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QUASIELASTIC AND FISSION TOTAL CROSS SECTIONS FOR ^{16}O ON ^{181}Ta AND ^{208}Pb *

F. Videbæk+, R.B. Goldstein, L. Grodzins, S.G. Steadman

Laboratory for Nuclear Science
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

and

T.A. Belote
University of Massachusetts
Boston, Massachusetts

and

J.D. Garrett+
Brookhaven National Laboratory
Upton, New York, 11973

ABSTRACT

The total quasielastic (inelastic plus few nucleon transfer) and fission cross sections have been measured for ^{16}O + ^{208}Pb at incident energies of 80, 83,88,90,96, and 102 MeV and for ^{16}O + ^{181}Ta at incident energies of 83, 90 and 96 MeV. The total quasielastic cross sections account for about 50% of the total ^{16}O + ^{208}Pb reaction cross section at the lowest incident energy which is near the Coulomb barrier. At the highest incident energy the ^{16}O + ^{208}Pb quasielastic cross section still accounts for 25% of the total cross section. The measured ratio of quasielastic to total cross section for ^{16}O + ^{181}Ta is less than for ^{16}O + ^{208}Pb; however, in the case of the ^{181}Ta target the inelastic transitions to the low lying levels in ^{181}Ta were not resolved from elastic scattering. Within the uncertainties of the measurements the sum of the measured quasielastic and fission cross sections for ^{16}O on ^{208}Pb accounts for the total reaction cross section, indicating that the probability of fission of the ^{224}Th compound and Th daughter systems is large. In contrast for ^{16}O + ^{181}Ta ($^{197}T\ell$ compound system) the fission and quasielastic channels account for only a small fraction of the total reaction cross section.

* This work performed under the auspices of E.R.D.A.

+ Permanent address: The Niels Bohr Institute, University of Copenhagen.

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Measurements of the total reaction cross section and the division of the cross section between the various reaction channels is an interesting problem in heavy ion reactions. Such measurements are simplified for the actinide compound systems where the fission barriers are sufficiently low so that nearly the entire compound system deexcites by fission. The present contribution reports such measurements of total inelastic, few nucleon transfer, and fission cross sections for $^{16}O + {}^{208}Pb$ (^{224}Th compound system) at incident energies of 80, 83, 88, 90, 96, and 102 MeV. For comparison similar measurements were made for $^{16}O + {}^{181}Ta$ (^{197}Tl compound system where the fission barrier is considerably higher) at incident energies of 83, 90 and 96 MeV.

The measurements were made using the beams of the Brookhaven National Laboratory tandem accelerators. The elastic, quasielastic (i.e. inelastic scattering plus few nucleon transfer), and fission differential cross sections were measured simultaneously using particle detector telescopes. The energy and mass resolution was sufficient to resolve the inelastic and quasielastic O contributions from the elastic group in the case of the ^{208}Pb target. For $^{16}O + {}^{181}Ta$, however, where excited states exist as low as 6 keV, the inelastic contributions below $E_x = 1.5$ MeV were not resolved from the elastic group. Since the incident energies used in these studies are just above the Coulomb barrier, the angle corresponding to a grazing collision is large. Therefore, groups corresponding to scattering and reactions on light target impurities could be identified easily and cause no problems except at the most forward angles where the quasielastic cross sections of interest are very small. The experimental procedures are discussed in further detail in ref. 1.

The measured total quasielastic, $\sigma_{q.e.}$, and fission, σ_F , cross sections are given in table 1 and are shown as a function of isotope in figs. 1 and 2 for the ^{208}Pb and ^{181}Ta targets respectively. Also tabulated and shown is the total reaction cross section, σ_R , that was predicted from the optical model using parameters which fit the measured elastic scattering data [1].

Table I. Comparison of measured quasielastic and fission cross sections with optical model total reaction cross sections

E_{lab} (MeV)	$E_{c.m.}$ (MeV)	$E_{c.n.}$ (MeV)	$\sigma_{q.e.}$ [a)] (mb)	σ_F [b)] (mb)	σ_R (mb)	$\sigma_{q.e.}/\sigma_R$	$(\sigma_{q.e.}+\sigma_F)/\sigma_R$
			$^{16}O + ^{208}Pb$				
80	74.29	27.80	64± 8	36± 4	113	0.57±0.07	0.88±0.11
83	77.07	30.58	129±18	108±10	287	0.45±0.06	0.83±0.10
88	81.71	35.22	222±31	350±40	562	0.40±0.06	1.02±0.13
90	83.57	37.08	201±25	377±50	668	0.30±0.04	0.87±0.11
96	89.14	42.65	>125 d)	685±70	939	>0.13 d)	>0.86 d)
102	94.71	48.22	313±28	844±90	1166	0.27±0.02	0.99±0.11
			$^{16}O + ^{181}Ta$				
83	76.26	51.46	130±57	11± 1	571	0.23±0.10	0.25±0.10
90	82.69	57.89	156±15	49± 5	894	0.18±0.02	0.23±0.02
96	88.20	63.40	187±16	140±14	1168	0.16±0.01	0.28±0.03

a) Total measured quasielastic cross section. Contains contributions from inelastic O plus a few nucleon O, N, C, and B transfer channels (see figs. 1 and 2). No significant cross sections were observed for final states having $Z > 8$. The inelastic ^{16}O contributions corresponding to states below $E_x = 1.5$ MeV were not resolved from elastic scattering in the Ta data.

b) Total measured fission cross section.

c) Total reaction cross section as calculated from the optical model -- see text.

d) The values given as lower limits do not include the O quasi-elastic channels which were not well resolved from the elastic scattering at this energy.

The total quasielastic cross section make up a sizeable fraction of the total reaction cross section of ^{16}O on both ^{181}Ta and ^{208}Pb targets. Ratios of $\sigma_{qe}/\sigma_R \gtrsim 0.5$ are observed for $^{16}O + ^{208}Pb$ near the Coulomb barrier (see Table 1). This ratio decreases to $\gtrsim 0.25$ at the highest energy measured for the ^{208}Pb target. For the ^{181}Ta target the measured quasi-elastic cross section accounts for a smaller portion of the total reaction cross section (see Table 1). The difference between the Ta and Pb quasielastic cross sections appears to be in the O channels (see Table 1). The inelastic excitation to the low-lying states in ^{181}Ta, which were not resolved from the elastic group, could be large enough to account for much of the observed difference.

The observed fission cross section almost certainly results from the compound system (first chance fission) or from a nucleus in the decay chain of the compound system (second, third, etc. chance fission). The quasielastic processes that have large cross sections leave residual nuclei at excitation energies below (or perhaps in the C channels near) the fission barrier, which is much higher than the particle emission thresholds for nuclei [2,3] near $A = 181$ and 208. Cross sections for ^{16}O induced reactions on heavy targets in which most of the mass of the projectile is transferred to the target (such as $(^{16}O,p)$ or $(^{16}O,\alpha)$) are expected to be vanishingly small [4].

The sum of the measured quasielastic and fission cross sections for ^{16}O on ^{208}Pb is compared in Table 1 with the total reaction cross section obtained from the optical model. Within the uncertainties of the measurements these reaction channels account for nearly all of the reaction cross section as determined from the optical model. Thus the probability of fission in the deexcitation of the compound system ^{224}Th formed from $^{16}O + ^{208}Pb$ must be large. This is not surprising, since the s-wave fission barrier of the lightest measured Th nuclei is 6-7 MeV [5], which is of the order of the particle emission threshold for these systems (B_n = 7.73 , 6.02 and 7.80 MeV for ^{224,223,222}Th respectively [6]). Furthermore there is sufficient excitation energy available in the compound system (see Table 1) for fission to compete after emission of one or more particles. Measured compound evaporation residue cross sections [7] for 83-91 MeV ^{16}O + ^{206}Pb are of the order of a few mb which is much less than the uncertainties in our measured cross sections.

In contrast, for ^{16}O + ^{181}Ta, the fission and quasielastic channels only account for a small fraction of the total reaction cross section as obtained from the optical model (see Table 1 and Fig. 2). Presumably this is the result of a fission barrier in the ^{197}Tl compound and lighter Tl systems that is much higher than the particle emission thresholds. Indeed measured fission barriers [2,3] in this mass region are $\gtrsim$ 22 MeV compared to neutron binding energies [6] of 8.98, 7.55, and 9.36 for ^{197,196,195}Tl respectively. Therefore, evaporation residue cross sections should account for a large part of the total reaction cross section of ^{16}O + ^{181}Ta .

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\+ Permanent affiliation: The Niels Bohr Institute, Copenhagen University, Copenhagen, Denmark.

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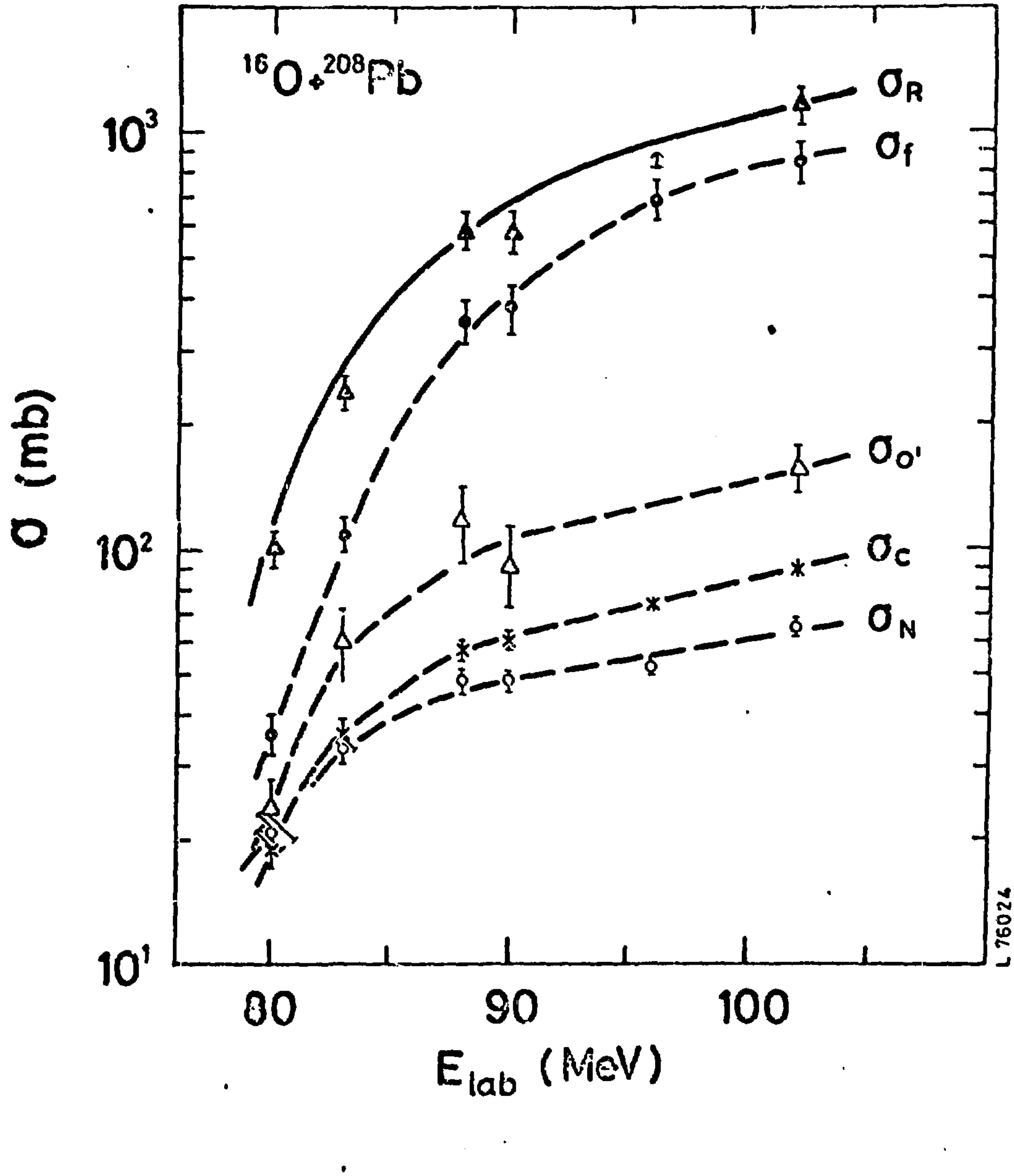
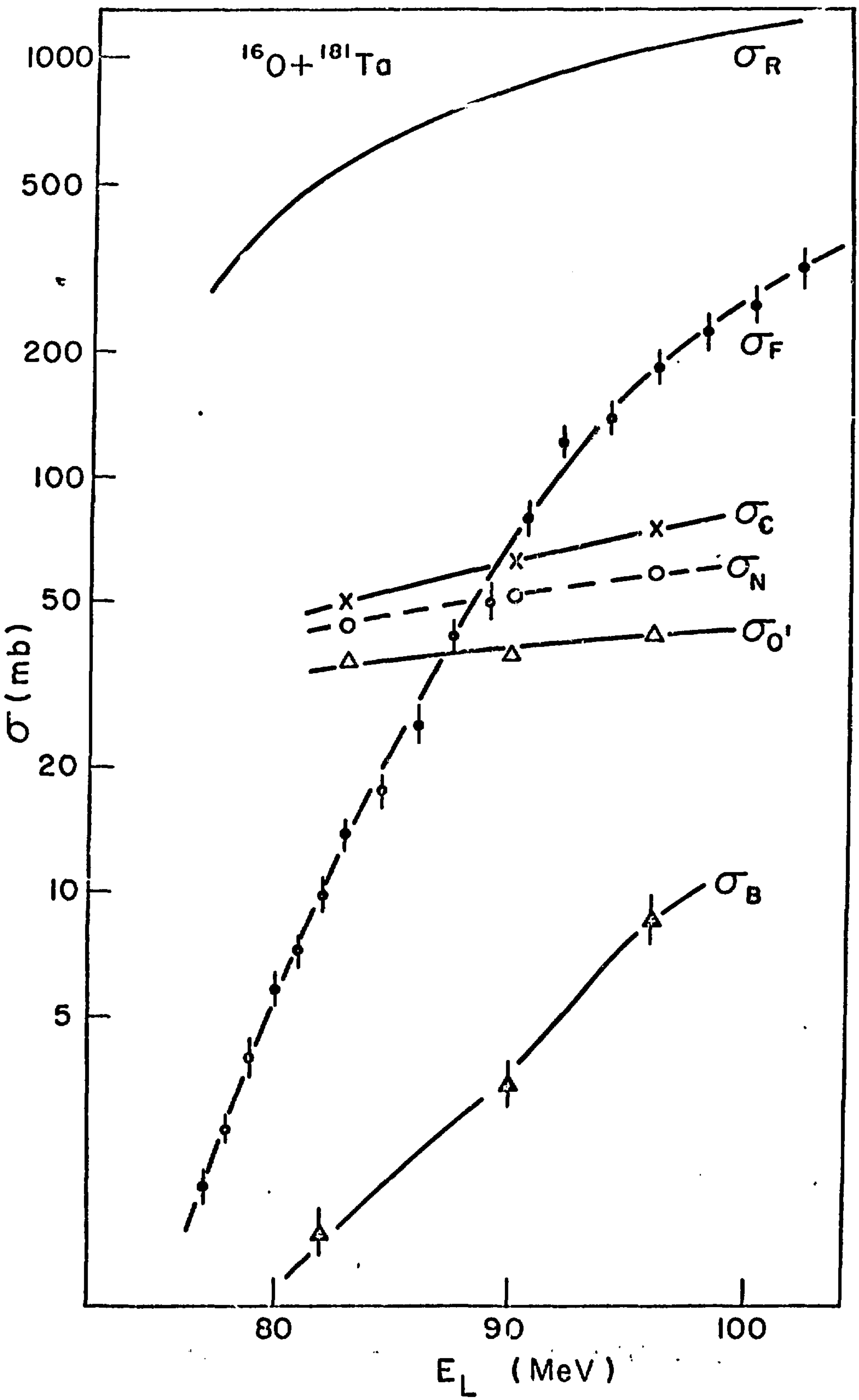
Figure Captions

Fig. 1 Total cross sections measured for the various quasielastic processes and fission induced by ^{16}O and ^{208}Pb as a function of the incident energy. σ_F , σ_O , σ_N , and σ_C are designated by solid circles, open triangles open circles, and crosses, respectively. The curves shown with the quasielastic and fission cross sections are only to guide the eye. Also shown is a comparison between the total cross sections measured in the quasielastic plus fission channels (solid triangles) and the reaction cross section, σ_R , predicted from the optical model.

Fig. 2 Total cross sections measured for the various quasielastic processes and fission induced by ^{16}O on ^{181}Ta as a function of the incident energy. σ_F , σ_O , σ_N , σ_C and σ_R are designated by solid circles, open triangles, open circles, crosses and closed triangles respectively. The curves shown with the quasielastic and fission data are only to guide the eye. The oxygen quasielastic channel does not include inelastic ^{16}O processes populating states in ^{181}Ta below an excitation of 1.5 MeV. Also shown is the total reaction cross section, σ_R , predicted from the optical model.



$^{16}O + ^{208}Pb$
σ_R
σ_f
$\sigma_{O'}$
σ_C
σ_N
10^3
10^2
10^1
σ (mb)
80
90
100
E_{lab} (MeV)
L 76024



$^{16}O + ^{181}Ta$
σ_R
σ_F
σ_C
σ_N
$\sigma_{O'}$
σ_B
1000
500
200
100
50
20
10
5
σ (mb)
80
90
100
E_L (MeV)