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Energies and J^π values of resonances in $^{12}C(^{16}O,^{8}Be)^{20}Ne$ reactions

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The $^{12}C(^{16}O,^{8}Be)^{20}Ne^*$ reactions to the low lying 0^+, 2^+, 4^+ and 3^-, 1^- states have been studied for $E_{c.m.} = 18.5$ to 22.7 MeV at intervals of $\sim$86 keV. Excitation functions indicate the presence of twelve resonances in this energy region, eight of which are given J^π assignments based on angular distributions of the $^8Be + ^{20}Ne(0^+)$ channel measured at each energy interval. A high degree of resonance energy correspondence between these and other reaction cross section anomalies is noted. It is apparent that the density of resonant states for the $^8Be + ^{20}Ne$ exit channel is much higher than reported in other channels.

[NUCLEAR REACTIONS $^{12}C(^{16}O,^{8}Be)^{20}Ne^*$; $E_{c.m.} \simeq 18.5$ to 22.7 MeV, $\theta_{c.m.} \simeq 13°$ to 73°; measured $\sigma(\theta, E)$ to low lying states, deduced resonance energies and J^π values.]

I. INTRODUCTION

Heavy ion resonances have been reported in one or more exit channels for a number of heavy ion combinations. Most prominent among these are $^{12}C + ^{12}C$ and $^{12}C + ^{16}O$, both of which have received widespread acceptance for exhibiting resonance behavior both above and below the Coulomb barrier. The resonance discovered initially in the $^{12}C + ^{16}O$ system was seen in many different reaction channels[1-3] and has been assigned[2] $J^\pi = 14^+$. Other resonances have now been reported with J^π values in some cases, but most studies are not comprehensive and typically spin assignments for resonances can be uncertain to $\pm 1\ \hbar$. Model descriptions of the heavy ion resonance behavior can be evaluated only after more definitive experimental information is obtained. Because of the nature of the resonance determinations thus far, the J^π and E_{res} values from at least two different reaction channels should agree before acceptance. The most recent reviews of the subject are provided by invited papers at the Winnipeg cluster model conference[4] and the discussions and references contained in the work of Malmin *et al.*[5]

The present work reports the measurement of angular distributions at ~50 energies between $E_{c.m.} = 18.5$ and 22.7 MeV for four reaction channels leading to low lying states of ^{20}Ne. A number of cross section enhancements are noted and the angular distributions of the ^{20}Ne (g.s.) channel allow J^π determinations. The criteria for resonance identification are discussed briefly and the correlation of resonance energies and J^π values from this and other recent works in the same energy domain is cited. The result is a complex pattern of resonance behavior which will likely not be explained by a two cluster rotational model.

II. EXPERIMENTAL PROCEDURE AND ^{8}Be ENERGY SPECTRA

A beam of negative oxygen ions was produced in a surface ionization sputter source[6] and accelerated to energies of 42 to 54 MeV by use of the Florida State University S-FN Tandem Accelerator. The beam bombarded carbon foil targets in a 46 cm diameter target chamber. Target areal densities of 25 to 40 $\mu g/cm^2$ provided beam energy losses comparable to the step size in the measured excitation functions. All significant resonance energies quoted herein have been corrected to the center of the target.

The detection of ^{8}Be reaction products is by the method of associated alpha-particle coincidence employing an array of eight Si(Li) detectors closely spaced at 5° intervals. Aluminum foil of thickness appropriate for stopping scattered heavy ions is placed over the detectors so that the forwardmost detector with active area of nearly 2 cm^2 can be positioned 5° from the primary beam without excessive count rate or heavy ion radiation damage. The detection efficiency and the associated circuitry are described elsewhere.[7] The energy spectra of ground state ^{8}Be particles from $^{12}C(^{16}O,^{8}Be)$ were recorded at 21 angles from $\theta_{c.m.} \simeq 13°$ to 75° and at 50 energies from $E_{c.m.}$ ~18.5 to 22.6 MeV in intervals of ~86 keV. An energy spectrum typical of the upper end of the bombarding energy range and the forwardmost angle is shown in Fig. 1. Prominent in the spectrum is the excitation of the $J^\pi = 0^+$, 2^+, 4^+, and 6^+ member of ground state rotational band of ^{20}Ne. The ^{8}Be yields are extracted for the residual nucleus ^{20}Ne in the $J^\pi = 0^+$ ground state and excited 2^+ and 4^+ states at $E_x = 1.63$ and 4.25 MeV and the 1^-, 3^- doublet near $E_x = 5.7$ MeV. Above an excita-

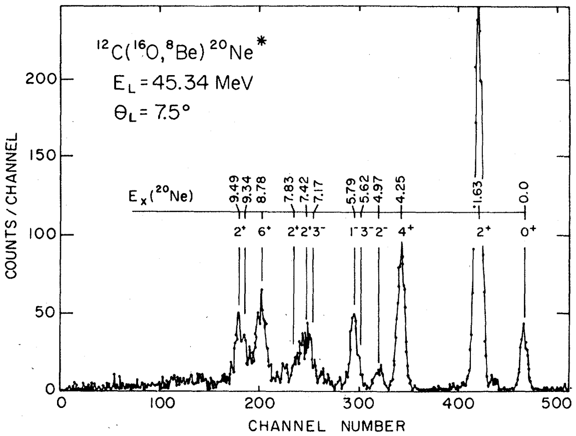

FIG. 1. Energy spectrum of ^{8}Be particles as formed by addition of alpha-particle energies in appropriate kinematic coincidence. Cross sections were extracted for all ^{20}Ne channels for $E_x < 6$ MeV.

tion of 6 MeV the ^{20}Ne spectrum is more complex than indicated in the figure and these yields were not extracted. Over some of the energy and angle range the small yield to the unnatural parity 2^- state at $E_x = 4.97$ MeV was also extracted.

III. EXPERIMENTAL RESULTS

Prior to the presentation of the measurements from which resonance energies and J^π values are extracted, a brief review of the criteria used for establishing resonances and their J^π values is appropriate. More general discussions of criteria have been presented in a critical review of the field by Taras,[4] and by Voit *et al.*,[8] to which the following comments are closely related.

Resonance criteria applied in the present work are as follows:

(a) The resonance should appear in the total cross section for a particular reaction channel or at least in an angle summed cross section,

$$\sigma_{\text{sum}} = \sum_{i=1}^{N} \sigma(\theta_i) \sin\theta_i \, .$$

The latter is employed here since data over the full angular range are not available.

(b) Resonances should appear in more than one channel. No matter how preferable, it is unnecessary, however, to require that all exit channels resonate.

(c) For spin zero systems, for example, the ground state channel of the present reaction, the cross section given by the function

$$\sigma(\theta, E) = \left| \sum_{l=0}^{L} A_l(E) e^{i\delta_l(E)} P_l(\cos\theta) \right|^2 \qquad (1)$$

should approximate $P_{L_{\text{res}}}{}^2(\cos\theta)$ when at the resonance energy. This condition is clearly too stringent because of interference effects with and contributions from other nonresonant partial waves, but one might expect the periodicity of the measured $\sigma(\theta)$ to match that of

$$P_l{}^2(\cos\theta)\,|_{l=L_{\text{res}}} \, .$$

The mere observation of $\sigma(\theta) \simeq P_l{}^2(\cos\theta)$ does not ensure a resonant l value as pointed out by Voit *et al.*[8] This effect will also be shown later in this paper where the background is nearly pure $l = 10$ for the ground state reaction, $E_{\text{c.m.}} \sim 18.5$ to 19.2 MeV. The observation of $\sigma(\theta) \simeq P_l{}^2(\cos\theta)$ in conjunction with (a) would, however, be good evidence for L_{res} identification.

Criteria not employed in this work include observation of maxima in angle integrated cross sections in all reaction channels. The absence of odd-l resonances in the data of Voit *et al.*[8] made this a useful criterion, unlike the present case. Statistical analyses have also been omitted as criteria. Again, whereas it may be preferable when statistical criteria support resonance assignments, Voit *et al.* have pointed out the inadequacy of a statistical analysis when intermediate structure and statistical widths are similar, which is the case in the present work. Shipira *et al.*[9] have also noted that in a computer simulated problem a statistical analysis was inconclusive even when the widths did differ substantially.

There are problems in the establishment of E_{res} and J^π for $^{12}C + ^{16}O$ resonances which are not present in the $^{12}C + ^{12}C$ system merely due to the additional presence of odd-l values in $\sigma(\theta)$. With twice as many l values contributing, the background cross section can be more complex, the resonant-l contribution may appear less strong in σ_{sum} even though the effect in $A_l(E)$ is similar, and overlapping resonances are much more probable. It has already been pointed out by James[10] that, for the $^{12}C(^{12}C, ^8Be)^{16}O$(g.s.) reaction, a very clear strong resonance in $A_l(E)$ may appear only very weakly in σ_{sum}, and that, conveniently for $^{12}C + ^{12}C$, the energy range over which a particular l value will resonate corresponds to a change in grazing angular momentum of $\lesssim 2\,\hbar$, thereby greatly reducing overlap problems for resonances of different l values. These phenomena together imply that here we may expect weaker maxima on resonance in σ_{sum}, more overlapping resonances in σ_{sum}, and less definitive shapes of $\sigma(\theta)$ on resonance than have been observed in the $^{12}C(^{12}C, ^8Be)^{16}O$(g.s.) reaction.[11] These are observational impediments, independent of the strengths of the resonances.

A. Excitation functions and resonance energies

The differential cross sections for ground state ^{8}Be exit channels with ^{20}Ne in the $J^{\pi}=0^{+}$, 2^{+}, and 4^{+} rotational band states are shown in Fig. 2. Combined data for exit channels ^{20}Ne*$(1^{-}, 3^{-})$ at $E_x \sim 5.63$ and 5.80 MeV were also extracted at fourteen angles but are not shown. Angle correlated maxima appear in the data of Fig. 2 over much of the entire angular range which is much greater than the statistical correlation angle. This displayed angle correlation is more prominent in the data leading to the higher angular momentum final state of ^{20}Ne since the number of exit channel partial waves which can contribute to the resonance amplitude is given by $(J_{\mathrm{Ne}^*}+1)$ as long as $J_{\mathrm{res}} \geq J_{\mathrm{Ne}^*}$. A large number of l values contributing to the resonance would tend to reduce the oscillatory behavior of the resonance part of Eq. (1) and make the resonance display at all angles. For the ^{20}Ne(g.s.) data this oscillatory angular behavior is very apparent, especially at the resonances near 19.9 and 20.9 MeV.

One way to average over energy dependent statistical fluctuations is to angle integrate the differential cross sections. Since complete angular distributions have not been measured, we have constructed the function σ_{sum}, defined earlier. Included in the summation are 18 angles for the 0^{+}, 2^{+}, and 4^{+} states of ^{20}Ne and 12 angles for the 3^{-}, 1^{-} doublet, omitting a few back angles where energy dependent data are incomplete. The results of these summations are shown in Fig. 3. The resonant structures which survive the data summing are obvious, but the resonance correlation between reaction channels requires closer inspection. Recognizing the frailty with which the resonances may be displayed, as discussed earlier, we have deduced the resonance energies listed in Table I. Probable errors in resonance energies and widths are estimated to be no more than 50 keV. The angular momentum assignments are

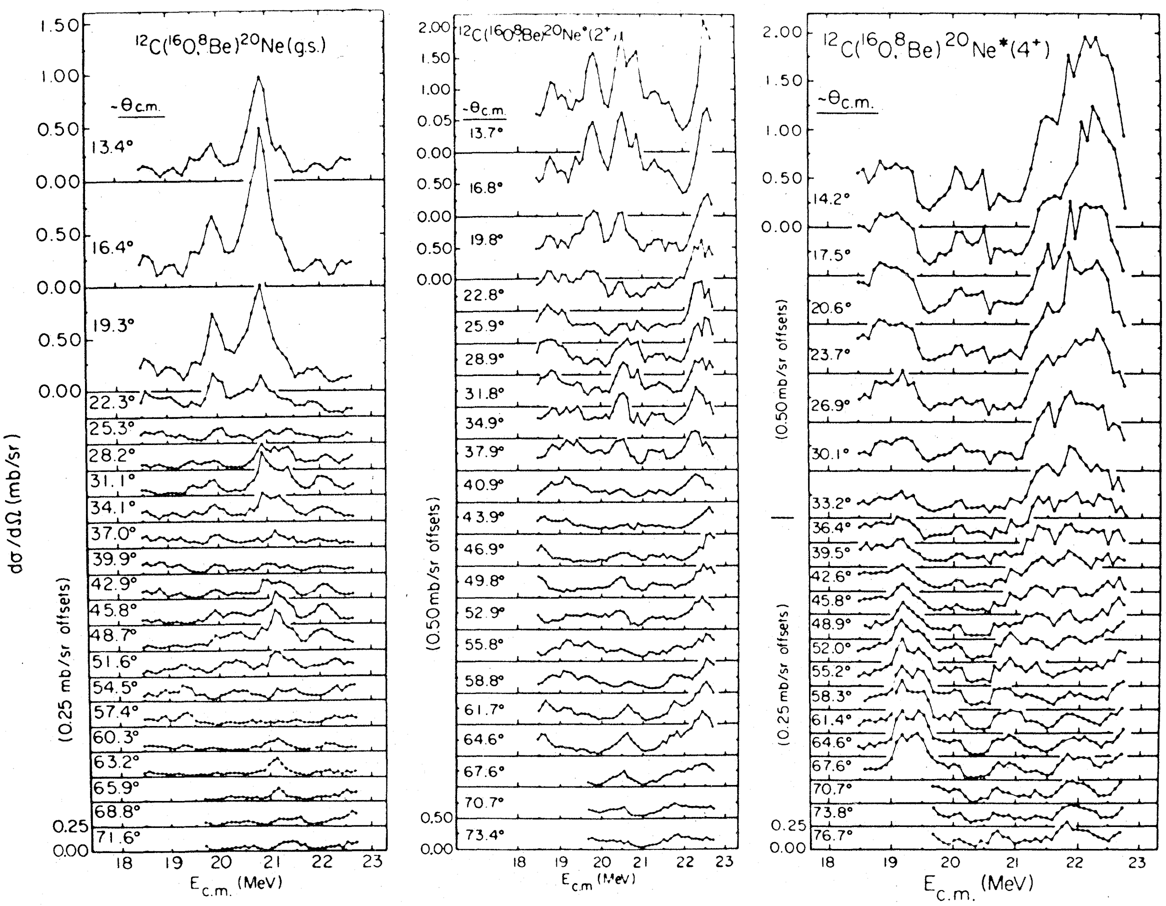

FIG. 2. Yield curves measured at twenty-one angles for channels leading to ^{20}Ne in the $J^{\pi}=0^{+}$, 2^{+}, and 4^{+} ground state rotational band.

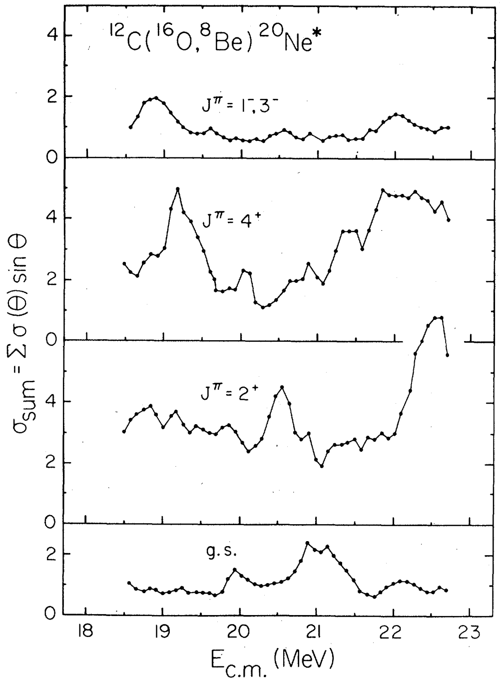

FIG. 3. Energy dependence of cross sections "integrated" over the angular range of the data.

discussed in the next section.

Some of the resonances are observed in all four exit channels, a good example of which is the first at $E_{c.m.} = 18.87$ MeV. There is a conspicuous absence of the well known $J^\pi = 14^+$ resonance[2] at $E_{c.m.} \simeq 19.7$ MeV. As noted earlier[12] the anomalies which predicate the 19.7 MeV resonance extend from $E_{c.m.} \sim 19.5$ to 20.0 MeV. Argument for a doublet in this energy region has been presented,[12] and while a state at $E_{c.m.}$ near 19.6 MeV is not displayed convincingly in σ_{sum}, Fig. 3, it is evident at many angles of the data for all three final states shown in Fig. 2. The presence of resonances of different spin at $E_{c.m.} = 19.15$ and 19.91 MeV would certainly tend to obscure a weak contribution near 19.6 MeV.

Also listed in Table I is the pronounced maxima in the 4^+ data of Fig. 3 at $E_{c.m.} \simeq 20.07$ MeV. This anomaly which shows throughout the 4^+ data of Fig. 2 is also weakly present at many angles for the 0^+ and 2^+ final state, however, it does not persist in σ_{sum} for those final states. Resonances in Table I which are observed in σ_{sum} in only one ^{20}Ne channel are listed because of their correlation with other reaction channels as will be pointed out later. Both anomalies near 20 MeV have dominant lower angular momentum components than the 14^+ resonance of Malmin, which may account for their presence in the ^{8}Be channels because of angular momentum matching.

B. Angular distributions and J^π assignments

The angular distributions of the ^{8}Be exit channel leading to the ^{20}Ne ground state are particularly useful in making J^π assignments since only one term in the Eq. (1) expression of the cross section will resonate. Although all of the ^{20}Ne ground state data are displayed in Fig. 2, individual plots of $\sigma(\theta)$ vs $E_{c.m.}$ are more informative in determining J_{res}.

The resonances at $E_{c.m.} = 18.87$ and 19.15 MeV, determined from the $^{20}Ne^*$ data of Fig. 3, are very weak in the ^{20}Ne ground state channel. The ground state angular distributions in this energy region are shown in Fig. 4. It is clear that any

TABLE I. Resonances in $^{12}C(^{16}O,^{8}Be)^{20}Ne^*$.

$E_{c.m.}$ [a] (MeV)	Relative presence in $^{20}Ne(J^\pi)$ final state [b] 0^+	2^+	4^+	$1^-, 3^-$	$\Gamma_{c.m.}$ [a] (keV)	$E_x(^{28}Si)$ (MeV)	J^π
18.87	*w*	*m*	*w*	*s*	320	35.62	10^+
19.15	*w*	*m*	*s*	-	300	35.90	11^-
(~19.65)	-	-	-	*m*	•••	(~36.4)	•••
19.91	*s*	*m*	-	-	280	36.66	12^+
20.07	-	-	*s*	-	<200	36.82	•••
20.55	-	*s*	-	*m*	260	37.30	•••
20.89	*s*	*m*	*m*	*w*	<300	37.54	13^-
21.14	*s*	*w*	-	-	<350	37.89	12^+
21.47	*w*	-	*s*	*w*	<300	38.2	13^-
21.8	-	-	*s*	-	•••	38.6	•••
22.1	*s*	-	?	*s*	<450	38.9	13^-
22.6	*w*	*s*	*w*	*w*	•••	39.4	$15^-(14^+)$

[a] Estimated probable error is 50 keV.
[b] *s* (strong), *m* (medium), *w* (weak), - (not observed).

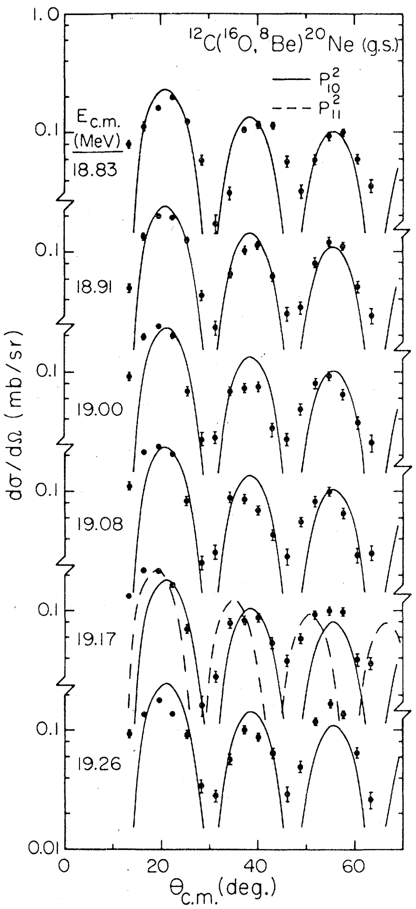

FIG. 4. Angular distributions of ^{12}C (^{16}O, ^{8}Be) ^{20}Ne (g.s.) in the vicinity of resonances at $E_{c.m.} = 18.87$ MeV, $J^{\pi} = 10^{+}$, and $E_{c.m.} = 19.15$ MeV, $J^{\pi} = 11^{-}$. The solid and dashed curves are square of Legendre functions with $l = 10$ and 11, respectively. The nonresonant background is dominated by $l = 10$.

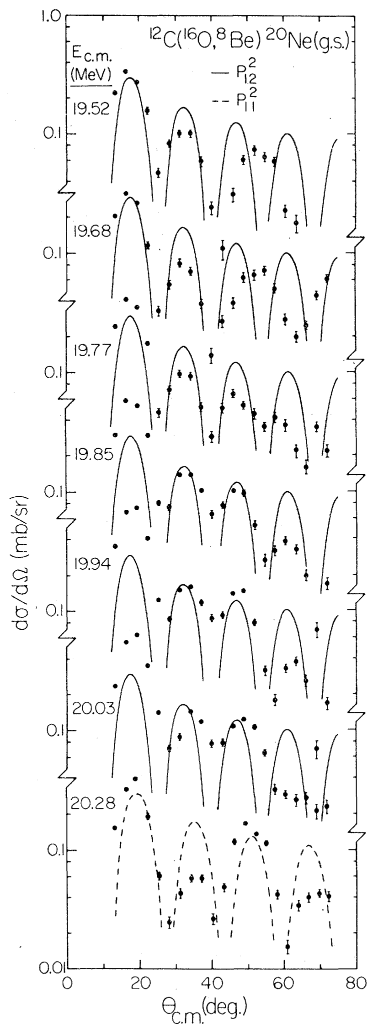

FIG. 5. Angular distributions of ^{12}C(^{16}O, ^{8}Be)^{20}Ne (g.s.) in the vicinity of the well known 14^{+} resonance at $E_{c.m.} \simeq 19.7$ MeV and the more recent 12^{+} at $E_{c.m.} = 19.92$ MeV. All Legendre curves are normalized to 0.3 mb/sr at the $\sim 20°$ maximum.

$\sigma(\theta)$ measured in this energy region is quite well approximated by the function $P_{10}{}^{2}(\cos\theta)$, indicating a dominance of $l = 10$ in the nonresonant part of $\sigma(\theta)$. Near the resonance, at 18.91 MeV, the function $P_{10}{}^{2}(\cos\theta)$ even more accurately represents the data and it is therefore given the assignment $J^{\pi} = 10^{+}$. Above 18.91 MeV there is a distinct shift in cross section maxima to smaller angles, i.e., higher partial waves, with a sudden return to the $l = 10$ background above the 19.15 MeV resonance, which is given therefore a tentative $J^{\pi} = 11^{-}$ assignment.

The energy region of the 14^{+} resonance of Malmin *et al.*[2,5] is considered in Fig. 5. All Legendre curves in this figure are normalized to 0.3 mb/sr at the forward maximum. At energies 19.52 and 19.68 MeV, there is a perceptible shift in the measured forward angle maximum in $\sigma(\theta)$ toward smaller angles, although it is insufficient to indicate an appreciable $l = 14$ contribution even though we have observed a slight maximum in the energy dependence at these angles (See Fig. 2). At $E_{c.m.} = 19.85$ and 19.94 the cross section is clearly dominated by an $l = 12$ component with a shift to a lower l value at higher energy off resonance. We assign $J^{\pi} = 12^{+}$ to the 19.91 MeV resonance and claim no observation of the 14^{+} resonance near 19.7 MeV in the ^{20}Ne ground state channel, probably due to an angular momentum mismatch.

The resonance at $E_{c.m.} \simeq 20.55$ MeV is not observed even weakly in the ^{20}Ne ground state channel. Arguments have been presented[13] for an assignment of $J^{\pi} = 15^{-}$ which if true would provide

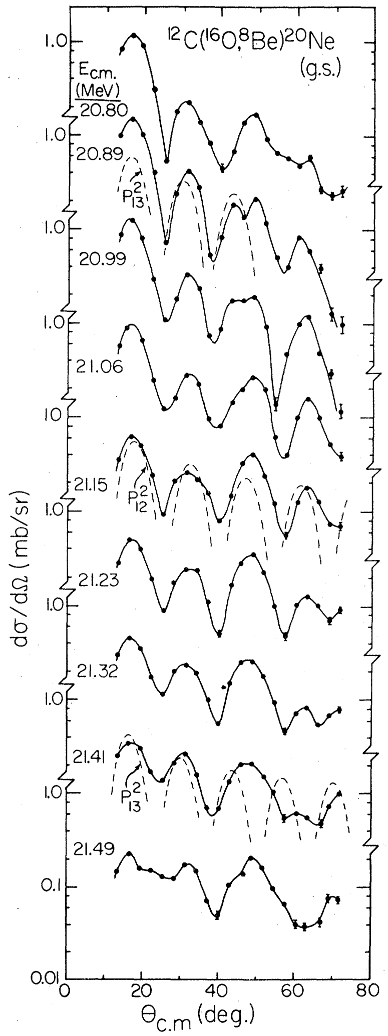

FIG. 6. Angular distributions of $^{12}C(^{16}O, ^8Be)^{20}Ne$ (g.s.) from $E_{c.m.} = 20.8$ to 21.5 MeV. Dashed lines are squares of Legendre functions as indicated, while solid lines serve only as a guide to the eye.

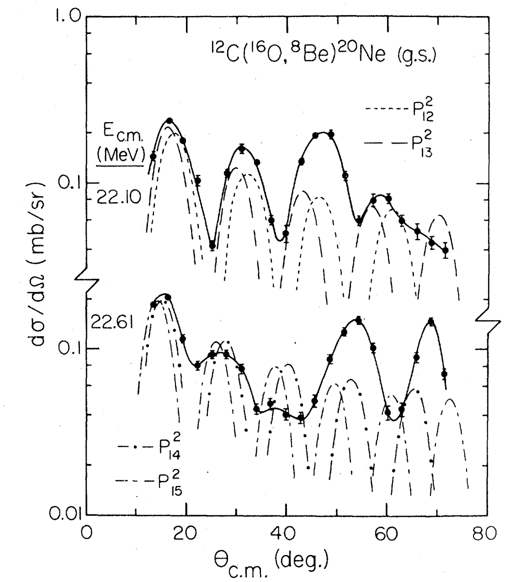

FIG. 7. Angular distributions of $^{12}C(^{16}O, ^8Be)^{20}Ne$ (g.s.) on the resonances at $E_{c.m.} = 22.1$ and 22.6 MeV which are given assignments of $J^\pi = 13^-$ and 15^- (14^+), respectively.

an angular momentum mismatch sufficient to make the state unobservable in this channel.

The data of Fig. 6 address the complex region of three resonances at $E_{c.m.} \simeq 20.89$, 21.14, and 21.4 MeV. The sudden shift in $\sigma(\theta)$ to three maxima with the periodicity of $P_{13}{}^2(\cos\theta)$, accompanied by a moderate maximum in σ_{sum} for all channels at $E_{c.m.} = 20.89$ MeV, make this an unmistakable resonance with $J^\pi = 13^-$. Equally strong in the ground state σ_{sum} is the 21.14 MeV resonance. The angular distribution in Fig. 6 is best described by $P_{12}{}^2(\cos\theta)$. At the 21.4 MeV resonance there is only a weak contribution in the ground state so it is not surprising that the 21.41 MeV angular distribution still has considerable influence from the 12^+ state at $E_{c.m.} = 21.14$ MeV. At 21.49 MeV, still further from the 12^+ resonance, the character of the 13^- is better displayed even though $\sigma(\theta)$ is quite irregular at this energy.

The angular distributions on the last two resonances listed in Table I are shown in Fig. 7. At 22.1 MeV the forward maximum of $\sigma(\theta)$ is well represented by $P_{13}{}^2(\cos\theta)$, whereas at other angles it is clear that there is still a considerable $l = 12$ contribution. The $l = 13$ assignment is justified by the energy dependence of $\sigma(\theta)$ over this broad resonance. In the off resonance region 21.7 to 21.9 MeV $\sigma(\theta)$ has a strong $l = 12$ component. Above resonance the second and third maxima move to larger angles, indicating again lower l value nonresonant terms until the weak additional maximum appears for the 22.6 MeV resonance. Here the difference between two l value assignments is slight, although we feel the data favor $J^\pi = 15^-$ for the weak resonance at 22.6 MeV.

IV. COMPARISON AND DISCUSSION

It is clear that the energy region $E_{c.m.} = 18$ to 23 MeV for the $^{12}C + ^{16}O$ system is rich in resonance phenomena. A number of different exit channels have been investigated with a variety of resonance energies and spin values reported including too many speculative spin assignments. In the following paragraphs we attempt to correlate the existing data on $^{12}C + ^{16}O$ resonances.

The resonance near $E_{c.m.} = 18.8$ MeV has been observed by measuring γ rays from inelastic scattering.[14–16] The data of Shapira *et al.*[14] and Branford *et al.*[15] are normalized to each other by Branford at $E_{c.m.} \simeq 18.5$ MeV with their resulting resonance energy of 18.6 MeV. The original data of Shapira would place the resonance energy closer to 18.8 MeV in better agreement with the present work. A tentative spin assignment[15] of (13^-) has been given without supportive data and it is in direct disagreement with our angular distribution measurement (See Fig. 4). Our $J^\pi = 10^+$ assignment agrees with the recent measurement of Bernhardt *et al.*[17]

The nonstatistical anomaly observed by Kolata *et al.*[16] near this energy is at 18.57 MeV with a less significant anomaly at 19.00 MeV. Whether either of these correspond to our 10^+ at 18.87 MeV or the weak 11^- at 19.15 MeV is difficult to say. A weak anomaly at 19.1 MeV is also present in some of the inelastic scattering data of Malmin *et al.*[5] which may be an observation of our 11^- level.

The region near the initially discovered[1–3] "quasimolecular" resonance at 19.7 MeV remains interesting. For some time there has been serious suggestion of a doublet near this energy[12,18] with direct support from the neutron channel data.[19] The recent multichannel reaction cross section work of Kolata *et al.*[16] supports this point of view with nonstatistical anomalies at $E_{c.m.} = 19.65$ and 19.86 MeV. The lower member is likely the oft-mentioned 14^+ and the upper one the 12^+ of the present work with an average energy[12,16,19] of 19.90 MeV. The apparent resonance in the ^{20}Ne*(4^+) channel at $E_{c.m.} \simeq 20.07$ MeV (See Figs. 2 and 3) is also supported by the reaction cross section data.[16] Data for the ^{12}C*(4.43 MeV) inelastic channel[5] might be interpreted as supportive of either or both resonances near 20 MeV.

The resonance appearing strongly in the ^{20}Ne*(2^+) and (1^-, 3^-) channels at 20.55 MeV would correspond to the 20.5 MeV anomaly reported by Malmin *et al.*[5] The fluctuation analysis of the reaction cross section data[16] does not reveal a resonance at 20.5 MeV but rather shows major anomalies at 20.72 and 20.93 MeV. Prior to these results it was believed that our 13^- resonance at 20.89 MeV, seen in all ^{20}Ne channels investigated, was the same as that of Charles at 20.79 MeV. These new data[16] led us to believe there may be two $J^\pi = 13^-$ resonances here, one near 20.75 MeV, formerly observed by Charles *et al.*,[18] and one near 20.9 MeV, prominently displayed in Figs. 2 and 3. The single anomaly at 20.8 MeV reported in the inelastic scattering[5] does not support the doublet interpretation.

The 12^+ resonance at 21.14 MeV is not definitely supported by any other work. An anomaly at 21.14 MeV in the reaction cross section data[16] is not sufficiently strong to be clearly nonstatistical.

The remainder of the resonances listed in Table I are well correlated with anomalies in the reaction cross section data.[16] The 21.4 MeV, 13^- and the 21.8 MeV resonances are near the strong anomalies at 21.47 and 21.79 MeV whereas those at 22.1 and 22.6 MeV have weak anomalies at corresponding energies of 22.11 and 22.65 MeV in the reaction analysis.[16] Even with this correspondence, the region $E_{c.m.} = 22$ to 23 MeV remains a confusing one. Kolata has observed weak anomalies at 22.11, 22.43, 22.65, and 22.86 MeV. Resonances reported in this region are a 13^- at 22.1 MeV (Table I), 15^- at 22.0 MeV,[5,14,20] a 15^- at 22.4 MeV,[21] a 15^- at 22.6 MeV (Ref. 20) (see also Table I), and a 14^+ at 22.79 MeV.[18] Although in many theoretical and phenomenological attempts to explain quasimolecular resonances these spin differences have been cited as in disagreement, it was suggested some time ago[18,20] that there may be more than one or two resonances in the area. Again these four anomalies, although weak, reported in the reaction data[16] support a multiple resonance interpretation with good correlation between observations from $E_{c.m.} = 22.0$ to 22.8

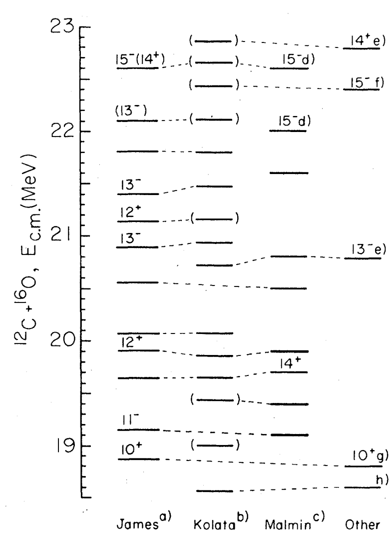

FIG. 8. Comparison of observed resonance structure in ^{12}C+^{16}O reactions from a number of authors: (a) present work and Ref. 12; (b) Ref. 16, levels in parentheses are based on cross section anomalies of less certain significance; (c) resonance energies and J^π values of 14^+ for the 19.7 MeV resonance and 15^- (16^+) for the 22.0 MeV resonance, Ref. 5; (d) J^π only, Ref. 19; (e) Ref. 18; (f) Ref. 20; (g) resonance energy, Ref. 12, J^π value, Ref. 17; (h) Ref. 15.

MeV, thus allowing the possibility of the different spins reported.

The observed resonances and anomalies from various authors are shown in Fig. 8. The dashed lines connect the possible correspondence of observations as discussed above. It should be noted that the observations of resonance positions 18.6 (Ref. 15) and 18.8 MeV (Ref. 14) are not based on independent sets of data. There are other possible correlations between the ^{8}Be data and small anomalies in total γ-ray yield data,[22] alpha-particle yields,[23] some proton exit channels,[14] and inelastic scattering.[5] Better, more complete measurements of $\sigma(\theta, E)$, possibly in smaller energy intervals and with thinner targets, are necessary for all these reaction channels if one is to verify these possibilities.

The J values assigned to resonances in this work are in all cases one or two units less than the entrance channel grazing angular momentum. This general feature can be understood by noting that the outgoing grazing angular momentum in the ground state ^{20}Ne channel is approximately two units less than the entrance channel, thus this reaction will "select" resonant states of lower l value. An analysis of all resonances observed in all ^{20}Ne channels shows that the rms mismatch is about one unit less for resonances seen strongly than for those observed weakly or not at all. There is far too much spread, however, to allow one to even set limits on J values of resonances based solely on the relative strength with which they are observed.

The many models which have been proposed to explain heavy ion resonance were reviewed recently[4,5] and will not be discussed here. It is sufficient to say that the potential models[24] to describe the broad features of fusion cross sections[25] must be modified to include possibly smaller cluster interactions in order to produce the multiplicity of narrower intermediate structures observed by Kolata *et al.*[16] and in the present work. A vibration rotation interaction to provide the fragmentation does not appear to be realistic because the fixed number of like spin fragments which are predicted does not agree with experiment. Similarly, superimposed rotational bands, without physical bases, used to "predict" spin values of resonances are of very little utility. It should be pointed out that the only model to offer an explanation of the 12^+ resonance at 19.9 MeV (Ref. 12) is a multichannel microscopic calculation which shows it to be an exit channel resonance in the ^{8}Be + ^{20}Ne system.[13]

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