NOTIZEN

Interaction of 14.0 MeV-Neutrons with ^{12}C in Stilbene

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The pulse height spectrum of all heavy charged particles induced by 14.0 MeV neutrons in a 1″ × 1″ stilbene scintillator was measured using a pulse shape discriminator and the associated particle technique. The proton pulse spectrum was subtracted and the remaining alpha-pulse distribution is shown in a diagram. The sum of the cross sections for the reactions $^{12}C(n, n')\,3\,\alpha$ and $^{12}C(n, \alpha)^{9}Be$ was determined to be $\sigma_c = (260 \pm 20)$ mb.

A widely used method in fast neutron spectroscopy is based upon the unfolding of the proton recoil pulse height spectrum which is induced in organic scintillators as e. g. in stilbene, NE 213 etc. The main problems giving rise to erraneous results are

1) Non-isotropy of the n-p differential elastic cross section at energies > 12 MeV,
2) edge effects in small and
3) multiple scattering in large scintillators,
4) non-linearity of the light-energy relation for heavy charged particles,
5) nonelastic neutron interactions with the carbon atoms of the scintillator.

Much effort has been devoted to the minimalizing of all these effects [1–5]. For neutron energies < 14 MeV the optimum scintillator dimensions with respect to items 2) and 3) are 1″ diameter by 1″ height for stilbene and about 2″×2″ for NE 213.

The non-elastic interaction of fast neutrons with the carbon atoms of organic scintillators has been studied by several authors [6–10]. The two main reactions occurring are

$$\text{a)}\ ^{12}C(n, \alpha)^{9}Be\,, \qquad \text{b)}\ ^{12}C(n, n')\,3\,\alpha\,.$$

In the first mode of disintegration only one α-particle is emitted in those cases where the ^{9}Be nucleus is left in its ground state. If it is exited to one of its higher states, it disintegrates into a neutron and two α-particles, simulating a reaction of type b) [22, 24]. Both reaction a) and b) have been studied in detail with nuclear emulsions, cloud chambers and semiconductor detectors [11–24]. For a) the differential cross section curves found are rather contradictory and for b) the branching ratios concerning the disintegration of the various ^{12}C-levels are not known very well.

Figure 1 shows a pulse height spectrum induced by 14.0 MeV neutrons in a 1″ × 1″ stilbene scintillator. It was taken in

1) coincidence with the α-particles from the neutron-generating reaction $T(d, n)\alpha$ and
2) coincidence with the output pulse of a pulse shape discriminator which eliminated electron pulses.

This triple-coincidence technique has the advantage that only pulses from 14 MeV neutrons are analyzed and that all gamma-induced pulses are discriminated including those generated by pure inelastic neutron scattering within the scintillator. By this means the proton background from lower energy neutrons is greatly reduced.

The measured distribution shows a nearly ideal proton pulse height distribution-necessarily not rectangular because of the nonlinear light curve-superimpo-

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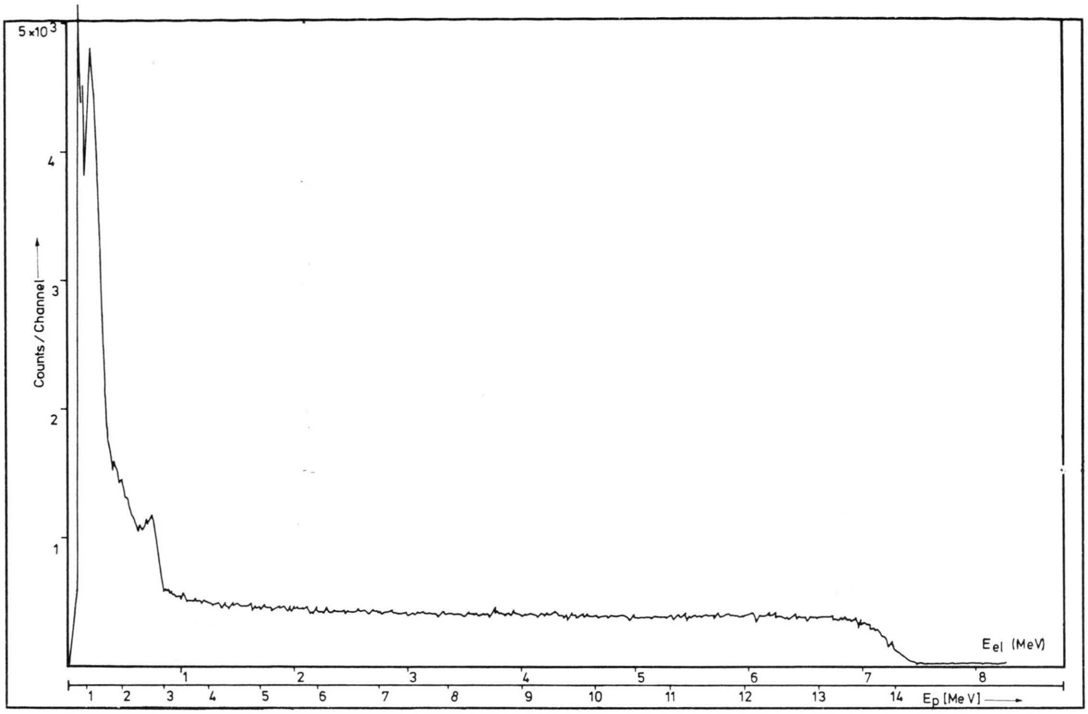

Fig. 1. Pulse height spectrum of the recoil protons and α-particles induced by 14.0 MeV neutrons in a 1″×1″ stilbene scintillator. The spectrum was taken in coincidence with the α-particles of the reaction $T(\mathrm{d,n})\alpha$ and the output pulse of the pulse shape discriminator. Calibration: 1 MeV $E_{\mathrm{el}} \triangleq 61.75$ Channels.

sed by the sharply rising α-distribution at an equivalent proton energy of about 3.0 MeV.

In order to obtain the pure α-spectrum by subtraction of the proton underlay, the following procedure was applied:
The proton light curve may be empirically written as:

$L_{\mathrm{p}} = c_1 E_{\mathrm{p}}^{c_2}$ (in units of 1 MeV- electron pulse height)

with $c_1 = 0.15$, $c_2 = 1.48$ (see [3]).
Then the proton pulse height spectrum is

$$\frac{\mathrm{d}N}{\mathrm{d}L_{\mathrm{p}}} = \frac{\mathrm{d}N}{\mathrm{d}E_{\mathrm{p}}}\,\frac{\mathrm{d}E_{\mathrm{p}}}{\mathrm{d}L_{\mathrm{p}}} = 0.675\,\frac{(6.67\,L_{\mathrm{p}})^{0.675}}{L_{\mathrm{p}}}\cdot\frac{\mathrm{d}N}{\mathrm{d}E_{\mathrm{p}}} \qquad (1)$$

The unknown term $\mathrm{d}N/\mathrm{d}E_{\mathrm{p}}$ is determined from (1) as an average value for a portion of the pulse spectrum which contains no α-particle pulses. This value is then in turn inserted in (1) and the pulse spectrum computed for the lower channels.

Figure 2 shows the α-particle spectrum obtained by this method. It was taken with a higher amplifier gain by a second pulse height analyzer at the same time as that shown in Fig. 1.

The separation of the α-particle distribution allows one to determine the sum of the cross sections for the reactions a) and b). But it must be emphasized here that it is impossible to obtain these cross sections separately by scintillator measurements. The reason is that according to some authors the differential cross section for reaction a) is peaked backward in the

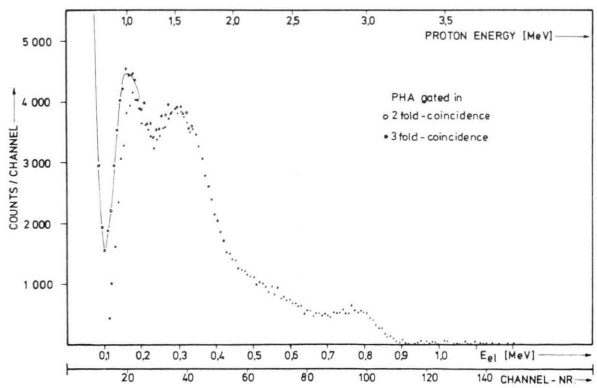

Fig. 2. Pulse height spectrum of all α-particles induced by 14.0 MeV neutrons in a 1″ × 1″ stilben scintillator. The spectrum was obtained after subtraction of the proton recoil distribution.

CM-system, so that a considerable contribution of α-particle pulses are mixed with the pulses due to the 3 α-disintegrations [15, 16].

The cross section sum may be determined without knowledge of the absolute neutron flux, but only from the ratio of α-pulses to that of the recoil protons.

Let N_α be the total number of induced α-particles (sum of α-counts in the 3-fold-coincidence gated spectrum), N_{pt} the total number of recoil protons produced in the scintillator, E_{p1} and E_{p2} some two energy values within the flat portion of the pulse distribution and N_{p1} the sum of counts within this portion, then we have:

$$\frac{N_\alpha}{N_{pt}} = \frac{n_c\,\sigma_c}{n_H\,\sigma_H} \text{ with } \frac{n_H}{n_C} = 0.8569 \text{ for stilbene}$$

and $\sigma_H = 0.690$ b ($E_n = 14$ MeV).

The proton number is computed from the relation

$$N_{pt} = \frac{14{,}0}{E_{p2} - E_{p1}} N_{p1}\,. \qquad (2)$$

The value for σ_C found in this manner is (260 ± 20) mb. It was obtained as an average from about 10 spectra including those taken with a 2″ × 2″ NE 213 scintillator.

The error of about 8% is mainly systematic. It is dependent on the form of the light curve in the proton energy range between E_{p1} and E_{p2}, because it is implicitely used in Eq. (2), and on the electronic threshold of the PSD-circuit, cutting off the α-spectrum.

The light curves used by the several authors differ mainly at lower and higher energies from one another [1, 3, 25, 26]. The influence of the PSD threshold is evident from Fig. 2: It is slightly above the first minimum in the spectrum, where the carbon recoil pulses mix with the α-pulses. So it is estimated that the value for σ_c rather tends to be somewhat larger than that given above. If one assumes an average cross section of 73 mb for the reaction $^{12}C(n, \alpha_0)^9Be$ (mean value from [11–15]) one obtains $\sigma(n, n')3\,\alpha = (190 \pm 20)$ mb.

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Relative Line Intensities in the Lyman Bands of HD and H_2

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Relative intensities of $P(J'+1)$ and $R(J'-1)$ lines have been measured in the $(v'=3, v'')$ progressions of the Lyman bands of HD and H_2. The intensity ratios are in good agreement with previous experimental data and with the results of theoretical calculations which account for the centrifugal distortion.

The influence of vibration-rotation interaction on calculated Franck-Condon factors and transition probabilities of spectral lines of hydrogen molecules has recently been studied by several authors [1–4]. It was found that inclusion of the centrifugal potentials in the calculations is necessary for precise theoretical predictions. The results of such calculations were put to an experimental test by Fink, Akins, and Moore [5] who measured the relative intensities of $P(J'+1)$ and $R(J'-1)$ lines in three $(v'=\text{const}, v'')$ progressions of the Lyman bands of HD, and compared the experimental line intensity ratios with theoretical data obtained from Franck-Condon factor calculations. Later Allison [6] compared the results of Fink et al. with more precise theoretical data obtained from calculations of the total transition probabilities of the corresponding lines. He found that all experimental values were slightly larger than the theoretical data. The present work was performed mainly to decide whether this finding was accidental or a real effect. Due to a more sensitive detection system the accuracy of the measurements could be essentially increased. Therefore, part of the measurements of Fink et al. were repeated, and additional measurements were performed in the $(v'=3, v'')$ Lyman band progression of H_2.

A fluorescence set-up with an argon microwave lamp was used to excite HD and H_2 to the HD$(B\,^1\Sigma_u^+;\ v'=3;\ J'=2)$ and $H_2(B\,^1\Sigma_u^+;\ v'=3;\ J'=1)$ levels, respectively, through absorption of the 1066 Å argon resonance line [7]. The $(v'=3, v'')$ fluorescence band progressions mainly consist of the $P(3)-R(1)$ and $P(2)-R(0)$ line pairs. The relative intensities of the lines were measured photoelectrically by means of a 1-m scanning monochromator (Hilger α Watts type E 766) and a channeltron photon counter (Bendix type BX 762). For measurements below 1250 Å a sodium salicylate coated EMI 6255 SA photomultiplier was used. Peak heights as well as peak areas were measured to obtain the intensity ratios of the $P(3)$ to $R(1)$ and $P(2)$ to $R(0)$ lines for all bands which were not seriously overlapped by other emissions. In Tables 1 and 2 the results are compared with the previous experimental data and with the theoretical values obtained from calculated total transition probabilities of the HD and H_2 lines [6, 8]. In most of the HD bands the experimental error limits could be reduced. In the HD as well as in the H_2 bands the experimental results are in very good agreement with the theoretical data. In both cases no systematic difference between theoretical and experimental data is observed. Thus the present results prove that the relative line intensities of $P(J'+1)$

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