lations. The results are shown as the curves in the figures; partial widths are given in keV. Qualitative agreement with the magnitudes and angular distributions of much of the data is good, although some difficulties are apparent. The cross section is generally not yet well described; the values of $S(\theta)$ at the 7.08-MeV resonance are fitted poorly. Still, these preliminary calculations are encouraging and they indicate the sensitivity of the measurements to the wave functions of the analog states. Note, for instance, that the large differences in the $\Delta S/S$ angular distributions between the two $\frac{3}{2}^+$ resonances at 7.08 and 7.53 MeV are explained by the very different values of the widths $\Gamma_{lj}^{p'}$ for the two resonances.

These results indicate that spin-flip measurements with polarized proton beams yield valuable information about IAR states and their parents. They provide conclusive evidence for the first time that p_z and A_z are generally different. The complementary information from p_z and A_z means that both are important spectroscopically. The method of measurement suggested in Ref. 1 and used here successfully for measurements at IAR's may also be extended to direct $(p, p'\gamma)$ reactions using polarized protons and ultimately to other direct reactions such as $(p, {}^3\mathrm{He}\gamma)$ (with polarized protons).

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α Decay of Neutron-Deficient Isotopes of Bismuth and Lead Produced in (Ar, xn) and (Kr, xn) Reactions

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Neutron-deficient isotopes of bismuth and lead have been produced in various heavy-ion-induced reactions. Argon and krypton ions were used as projectiles on ^{159}Tb, ^{155}Gd, and ^{109}Ag. We observed α emission from bismuth nuclides and isomers with $A = 190-197$ and from lead isotopes with $A = 186-190$. We give results on mass assignments, α-decay energies, half-lives, and α branching ratios. Two new lead isotopes were found: ^{187}Pb, $E_\alpha = 6.08$ MeV, $t_{1/2} = 17.5$ sec; and ^{186}Pb, $E_\alpha = 6.32$ MeV, $t_{1/2} = 7.9$ sec. No α-emitting isotopes of thallium were found, and upper limits significantly below 1% can be set on the α branching ratios of Tl isotopes with $A = 182-187$.

The properties of neutron-deficient α emitters of bismuth and lead are not well known. The information listed in a recent compilation[1] or in the latest nuclide charts is based mostly on unpublished reports,[2-4] and details of the basis of the mass assignments are not available. We have investigated the production and decay of these nuclides in a variety of reactions.[5] We have confirmed the validity of most of the previous assignments but have found several discrepancies in the details of the decay properties. Two new lead isotopes, ^{186}Pb and ^{187}Pb, have been found, and

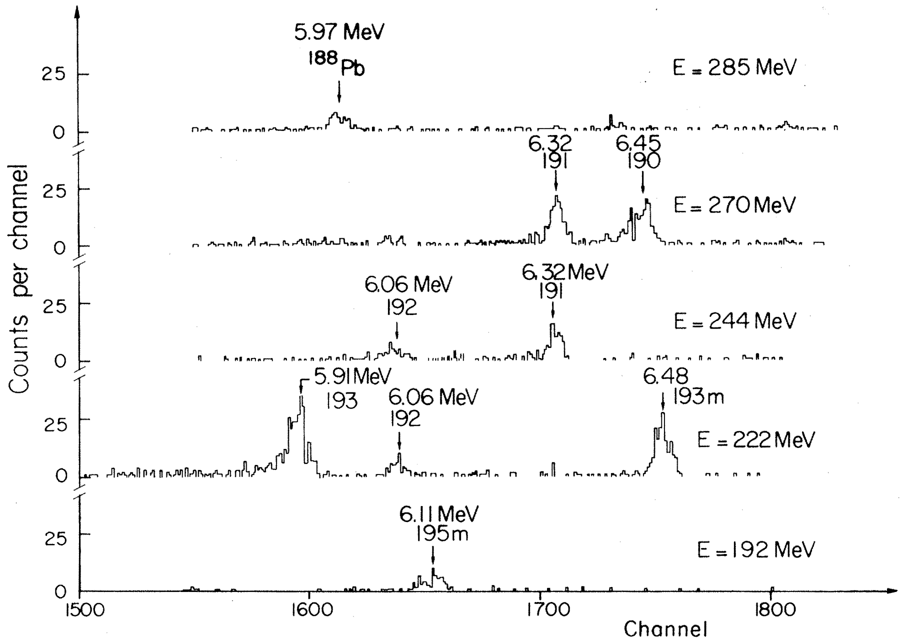


FIG. 1. α spectra obtained in the reaction of ^{159}Tb with ^{40}Ar ions of the indicated energies.

α branching ratios for most of the nuclides have been determined for the first time. We have also searched for α emission in the decay of thallium nuclides but failed to find any evidence for this process. On the basis of this result we can set upper limits on the α branching ratios of a number of thallium isotopes.

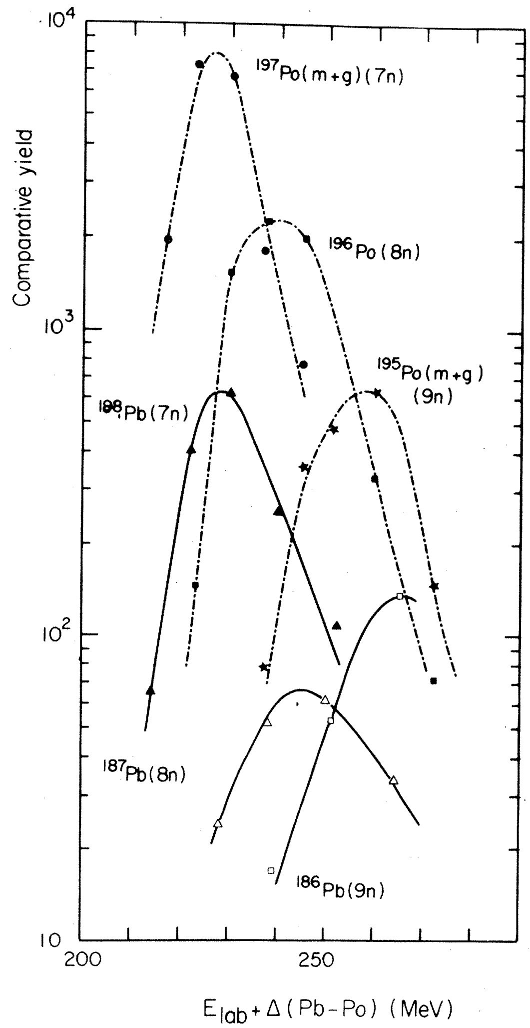
The bismuth isotopes were produced in the following reactions: ^{203}Tl(^{3}He, xn), ^{159}Tb(^{40}Ar, xn), and ^{109}Ag(^{84}Kr, xn). Lead nuclides were produced in the reactions ^{155}Gd(^{40}Ar, xn). These measurements also served to ensure that the α peaks attributed to bismuth isotopes did not, in fact, arise from the decay of lower-Z nuclides. The formation of Tl isotopes was investigated in reactions ^{151}Eu(^{40}Ar, xn), and the contribution to the observed peaks from mercury or gold isotopes was determined by bombardment of natural samarium with ^{40}Ar ions. In order to check the operation of the apparatus, provide α calibration lines, and obtain the information required for mass assignments and α branching-ratio determinations, the well known polonium α emitters were produced in the reactions ^{206}Pb(^{3}He, xn), ^{164}Dy(^{40}Ar, xn), and ^{116}Cd(^{84}Kr, xn).

The experiments with ^{3}He ions were performed at the Orsay synchrocyclotron and covered the energy range of 85 to 205 MeV. The experiments with Ar and Kr ions were carried out at the accelerator ALICE at Orsay. The incident energies of these projectiles were 302 and 500 MeV, respectively, although in many cases the full energy was not available because of the energy loss in an entrance foil to our target chamber. The experiments involved use of the helium jet technique[6-7] in combination with α spectroscopy. The experiments consisted of excitation function measurements and half-life determinations of the various α peaks. Further details will be given in a forthcoming article.[8]

Figure 1 shows some typical spectra obtained in the irradiation of Tb with Ar ions. The gradual appearance and disappearance of the various peaks with increasing energy is quite typical of compound nuclear reactions induced by heavy ions. The indicated mass assignments were made by comparison of the excitation functions with those of the known polonium isotopes. It was assumed that once the c.m. bombarding energies were corrected for differences in Q value, the shapes of the corresponding Po and Bi, or Po and Pb excitation functions should be similar, with the maxima occuring at the same energy. An example of this assignment procedure for the new Pb isotopes is shown in Fig. 2.

Table I presents a summary of the results obtained for bismuth isotopes. The odd-mass isotopes have isomeric states which are also α emitters, and the distinction between the ground and isomeric states was made on the basis of energy systematics. The α branching ratios were determined by comparison of the relative cross sec-

FIG. 2. Comparison of the excitation functions of Pb isotopes formed in reactions ^{155}Gd(^{40}Ar,xn) with those of Po isotopes from reactions ^{164}Dy(^{40}Ar,xn). The Po curves (dashed lines) are plotted at the laboratory bombarding energies. The Pb curves (solid lines) have been shifted to account for the difference in Q values as well as in the conversion from $E_{\rm lab}$ to $E_{\rm c.m.}$. The Pb curves have been arbitrarily shifted relative to the Po curves along the ordinate for display purposes. ($m+g$) indicates that both the metastable and ground states have been measured.



tions at the peaks of the corresponding polonium isotopes found by the emission of the same number of neutrons. Since the Po α branching ratios are known, the Bi α branching ratios could be deduced on the assumption that the cross sections for the formation of corresponding Po and Bi nuclides are equal. This procedure assumes that fission competes to a comparable extent in the de-excitation of Po and Bi compound nuclei (the competition of charged-particle emission is also assumed to be the same, but this is a minor effect). Some justification that this assumption is not too bad can be seen in the rather good agreement in branching ratios obtained by means of this procedure for ^{3}He- and ^{40}Ar-induced reactions, in spite of the much greater importance of fission in the case of the Ar projectile. We plan to correct the branching ratios for differences in fissility in our more complete report.[8]

In the case of the odd-A Bi isotopes we also had

TABLE I. Summary of results for Bi α emitters. R_α indicates the branching ratio for α decay.

Nuclides	E_α (MeV)	$t_{1/2}$	R_α (^{3}He,xn)	R_α (^{40}Ar,xn)	R_α (average)	Tarantin et al. E_α (MeV)	Tarantin et al. $t_{1/2}$	Siivola E_α (MeV)	Siivola $t_{1/2}$
197m	5.77±01	~10m	0.11%	-	0.11%	5.81±.02	9.5m	5.81	8.0m
195m	6.11±.01	105±7s	3.9%	-	3.9%	6.15±.02	80s	6.13	85s
195	-	-	<0.15%	-	<0.15%	5.48±.02	4m	5.42	2.5m
194	-	-	<0.15%	-	<0.15%	5.67±.02	62s	5.61	85s
193m	6.48±.01	3.48±.18s	38%	28%	33%	6.50±.02	3.15s	6.50	3.2s
193	5.90±.01	62.2±3.6s	10%	8.8%	9.4%	5.95±.02	62s	5.91	60s
192	6.06±.01	42.3±2.3s	5.3%	7.1%	6.2	6.09±.02	-	6.07	48s
191m	-	-	-	<8%	<8	-	-	6.90	-
191	6.32±.01	12±0.7s	-	19%	19	-	-	6.33	15.4s
190	6.45±.01	5.4±0.5s	-	32%	32%	-	-	6.46	-

TABLE II. Summary of results for Pb α emitters. R_α indicates the branching ratio for α decay.

Mass no.	E_α (MeV)	$t_{1/2}$ (sec)	R_α (%)	E_α[a] (MeV)	$t_{1/2}$[a] (sec)
190	5.59 ± 0.01	...	...	5.55	66
189	5.73 ± 0.01	...	0.2	5.73	50
188	5.99 ± 0.01	23.6 ± 4.5	1.5	5.99	26
187	6.08 ± 0.01	17.5 ± 3.6	0.7	...	...
186	6.32 ± 0.01	7.9 ± 1.6	5	...	...

[a]Given by Siivola, Ref. 3.

to assume an isomer ratio. We used a value of 5, similar to that found for the Po isotopes. However, in the case of Bi it is the ground state which has the higher yield. This is reasonable since the spin of the odd-A Bi ground states is $\frac{9}{2}^-$ and that of the isomers probably $\frac{1}{2}^-$ or $\frac{3}{2}^-$.

In the experiments with the ^{3}He beam we were able to detect all the listed Bi nuclides down to ^{191}Bi. The use of the Ar beam also allowed us to detect ^{190}Bi. We were unable to detect any Bi isotopes of lower mass number even though the bombarding energy was sufficiently high to produce ^{189}Bi and perhaps also ^{188}Bi. This was also found to be the case with incident Kr ions where Bi isotopes of even lower mass number could have been produced. It appears that the competition from fission must greatly reduce the cross sections for the formation of Bi isotopes below 190.

Table I also summarizes the results reported by Tarantin, Kabachenko, and Demyanov[2] and Siivola.[3] There is good agreement in the mass and isomer assignments although there are some differences with the reported energies and half-lives. In general we obtain better detailed agreement with the data of Siivola. One important difference is that we were unable to obtain definite evidence for α decay from ^{195}Bi, ^{194}Bi, and ^{191m}Bi and list upper limits to the branching ratios which are quite low for ^{195}Bi and ^{194}Bi.

Our results on lead α emitters are summarized in Table II. The mass assignments and branching ratios were determined in the same manner as for bismuth. Where comparison is possible, the agreement with the results of Siivola is satisfactory.

The possibility of α decay of neutron-deficient Tl isotopes was investigated by bombardment of ^{151}Eu by Ar ions. Although a number of α peaks were observed, bombardment of natural Sm by Ar ions yielded the same peaks, strongly suggesting that they were due to isotopes of mercury or gold. The shapes of the excitation functions were also generally inconsistent with those obtained for the other (Ar, xn) reactions. On this basis we can conclude that the α branching ratios of Tl isotopes with $A = 182-187$ must be substantially less than 1%.

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