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COULOMB EXCITATION OF VIBRATIONAL LEVELS BY HEAVY IONS

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Chalk River, Ontario, Canada

RESEARCH CONTRIBUTION

PROPOSED SESSION NO. 6 - Properties of Individual Levels

Title: Coulomb Excitation of Vibrational Levels by Heavy Ions

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Abstract:

The Coulomb excitation of high-lying levels in heavy nuclei have been studied by γ- and β-ray techniques. In U^{238} and Th^{232} evidence is found for octupole excitation of negative parity bands and for quadrupole excitation of β- and γ-vibrational bands. Preliminary results for several other even-even and odd-mass nuclei have been obtained.

COULOMB EXCITATION OF VIBRATIONAL LEVELS BY HEAVY IONS

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The Coulomb excitation process offers interesting possibilities for the study of nuclear vibrational levels.[1] This paper reports measurements recently carried out by means of oxygen ions from the Hilac at an energy corresponding to approximately half the Coulomb barrier. Gamma rays from thick metallic targets were detected by a 3x3-in. NaI crystal and recorded either in singles or in coincidence with back-scattered projectiles.[2] The coincidence spectra were generally much cleaner than the singles spectra, and were preferred for evaluation of the reduced transition probabilities by means of the classical Coulomb excitation theory.[1]

In nearly all cases hitherto studied the Coulomb excitation has been of electric quadrupole type. However, electric dipole or electric octupole excitations can be expected where states of the proper spin and parity are found. It was natural to look for these excitations in the heavy element region, where low-lying states of negative parity systematically occur in even-even nuclei. Gamma-ray studies on a Th^{232} target showed two major groups at 760 and 1040 kev. The width of the groups clearly indicated these as being complex. This was to be expected, as the multiple Coulomb excitation process populates several states in the rotational band connected with each vibrational state and these states, furthermore, decay to several of the states in the ground-state band. However, the total transition probabilities to a specific rotational band is not affected by the multiple excitation, as it only gives rise to a redistribution of the intensity in the upper band.[3]

These considerations in mind, we found it worth while to investigate the character of the excitations by studies of the excitation functions for

the unresolved peaks. Figure 1 shows the excitation functions for the Th^{232} groups recorded in coincidence with particles scattered through an average angle of 140 deg. The experimental points are in good agreement with the theoretical excitation functions for E2 in the case of the 760-kev group. Indeed, it is known from the work of Durham et al.[4] that this group corresponds to excitation of a 2+ β-vibrational state at 775 kev and a 2+ γ-vibrational state at 788 kev. The excitation function for the 1040-kev group appears to be too steep to be an E2, whereas the agreement with an E3 excitation function is good. The theoretical curve for an assumed E1 excitation would be more flat than that for the E2.

With U^{238} we observed composite peaks at 660 and 1060 kev. The excitation functions indicated that the lower energy group was due to an E3 excitation, whereas the higher group was in agreement with an E2 assignment. This assumption was supported by studies of the relative yields of the two peaks when recorded in coincidence with forward scattered projectiles. In agreement with the theory,[1] a decrease of the yield of the 660-kev group relative to the 1040-kev group was observed.

These data indicate that we observe octupole excitation of negative-parity bands in U^{238} and Th^{232}. The excitation can take place to the 3- rotational states of these bands or can, for example, proceed via an E2 excitation to the first rotational state followed by an E3 excitation to the 1- state. Our data are best accounted for if we assume about equal population of the 1- and 3- states, in agreement with the estimated intensity of multiple Coulomb excitation. The resolution of the γ-ray spectrometer is not sufficient to allow a detailed investigation of the excited states. In order to get improved resolution we have constructed a wedge-gap β-spectrometer[5] for the detection of conversion electrons. Figure 2 shows a part of the electron

spectrum from U^{238} when bombarded with O^{16} ions. The pronounced peaks are the K and the L lines due to monopole transitions from the β-vibrational states. The satellite peak on the L line could perhaps be due to the γ vibration, bringing these two states close together, as for Th^{232}. The smaller peaks at lower energy are interpreted as K-conversion lines from transitions proceeding from the 1- and 3- states to the ground state and the first rotational state. The electron intensities are in good agreement with an E1 assignment for these transitions. Preliminary results for the energies and transition probabilities in these and other nuclei are collected in Table I.

REFERENCES

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TABLE I

Gamma ray energies and reduced transition probabilities for excitation observed with O^{16} ions. It has in all cases been assumed, that the transition energy equals the energy of the γ-ray. Where the isotope responsible for a transition is not known the abundance is assumed to be 100%. Except for the U and Th levels discussed in the text the multipolarity of the excitation is assumed to be E2. The single particle units used are $3 \times 10^{-5} A^{4/3} e^2 \times 10^{-48}$ cm^4 for E2 and $4.2 \times 10^{-7} A^2 e^2 \times 10^{-72}$ cm^6 for E3.[1]

Nucleus	γ-energy kev	$B(E2)/e^2$ 10^{-48} cm^4	$B(E2)/B(E2)_{s.p.}$
Ho^{165}	520 ± 15	0.016	0.59
--	575 ± 15	0.010	0.37
--	705 ± 15	0.027	1.00
Ta^{181}	780 ± 20	0.010	0.33
-- ?	1230 ± 40[a]	0.15	4.9
-- ?	1400 ± 40	0.11	3.6
W^{186}	645 ± 15	0.053	1.67
--	780 ± 15	0.16	5.0
$Re^{185-187}$	875 ± 20	0.018	0.57
--	1010 ± 20	0.008	0.25
--	525 ± 15	0.015	0.47
--	650 ± 15[a]	0.025	0.79
Au^{197}	550 ± 10	0.39	11.2
Th^{232}	760 ± 20[a]	0.25	5.7
U^{235}	650 ± 30	0.11	2.5
--	900 ± 40[a]	0.11	2.5
U^{238}	1060 ± 30[a]	0.22	4.9
		$B(E3)/e^2$ 10^{-72} cm^6	$B(E3)/B(E3)_{s.p.}$
Th^{232}	1040 ± 30[a]	0.29	13.0
U^{238}	660 ± 20[a]	0.49	21.0

[a] Composite line

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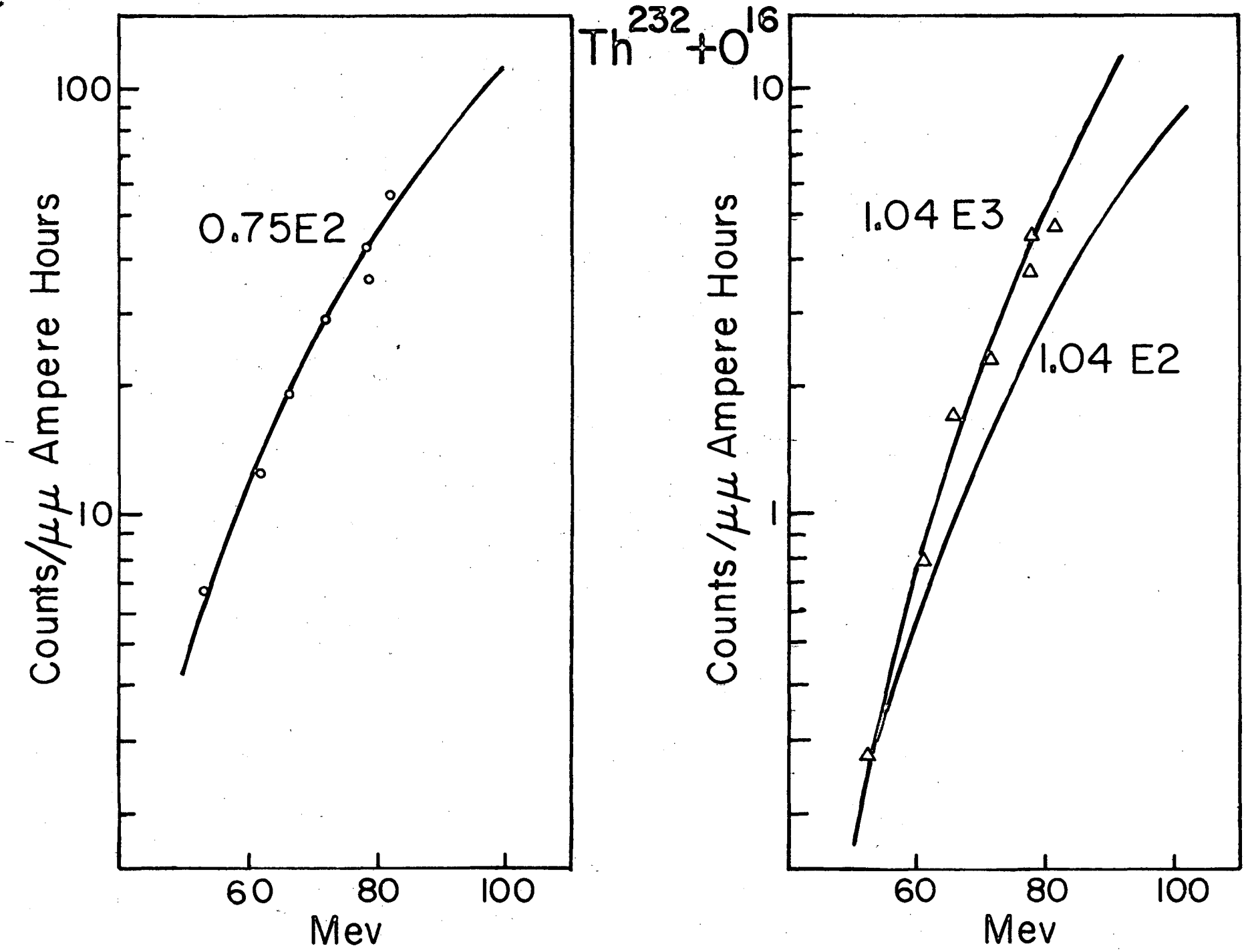
$Th^{232} + O^{16}$
0.75E2
Counts/μμ Ampere Hours
100
10
60
80
100
Mev
1.04 E3
1.04 E2
Counts/μμ Ampere Hours
10
1
60
80
100
Mev

Fig 1

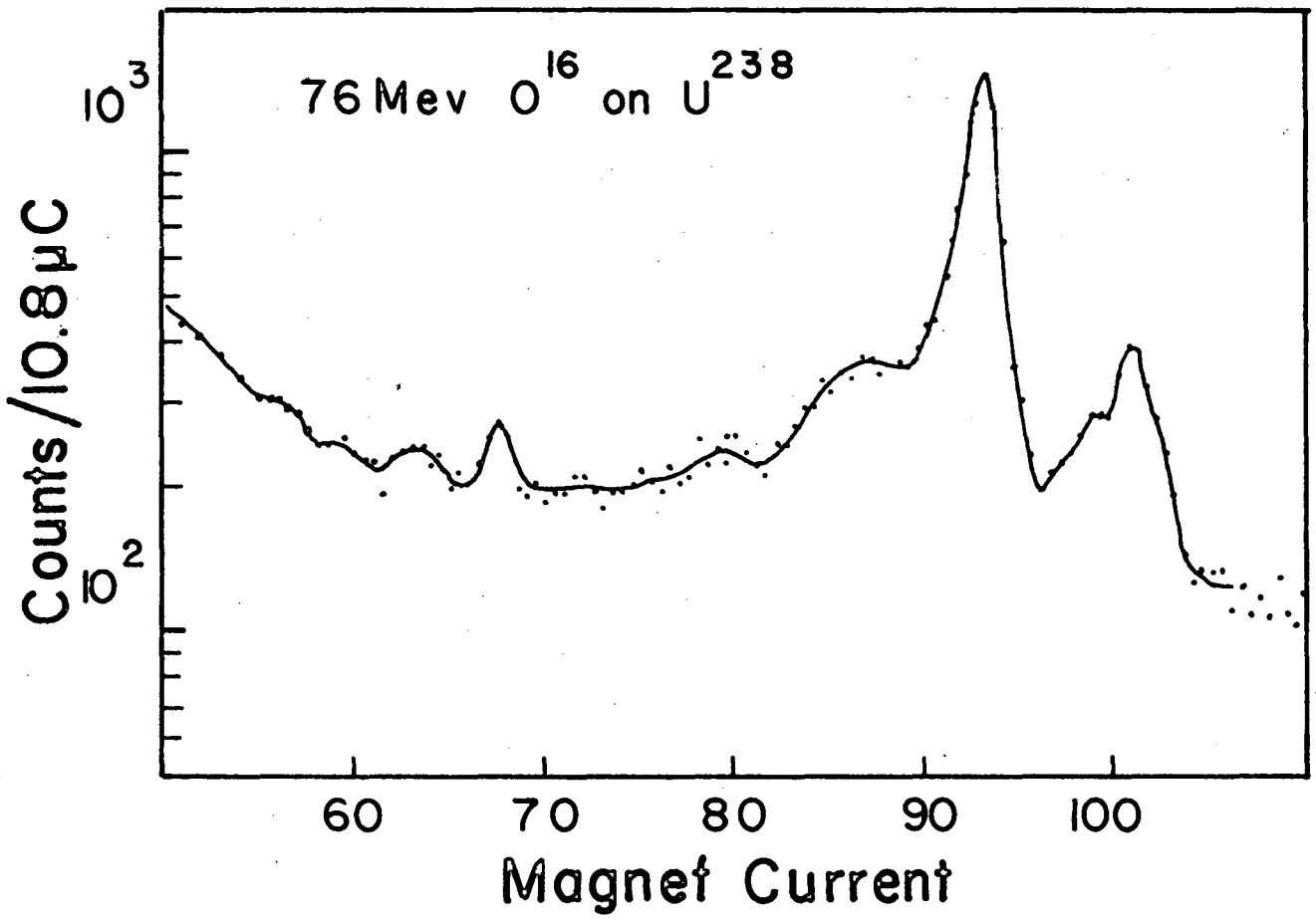
76 Mev O^{16} on U^{238}
10^3
10^2
Counts/10.8μC
60
70
80
90
100
Magnet Current

Fig 2