An Upper Limit for the $(\alpha, \pi^-)$ Reaction on $^{181}$Ta

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Abstract. In order to search for traces of the $^{181}$Ta$(\alpha, \pi^-)^{185}$Os reaction a foil stack of very pure tantalum was bombarded with an $\alpha$-beam of 173 MeV. A radiochemical separation method was applied to four parts of the stack. So two sources corresponding to energies above and below the $(\alpha, \pi^-)$ threshold were obtained and searched for contents of $^{185}$Os. Using a well shielded Ge(Li) detector weak 646 keV transitions belonging to $^{185}$Os were observed for all samples. Since the origin of this activity is uncertain for the samples below threshold only an upper limit of 100 nb can be set for the $(\alpha, \pi^-)$ reaction on $^{181}$Ta above threshold.

1. Introduction

The observation of pions following the bombardment of carbon by protons of 185 MeV by Dahlgren et al. [1] has opened a new field in medium energy nuclear physics: the investigation of “exotic” nuclear reactions.

Though the threshold for the pion production in free nucleon-nucleon collisions is 291 MeV, the production of pions in nuclei is allowed below this energy by energy and momentum conservation laws, if the recoil momentum is transferred to the whole residual nucleus. In fact, the angle integrated cross sections for individual levels in the $^{12}$C$(p, \pi^-)^{13}$C reaction are reported [2] to be of the order of 1 to 4 $\mu$b. The theoretical interpretation of a variety of similar reactions by Huber et al. [3] showed that the experimental results may only be explained by taking into account short range nucleon-nucleon correlations. Huber [4] also discussed the possibility of producing pions by complex particles as bombarding projectiles. So far, there is only one theoretical prediction on the electromagnetic pion production in nucleus-nucleus scattering below the Coulomb barrier [5].

The aim of the present investigation is to give a first experimental answer to that problem by studying the collisions of $\alpha$-particles with a heavy nucleus. As the most promising case for producing pions the $^{181}$Ta$(\alpha, \pi^-)^{185}$Os reaction was selected for reasons discussed in the following section. The threshold of this reaction is at 145.57 MeV. Using the $\alpha$-beam of the Jülich isochronous cyclotron at 173 MeV the measurement of a rough excitation function of the yield has been possible by employing the well known foil stack technique and a special procedure to identify weak traces of the radioactive $^{185}$Os residual nucleus.

2. Experimental Method

The investigation of the $(\alpha, \pi^-)$ reaction seemed to be more promising than that of $(\alpha, \pi^0)$ or $(\alpha, \pi^+)$, since in the $(\alpha, \pi^-)$ process the charge number $Z$ of the target nucleus is raised to $Z+3$ and hence an isotope is produced which cannot be synthetized by any other $\alpha$-induced reaction. If the isotope of charge $Z+3$ is radioactive and can be chemically separated from all other reaction products a low background trace analysis of it is feasible. It was found that tantalum is best suited as target material for the following reasons:

a) It is a very heavy, nearly monoisotopic element having a low $(\alpha, \pi^-)$ threshold near the pion rest mass.
b) It is available in metallic foils of rather high purity which are suited for foil stack bombardment hence excitation functions are easily measured above and below threshold simultaneously.

c) The element osmium produced in the \(^{181}\text{Ta}(\alpha, \pi^-)\) reaction can be transformed into the very volatile OsO\(_4\) (m.p. at 100 °C) so that the radioactive \(^{185}\text{Os}\) nuclei might be rather completely separated by distillation from the other radioactive isotopes of Re, W, Ta, Hf and Lu which are in bulk formed by (\(\alpha, x\) Nucleon) reactions and following \(\beta\)-decays.

d) The nucleus \(^{185}\text{Os}\) is easy to identify by its strong 646 keV gamma transition following electron capture (\(I_t = 80\%\)). Its long half-life of 93.6 d is favourable for the time-consuming radiochemical separation and for tests of the method.

e) Another point for using tantalum is more accidental: in Bonn, \(\text{Ta}(\alpha, x n)\) excitation functions up to 173 MeV have already previously been investigated by Hermes et al. [6] and Machner et al. [7] a fact that proved to be helpful in planning as well as in analyzing the experiment.

Two irradiations were carried out: In the first experiment a stack of 56 commercially available tantalum foils of 16 mm \(\varnothing\) and 30 \(\mu\)m thickness was irradiated for 6 h at \(E_\alpha = 170.3\) MeV collecting a total charge of 420 \(\mu\)C. In the second run 60 foils of high purity tantalum (99.996 \%) of 28.3 \(\mu\)m thickness were bombarded for 5.25 h at \(E_\alpha = 172.7\) MeV with a total charge of 5030 \(\mu\)C. After about two weeks when the strong activities with shorter half-lives had vanished the foil stacks were divided into four (respective five) parts of about equal thickness so that two parts covered the region above and two (respective three) parts the energy region below the (\(\alpha, \pi^-\)) threshold (cf. Figs. 2, 3). For the analysis the energy range tables of [8] were used.

Fig. 1. The upper spectrum shows the long run yield of the distillation probe of foils 2 to 10 at \(E_\alpha = 165\) MeV. A weak peak at 646 keV is tentatively ascribed to radioactive \(^{185}\text{Os}\). Known and unknown transitions not present in the background spectrum (lower part) are also indicated (for more details see text).