectively). The O^{18} gas was 97.5% pure and the Ne^{22}, 91.3% with 8.2% Ne^{20}; the impurities created no difficulties.

Figure 1 shows energy spectra from the $O^{18}(p,t)O^{16}$ and $O^{18}(p,He^3)N^{16}$ reactions, while fig. 2 shows spectra for $Ne^{22}(p,t)Ne^{20}$ and $Ne^{22}(p,He^3)F^{20}$. The helium-3 spectra have been shifted relative to the tritons to indicate the expected correlation of analogue states. The 0+, T=2 states are sharp, having widths defined by the experimental resolution. (The states tentatively identified as 2+, T=2 are discussed later.) Strong population in both spectra of many T=1 analogue states is also apparent.

Within the framework of charge independence of nuclear forces, these (p,t) and (p,He^3) transitions populating analogue T=2 states proceed from identical initial to final states via only ^1S,T=1 pickup. Hence their cross sections, in the limit of no Coulomb mixing or distortions in the final states, should be identical apart from a constant factor. One therefore expects quite similar angular distributions in these experiments for transitions to pairs of T=2 analogue states. Experimental support for this has been recently demonstrated by Cerny and Pehl[3] in similar reaction on O^{16}. (A comparison of the Coulomb mixing in these T=2 analogue states as estimated from the remaining

differences in the absolute cross sections requires further data and analysis; this and the population of the T=1 states will be discussed in a future publication.) Transitions to non 0+,T=1 states are not so simply related, since T=1 → T=1 (p,He^3) reactions may also proceed by ^{3}S,T=0 pickup whereas to first order all (p,t) transitions are restricted to ^{1}S.

The 0+ → 0+, L=0 (p,t) transitions possess characteristic angular distributions at this energy peaking at ≈ 26°-32° c.m. for light targets. Figure 3 presents the O^{18},Ne^{22}(p,t)O^{16},Ne^{20} ground state and the alleged lowest T=2 state angular distributions; also shown are the O^{18},Ne^{22}(p,He^3)N^{16},F^{20} lowest T=2 state angular distributions. As expected, all the angular distributions of the levels indicated as 0+,T=2 parallel those of the known L=0 (T=0) ground state transitions. The absolute cross-section, apart from statistics, should be accurate to ±10% and the statistical error varied from 4 to 25%.

Also indicated in figures 1 and 2 are less prominent states labelled 2+, T=2. These lie above the 0+,T=2 states by approximately the excitation of the 2+, first excited states[4)] of the analogue nuclei C^{16} and O^{20}. The combination of increasing background at small angles plus the shape of the L=2 angular distributions causes these 2+,T=2 transitions to be most prominent at 20°. This is illustrated for the O^{18} target in fig. 1; both the 2+,T=0 and 2+,T=2 states are relatively large at this angle. By 25°, however, as is indicated in fig. 2 for Ne^{22}, the 2+,T=0 group is quite small and the 2+,T=2 group is nearly obscured by the background. (A group between the 0+ and 2+,T=2 states is apparent in the Ne^{22}(p,He^3)F^{20} spectrum in fig. 2 and also appears in both spectra at other angles. We at present assume this is a T=1 state since no appropriate analogue state is known or expected in the O^{20} level scheme.) Angular distributions arising from these supposed 0+,T=1 → 2+,T=2 transitions should be similar and possess an L=2 shape; angular distributions to the states

labelled as 2+,T=2 in O^{16}, F^{20}, and Ne^{20} are also shown in fig. 3; the observable range of excitation in N^{16} was insufficient to locate the 2+,T=2 state. Shown for comparison is the $O^{18}(p,t)O^{16*}$ (9.85 MeV, 2+,T=0) angular distribution which illustrates the L=2 behavior expected. A characteristic shape for L=2 (p,t) transitions is found in heavier elements[5], but some variation in L=2 shapes in light elements has been observed by us, though none could be confused with L=0 behavior. The angular distributions to these alleged T=2 states are similar, definitely posses L > 0, and are consistent with L=2 behavior; their identification as 2+,T=2 analogue states appears reasonable.

Table 1 presents the predicted and experimental values for the excitations of the 0+,T=2 analogue levels in the T_Z=1 and 0 isobars. The predicted values are obtained by taking the mass difference between the ground states of the isobars and adding to this the appropriate Coulomb energy corrected for the neutron-hydrogen atom mass difference. Reference 1 gives the procedure when mirror nuclei are used to calculate the Coulomb energy. Since, however, the Thomas-Ehrman shift[6] in these light nuclei might produce somewhat questionable values for the Coulomb energy, the calculation was repeated obtaining the Coulomb energy from comparisons within T=1 multiplets, for example C^{14} and O^{14}. Table 1 shows the predictions of both schemes.

The agreement between the predicted and experimental excitations shown in table 1 is quite good; furthermore, except for Ne^{20}, no appreciable difference in the two sets of predictions is noticeable. Coulomb predictions based on accurate nuclear radii in these light elements would be necessary to ascertain exactly any differences between experiment and calculation. For example, using the r.m.s. radius for N^{14}(2.45f.) as typical of the mass 14 isobars and correcting to the r.m.s. radius of O^{16}(2.65f.)[7], rather than using the ratio $(14/16)^{1/3}$

as in the table, one obtains a predicted excitation for the 0+,T=2 state in O^{16} of 22.9$_2$ MeV, well within the experimental error. The present agreement is quite sufficient to indicate the absence of strong Thomas-Ehrman shifts on widely different spatial wave functions, relative to lower T-states, in these generally particle-unstable T=2 states. These data on the mass 16 and 20 isobars are displayed in fig. 4, which also illustrates the good agreement among the observed excitations of the 2+,T=2 isobaric analogue states.

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Table 1

Comparisons of the predictions based on Coulomb energies to the experimentally determined excitation energies for the lowest-lying T=2 states

Nucleus	Prediction from Coulomb energy differences using		Experimental value (MeV)
	Mirror nuclei (MeV)	T=1 multiplets (MeV)	
N^{16}	10.04	10.05	$9.9_1 \pm 0.1$
O^{16}	23.13	23.13	22.9 ± 0.1
F^{20}	6.38	6.40	$6.4_3 \pm 0.1$
Ne^{20}	16.59	16.67	16.8 ± 0.1

Figure Captions

Fig. 1. Top: Triton energy spectrum at 20 degrees from the $O^{18}(p,t)O^{16}$ reaction. Bottom: He^3 ion energy spectrum at 20 degrees from the $O^{18}(p,He^3)N^{16}$ reaction.

The spectra have been lined up to match the analogue states of O^{16} and N^{16}. Some low-lying T=1 and 2 states are indicated; the states labelled T=2 are analogues of C^{16}.

Fig. 2. Top: Triton energy spectrum at 25 degrees from the $Ne^{22}(p,t)Ne^{20}$ reaction. Bottom: He^3 ion energy spectrum at 25 degrees from the $Ne^{22}(p,He^3)F^{20}$ reaction.

The spectra have been lined up to match the analogue states of Ne^{20} and F^{20}. Some low-lying T=1 and 2 states are indicated; the states labelled T=2 are analogues of O^{20}.

Fig. 3. Angular distributions of tritons and He^3 ions from some of the reactions induced by 43.7 MeV protons on O^{18} and Ne^{22}.

Fig. 4. Schematic representation of the mass 16 and 20 isobars, emphasizing the correlation of the T=2 states.

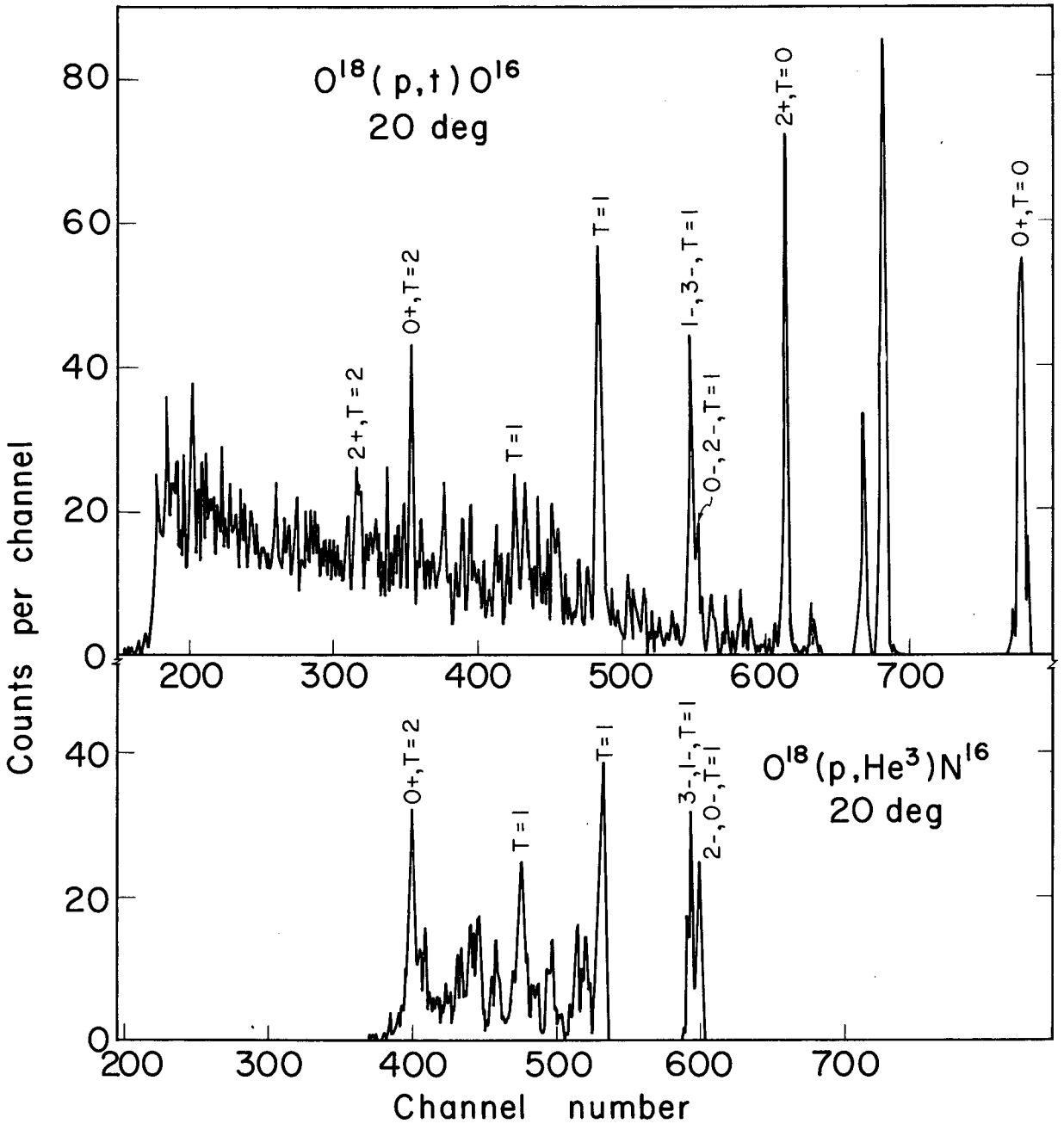

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Fig. 1

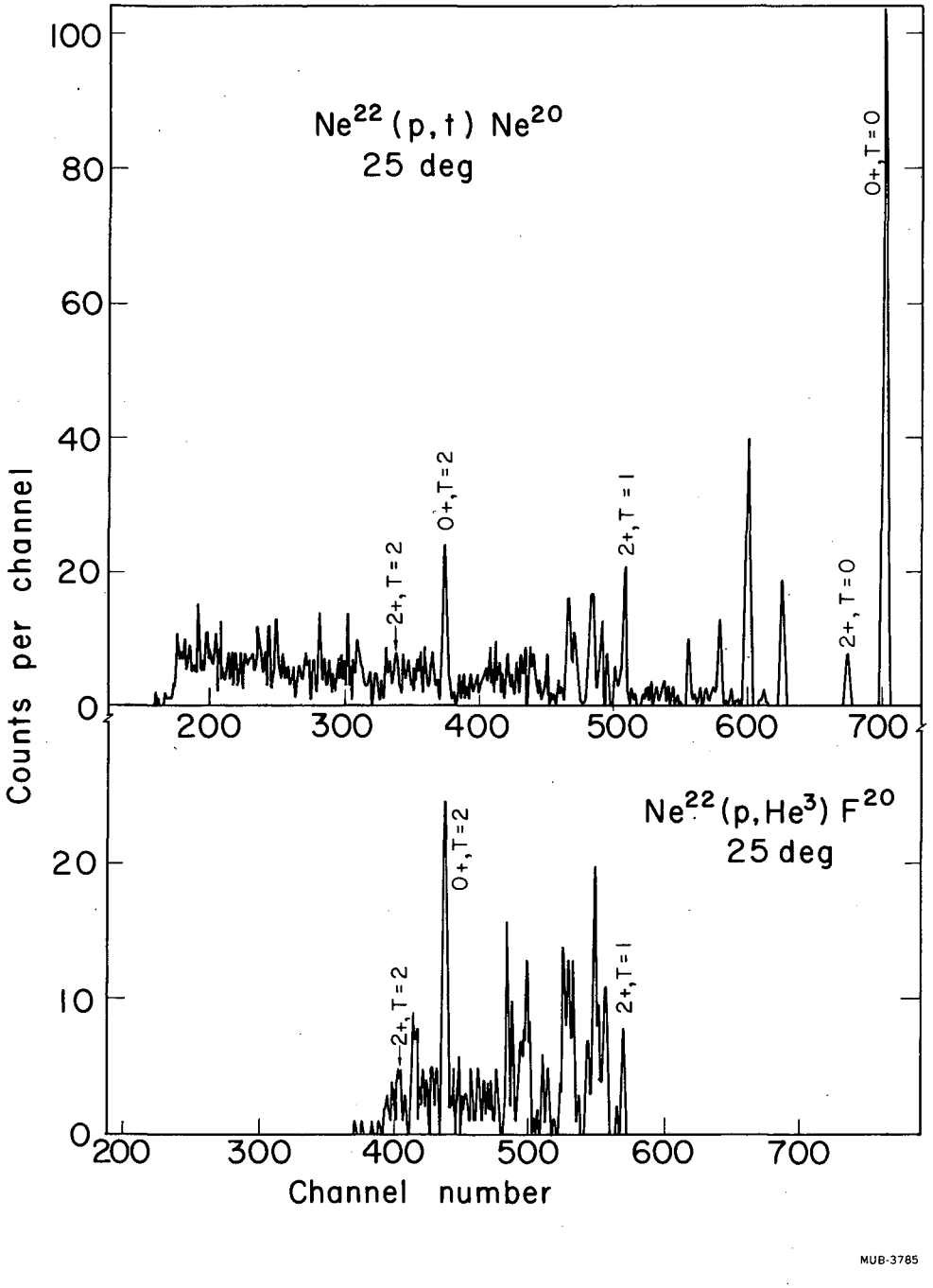
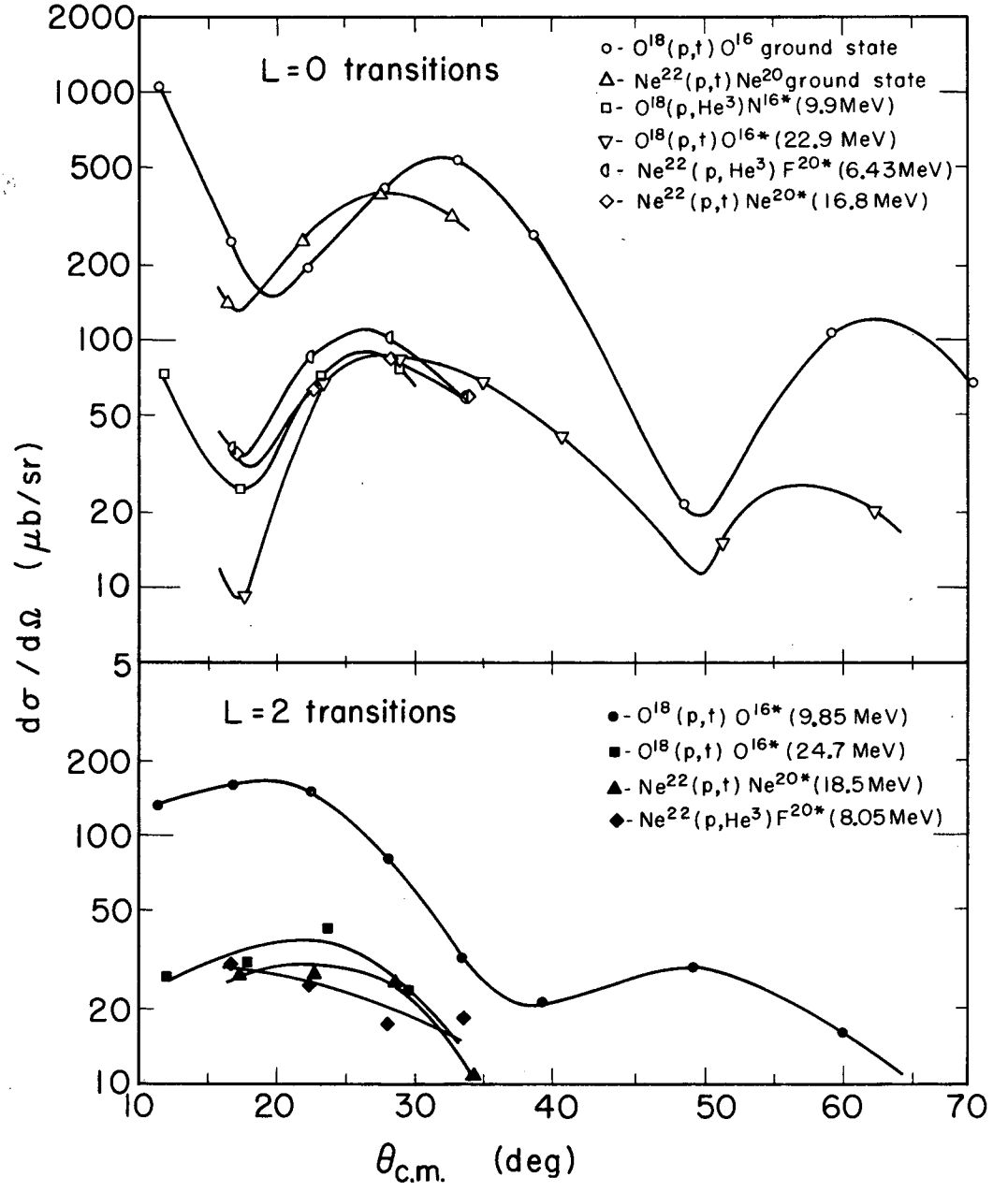

Ne22 (p, t) Ne20
25 deg
0+, T=0
0+, T=2
2+, T=2
2+, T=1
2+, T=0
Counts per channel
Ne22 (p, He3) F20
25 deg
0+, T=2
2+, T=2
2+, T=1
Channel number
MUB-3785

Fig. 2



MUB-3784

Fig. 3

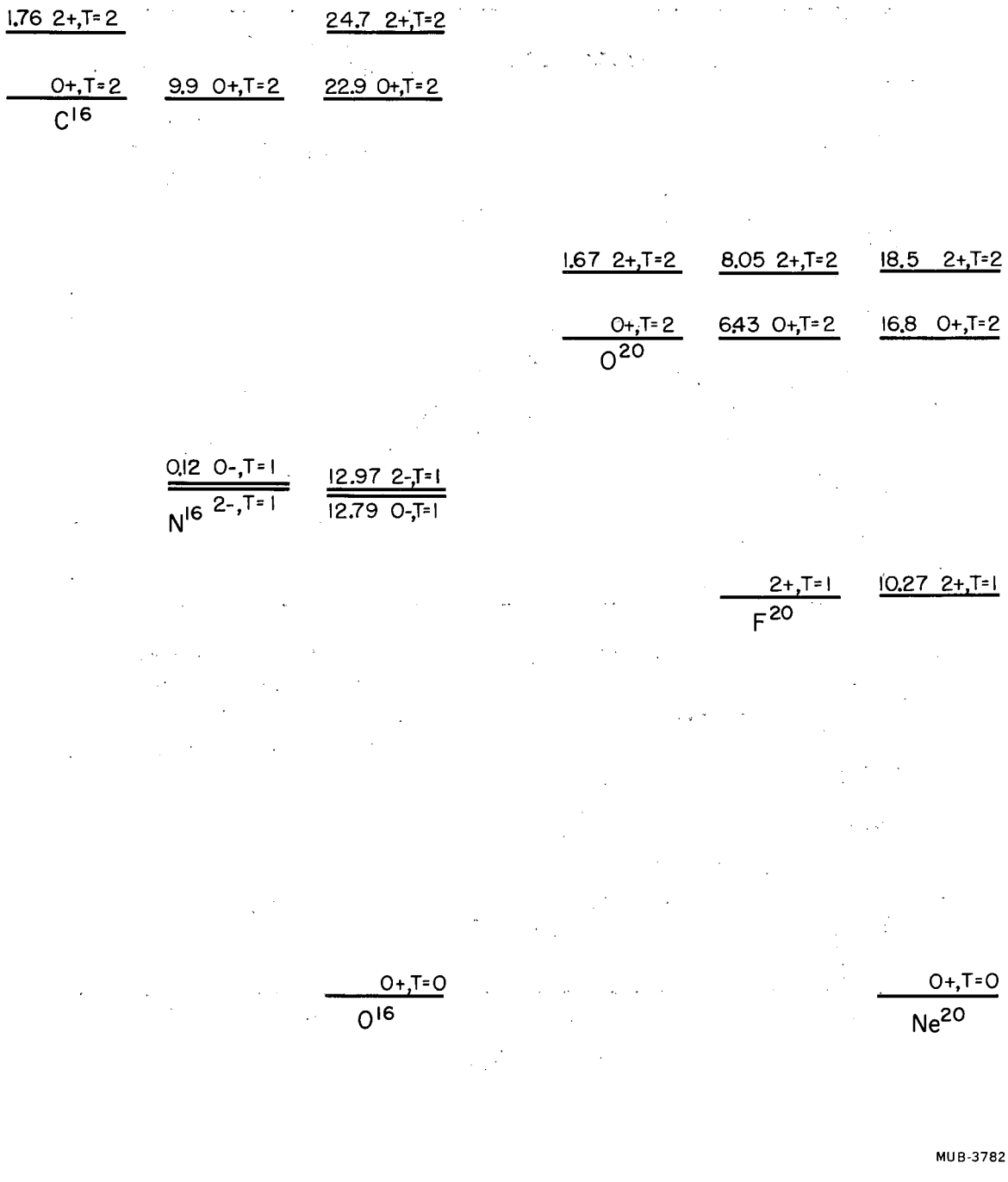

1.76 2+,T=2
24.7 2+,T=2
0+,T=2
9.9 0+,T=2
22.9 0+,T=2
C16
1.67 2+,T=2
8.05 2+,T=2
18.5 2+,T=2
0+,T=2
6.43 0+,T=2
16.8 0+,T=2
O20
0.12 0-,T=1
12.97 2-,T=1
N16 2-,T=1
12.79 0-,T=1
2+,T=1
10.27 2+,T=1
F20
0+,T=0
O16
0+,T=0
Ne20
MUB-3782

Fig. 4

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