The ($^2\text{H} - d$)-Reactions below 200 keV

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The $^2\text{H}(d, n)$- and $^2\text{H}(d, p)$-reactions are studied for deuteron energies below 200 keV. It is shown that the R-matrix approach of Konopinski and Teller, which is very sensitive to the channel radius used, can be approximated in a way that the dependence on the channel radius does not appear explicitly. This approach appears to be formally equivalent to a kind of “direct approach” of Boersma. This equivalence answers the question why a direct approach to these reactions works at all at low energies. Each reaction is described by three parameters which are determined in a fit to the up to now available data.

1. Introduction

The reactions $^2\text{H}(d, n)$ and $^2\text{H}(d, p)$ have been investigated since the early days of accelerators in nuclear physics [1, 2]. The first anisotropic angular distribution in nuclear reactions was observed in the $^2\text{H}(d, p)$-reaction [3], leading to the prediction of LS-coupling [4]. It was just this observation which lead to the prediction of polarization phenomena in nuclear reactions [5]. Naturally these two reactions have been the objects for theoretical studies of nuclear reaction phenomena from the very beginning [4, 6, 7]. A long series of experimental and theoretical papers demonstrates the continuous interest in them [8, 9].

Nowadays the experimental research is concentrated on the study of polarization phenomena [10], using mainly polarized ion sources. Within the course of such experiments the importance of the quintet contributions in the $^2\text{H} - d$ channel was established [11, 12]. In other experiments an anomaly was observed in the excitation function, especially of the tensor analysing power $A_T$ [12, 13, 14].

A great part of the new theoretical work concentrates on the understanding of these reactions within a microscopic nuclear reaction theory [15]. One of the unsolved problems is the explanation of the large difference of the anisotropy of the angular distributions of the $^2\text{H}(d, n)$- and $^2\text{H}(d, p)$-reactions. The latest attempt attributes this difference to, up to now, unknown levels in $^4\text{He}$ which have no pure isospin [16] because of Coulomb mixing.

This short review demonstrates the complexity of these two reactions even at the lowest energies. In spite of a very large number of experiments
there is not too much which can be compared directly. Because of the very low energies more or less thick targets have been used in the experiments, ranging from a few keV to a target thickness larger than the range of the bombarding deuterons used. As a consequence the observed quantities are averaged over different energy intervals in the various experiments.

In order to compare the data of the different experiments a reevaluation was started, taking into account the various target thickness and target materials used in the different experiments. These calculations and the data themselves are presented in Chap. 2. In Chap. 3 a low energy $R$-matrix approach is presented. The results are compared with those of an approach starting with a more direct interpretation [17]. Chap. 4 is devoted to a comparison of the low energy approach to the experimental data. The appendix contains some formulas which are necessary to obtain the results of Chap. 3.

### 2. Collection of the Available Data

#### 2.1. Determination of an Averaged Energy

To compare data, obtained with a thick target with those achieved with thin targets an averaged energy was calculated. After travelling a certain distance $x$ within a target, a particle with primary energy $E_0$ has the energy

$$E(x) = E_0 - \int_0^x \frac{dE}{dx} (E(x')) \, dx'.$$

$(dE/dx)$ is the energy loss of the particle [18] which, because of its energy dependence, depends on the travelled distance $x$. In order to get the averaged energy $E_{av}$ for a certain type of reaction $\alpha$, e.g. $^2\text{H}(d, p)$, one has to calculate

$$E_{av}^\alpha = \int_0^d p^\alpha(E(x)) E(x) \, dx / \int_0^d p^\alpha(E(x)) \, dx.$$

In this equation $d$ means the target thickness and $p^\alpha(E(x))$ the probability, that a certain reaction $\alpha$ will take place at a certain energy $E(x)$. Obviously this ansatz assumes that $p^\alpha$ depends on $x$ only because of its energy dependence. An additional possibility would be e.g. an angular dependence of $p^\alpha$. In order to avoid complicated calculations this possible angular dependence was neglected. Then it is reasonable to assume that $p^\alpha(E(x))$ is proportional to the total cross section for the reaction $\alpha$:

$$E_{av}^\alpha = \int_0^d \sigma_{tot}^\alpha(E(x)) E(x) \, dx / \int_0^d \sigma_{tot}^\alpha(E(x)) \, dx.$$