ALPHA DECAY OF NEUTRON DEFICIENT ISOTOPES OF MERCURY AND RADON AND THEIR DAUGHTERS

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1. INTRODUCTION

Among the neutron deficient isotopes produced at the ISOLDE isotope separator on-line facility at the CERN 600 MeV synchro-cyclotron[1] are two groups of alpha-radioactive isotopes. One group consists of light α-unstable mercury isotopes and their α-active gold and platinum daughters, the other of radon isotopes leading to a range of α-active polonium and astatine isotopes. The production of these isotopes is based on two target systems[2] one containing molten lead (740°C) for the production of mercury and another containing $Th(OH)_4$ at room temperature for the production of radon. These targets were among the first to be brought in operation at ISOLDE and a number of experiments involving α-decay performed with isotopes from these targets have been completed[3,4].

The present paper presents a survey of the knowledge of the systematic trends in α-decay obtained with these isotopes. In the interest of completeness we have incorporated also existing information[5,6,7,8] on the α-decay properties of the elements studied.

2. ALPHA SPECTROSCOPY

All experiments were performed on-line by means of the beam-handling and tape-transport systems described in ref. 9. Depending upon the experimental situation the counting stations were equipped with surface-barrier

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Si-detectors, Ge(Li) detectors or scintillation detectors. The alpha spectra were recorded with a 4096 channel analyzer usually operating in a 8 x 512 channel multispectrum mode allowing recording of successive spectra. The intervals of collection, cooling, and counting as well as the recycling operations were controlled automatically.

The isotopic purity of the sources was normally very high and the clean spectra thus obtained permitted, combined with the unambiguous mass assignments provided by the mass-separating stage, reliable determinations of half-lives and Q-values. Examples of singles α-spectra and decay curves are shown in figs. 1 and 2. Branching ratios for α-decay, b_α, defined as $\alpha/(\alpha+\beta^{+}+EC)$, were obtained using either genetic relationships[3,4] or intensity calibrated detector systems[3].

Recent improvements in the performance of the isotope separator[10] (at the maximum the yield curve now shows saturation activities of about 10^{8} dis/sec) have added one isotope, ^{178}Hg, to the mass range observed[3] for mercury and permitted the determination[11] of the half-lives for ^{179}Hg and ^{178}Hg.

3. RESULTS

In fig. 3 is shown the experimental Q-values for α-decay of the various even-Z elements in the region around Z=82 as a function of the neutron number N. It is noted that the monotonic decrease of the Q-value with increasing neutron number for each element observed in the mass region above the N = 126 closed neutron shell also clearly exists in the region below N = 126. So far only two exceptions are observed, namely ^{183}Hg and ^{185m}Hg, and there is as yet no explanation of these two "anomalies". The 17 sec ^{185}Hg Q_α-value[3] that fits in nicely in the general trends of fig. 3 does not correspond to a ground state to ground state transition as it is gamma-coincident[3]. The curves represent the calculations by Zeldes et al.[12] (for comparisons with other mass calculations see ref. 3) and in this region the agreement is reasonably good. The Pb (Z = 82) isotopes found by Siivola[13] form an exception to this as they fall about 1.5 MeV below the curve. The average deviations for Z = 86, 84, 80, and 78 are 45 keV, 90 keV, 395 keV and 125 keV, respectively.

Further, the knowledge of the three parameters $T_{1/2}$, Q_α, and b_α, enables one to extract the systematic behaviour of the partial half-life for α-emission and the relative widths for α-decay. Fig. 4 shows a modified Geiger-Nuttal plot in which the partial half-lives for α-decay of the even platinum, mercury, polonium and radon isotopes are plotted against the barrier-penetration, parameter $\sqrt{\frac{A_D}{A_D+4}}\ \sqrt{Z}\ A^{1/6}\gamma(x)$ which in the simple one-body model[14] of the α-decay contains the dependence of the half-life upon the Q-value and the charge and mass of the daughter nucleus. Here the parameter x is the ratio of the Q_α-value to the height of the Coulomb barrier. The straight line in this plot represents the one-body model prediction using a radius parameter of 1.55 fm and the condition that the experimental half-life of ^{212}Po is reproduced correctly.

It appears from fig. 4 that this traditional approach accounts well for the A, Z, and Q dependence of observed partial half-lives over a range of a factor 10^{18}. The deviations above and below the line correspond to hindrance and enhancement effects (relative to the one-body model calculation), respectively. These effects are more clearly illustrated in fig. 5 where the relative widths, γ^2, for α-decay are plotted versus neutron number N. Here the relative width is defined as the ratio of the experimental transition probability to the transition probability deduced from the line in fig. 4 so that ^{212}Po in these units has the width unity. Data for other platinum, polonium, and radon isotopes have been included to show the effects of the closed major shells at $Z = 82$ and $N = 126$. The shell closure manifests itself not only through abrupt changes in the gross decay features - i.e. Q_α-value and half-life - but persists also in the widths. The crossing of the $N = 126$ neutron shell dramatically changes the width by one order of magnitude and also the filling of the proton shell at $Z = 82$ gives rise to a decrease in α-width coming from either side but the determination of the widths for α-decay of the light lead isotopes has not yet been possible.

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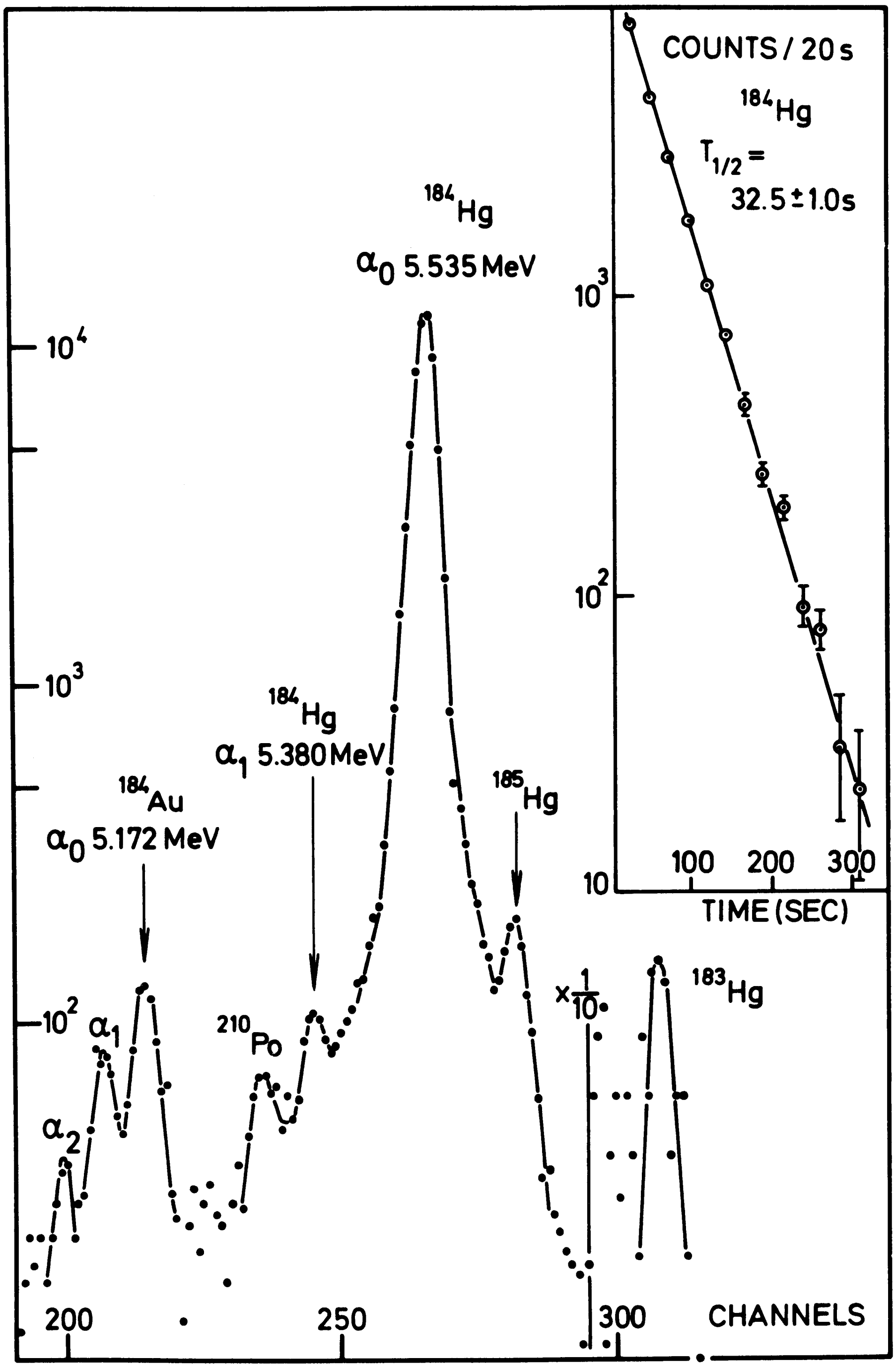

Fig. 1

Singles α-spectrum at A = 184. Besides the main 5.535 MeV line from 32.5 sec ^{184}Hg the α-transition to the 2+ state at 155 keV in ^{180}Pt is observed together with several α-lines from the decay of ^{184}Au. The contaminations from neighbouring masses are both below 1 $^{o}/oo$. In the insert decay curve for 32.5 sec ^{184}Hg.

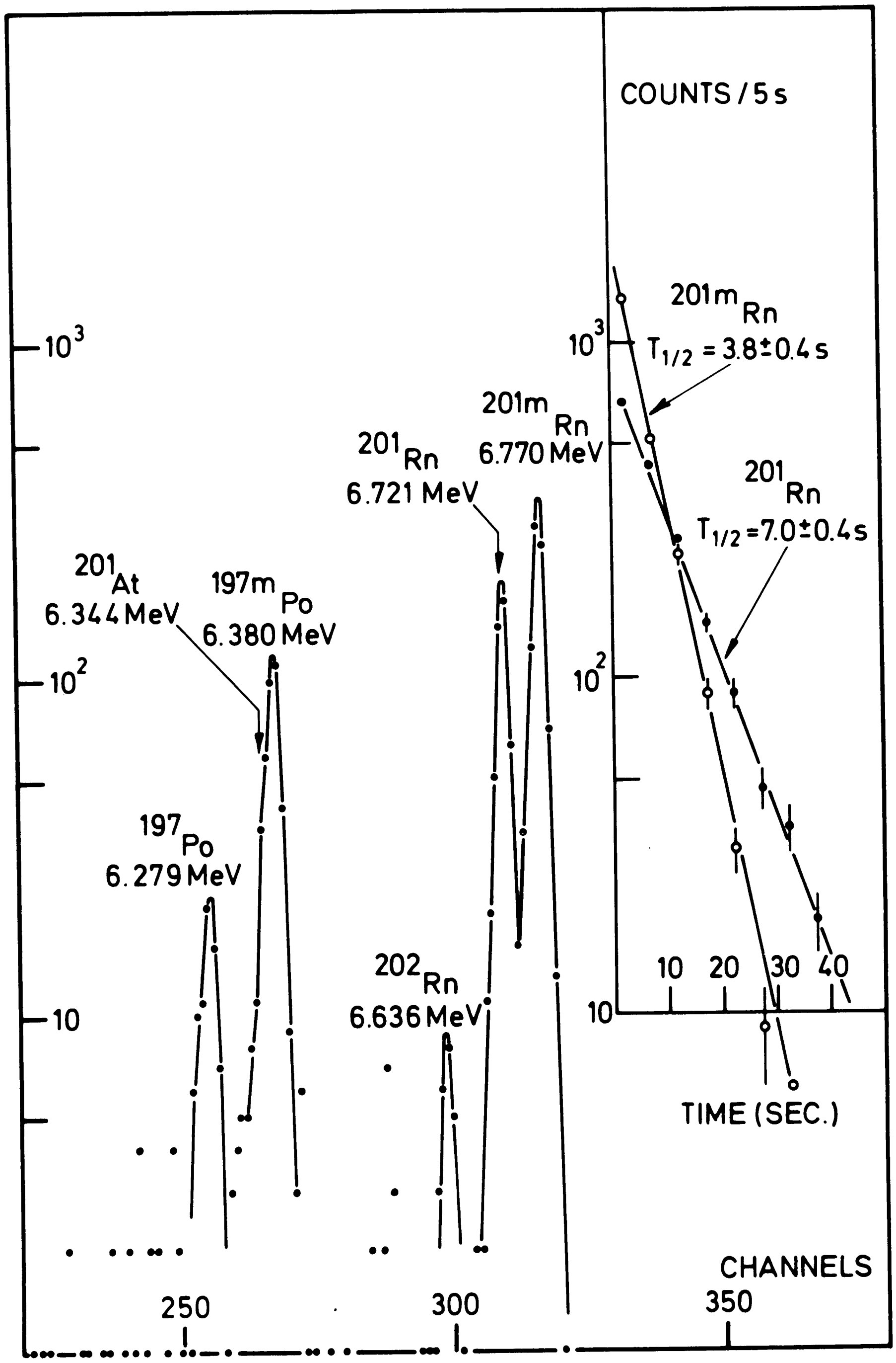

Fig. 2

Singles α-spectrum of the 3.8 sec and 7.0 sec ^{201}Rn isomers and their ^{197}Po daughters with halflives of 26 sec and 60 sec. Also identified is the 6.344 MeV line from ^{201}At. Collection- and counting-intervals of 5 sec and 10 sec, respectively. Slight contamination from the 50X more abundant ^{202}Rn is observed.

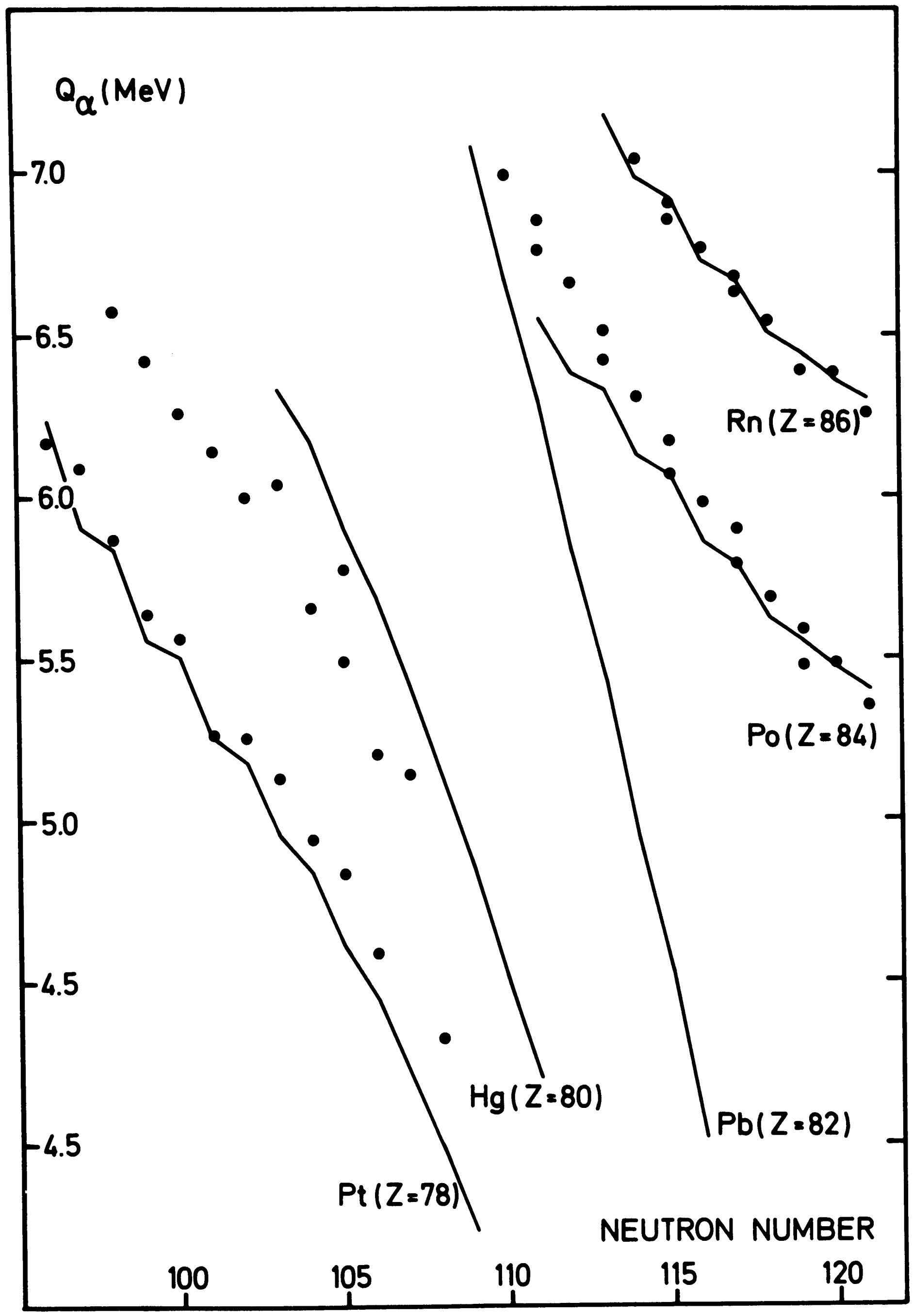

Fig. 3

Comparison of experimental α-decay Q-values with the calculations of Zeldes et al. for platinum, mercury, polonium, and radon isotopes.

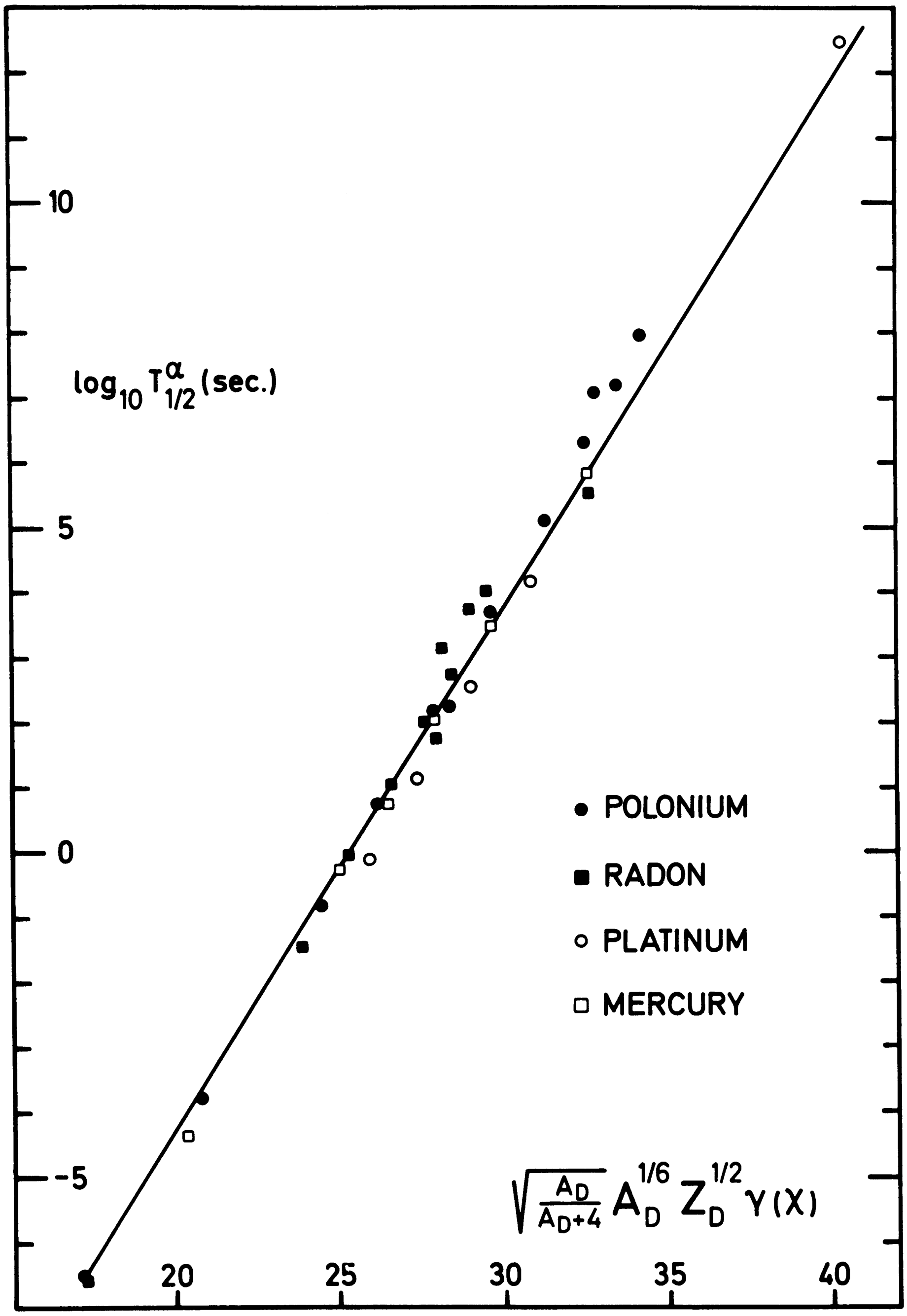

Fig. 4

Partial half-lives for α-decay of platinum, mercury, polonium, and radon isotopes plotted against the barrier-penetration parameter $g(Z,A)\gamma(x)$. The straight line has a slope corresponding to $r_o = 1.55$ fm and is normalized to reproduce the α half-life of ^{212}Po.

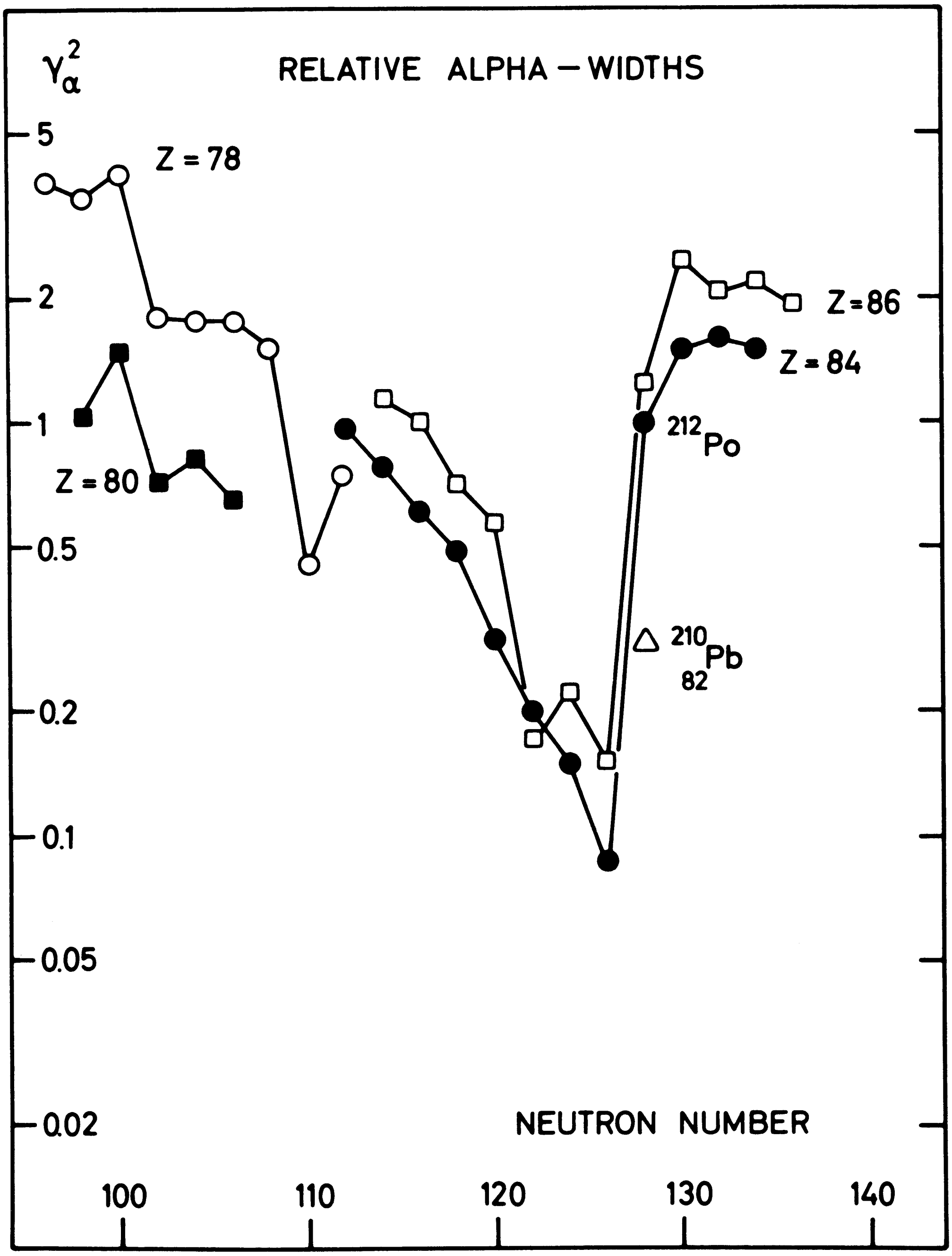

Fig. 5

Reduced α-widths defined as the ratio of the experimental transition rates to the one-body model transition rates represented by the straight line in fig. 4.