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FLUX ALBEDO OF NEUTRONS WITH THERMAL AND 1.45 eV ENERGIES

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Abstract

The increment of reflected thermal and 1.45 eV resonance neutrons as a function of reflector thickness has been measured up to 8cm for various elements and compounds. Analytical expression is given for the description of magnitude and shape of the experimental data. Macroscopic reflection cross sections were determined for some bulk elements and compounds for the first time.

I. Introduction

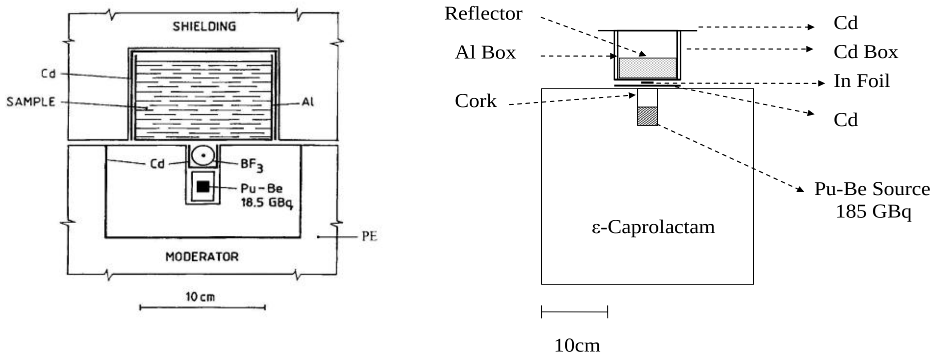
The neutron absorption, moderation, and reflection techniques based on small radioactive sources and 1/v detectors, e.g. Dy, In, Au foils as well as ^{3}He, BF_3 counters are widely used in chemical analysis of bulk samples, especially for the determination of H and moisture contents [1,2]. These techniques have played a leading role among the instrumental analytical methods not only in agriculture, civil engineering, hydrology and industry [3] but recently also in the detection and identification of anti-personnel landmines, illicit drugs and explosives [4]. The principle of flux albedo based on paraffine as the moderator and the reflector introduced by Amaldi and Fermi [5] was generalized for two media of different neutron diffusion properties [1,6]. Considering the practical applications a number of measurements were done for different types of reflector substances and their thicknesses on the value of reflected neutrons. It was found that the rate of reflected neutrons differs significantly for various reflectors and reaches saturation at about 8-10cm thicknesses [7,8]. The flux distributions of incident and reflected neutrons in the interface of moderator and reflector as well as in the free surface of the moderator have been measured with a high spatial resolution using activation foils [5,8,9].

The aim of the present work was to complete the experimental data for the flux albedo of thermal neutrons and to extend this method for the reflection of 1.45 eV resonance neutrons. In addition, the yield of reflected neutrons as a function of the thickness of the reflector was intended to be described by a simple analytical expression.

II. Experimental

Thermal neutron reflection equipment (Fig.1a), Bitatron, developed in Debrecen [10] for the qualification of asphalt concrete via its bitumen content is still in operation. This was used for the determination of H content of various samples (motor oils, crude oils, vegetable oils, metals, alloys, dummy landmines, hydrocarbons, organic and inorganic compounds, etc.) of different thicknesses [1,11]. The excess counts of reflected neutrons produced by a Pu-Be source of 18.5 GBq have been detected by a small BF_3 counter. The diameter and length of its sensitive region are 18mm and 80mm, respectively. The 102mm diameter of the reflectors is comparable both with the sensitive length of the counter and the FWHM value of lateral flux distribution of thermal neutrons measured with Dy foils.

Arrangement used for the measurements of the flux albedo for the 1.45 eV resonance neutrons is shown in Fig.1b. The Pu-Be source of 185 GBq activity was placed 4.0cm under the surface of the ε-caprolactam moderator along its central line and covered with a cork. The Cd covered sample holder of 102mm inner diameter was placed on the free surface of the moderator. The FWHM value measured for the lateral flux distribution of epithermal neutrons on the free surface of the moderator was found to be ~10cm which is comparable with the diameter of the reflector materials. Indium foils of 19mm diameter and 0.1mm thickness covered with cadmium layers on both sides rendered to detect the neutrons above the 0.55 eV Cd cut-off energy via the ^{115}In(n,γ)^{116}In^{m} reaction possible. The value of resonance integral is (2114±23)b as given by Linden et al. [12] for the production of In^{m1+m2} isomeric states. The beta activity of the ^{116m}In of 54.29min half-life [13] was measured with an end-window GM counter using 50min activation, 14min cooling and 50min measuring times. The contribution of other reaction channels to the ^{116m}In beta activity by selection of these time intervals could be neglected. The activity of the ^{116m}In is produced mainly by the flux albedo of 1.45 eV resonance neutrons. This statement is proved by the low yield of the ^{197}Au(n,γ)^{198}Au reaction produced via the 4.90 eV resonance neutrons in the arrangement shown in Fig. 1b.



(a) (b)

Figure: 1a. Set up of neutron reflection measurement (Bitatron).
Figure: 1b. Set up used for the detection of resonance neutrons.

III. Results and Conclusions

The relative number of excess counts, $R(x) = [(I(x) - I_0)/I_0]$ measured with (I(x)) and without (I_0) a reflector was determined for different elements and compounds as a function of sample thickness. The values of R(x) function are proportional to the product of the number of identical atoms per cm^2 and the reflection cross section [14], i.e.

$$R(x) = CN\sigma_\beta x \qquad (1)$$

where N and x are the number of atoms per cm^3 and the thickness of the reflector in cm.

Eq. (1) indicates that R(x) is proportional to the number of reflected neutrons from a $1cm^2$ surface of the reflector. Substituting $C = 10^{-24}$ cm^2 in Eq.(1) the value of σ_β is obtained in barn. In Eq.(1) is assumed that the neutrons penetrate a thin layer of reflector without attenuation. However, in this experiment the total thickness of the reflector can achieve the saturation value in the number of reflected neutrons as shown in Figs. 2.a,b.

The values of excess counts and the activities of the In foils are related to the ratio of the absorbed, n and the incident, n_0 number of neutrons, i.e.

$$n/n_0 = \exp(-N\sigma_\beta x) \qquad (2)$$

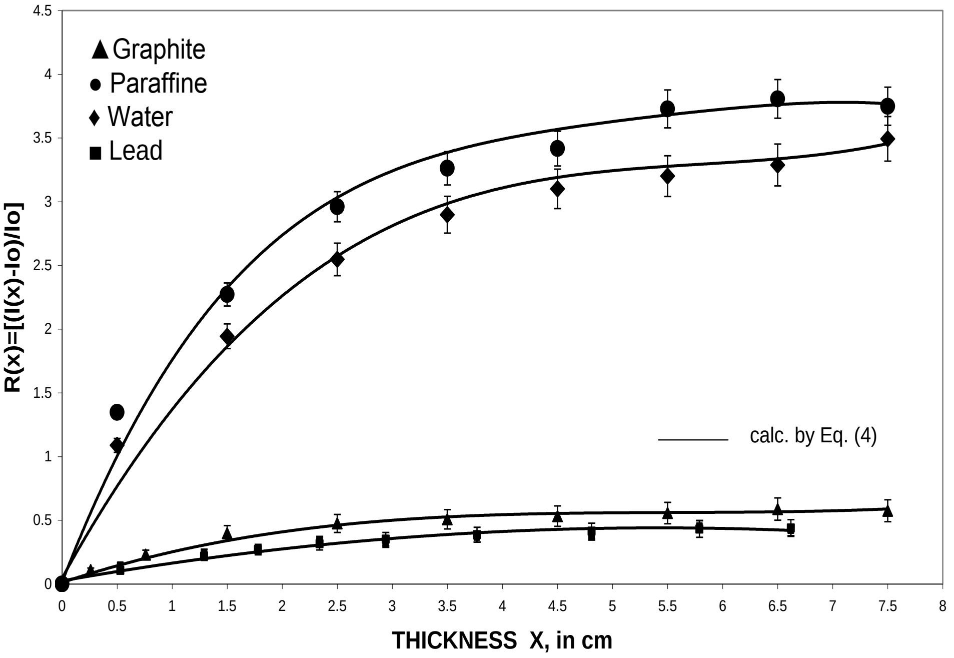
Eq. (2) makes it probable that a neutron traverses the reflector of thickness, x. The probability of a neutron to be reflected is

$$(n - n_0)/n_0 = [1 - \exp(-N\sigma_\beta x)], \qquad (3)$$

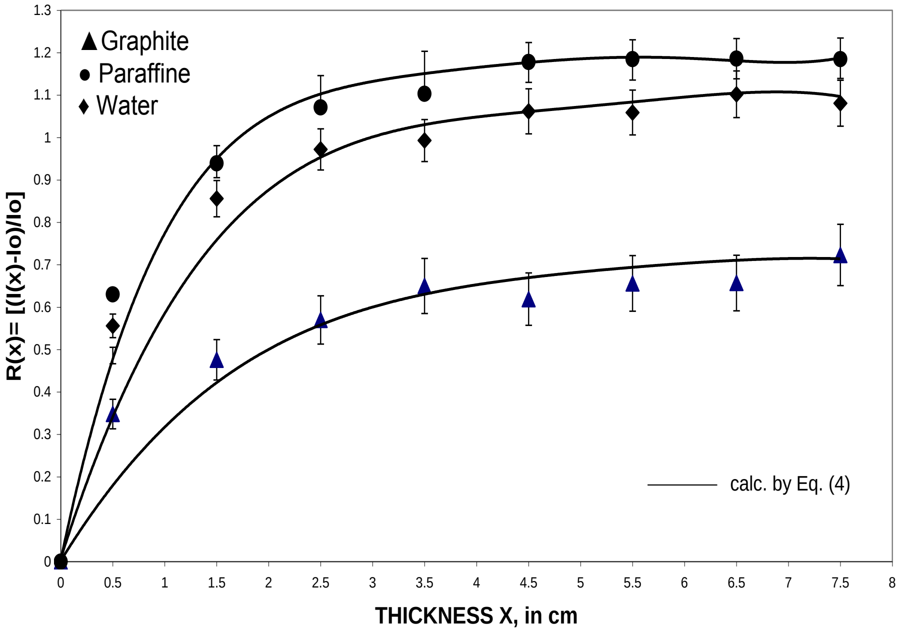
so the increment of the excess count or activity produced by the reflected neutrons as a function of x is given by

$$R(x) = R_0[1 - \exp(-N\sigma_\beta x)] = R_0[1 - \exp(-\Sigma_\beta x)], \qquad (4)$$

where Σ_β is the “so called” macroscopic reflection cross section of neutrons [14] for a given material. The values of Σ_β were deduced from the experimental data obtained for the R(x) function.


▲ Graphite
● Paraffine
♦ Water
■ Lead
calc. by Eq. (4)
R(x)=[(I(x)-Io)/Io]
THICKNESS X, in cm
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8

(a)



(b)

Figure: 2.a,b. Dependence of albedo upon the reflector thickness and material for thermal (B) and resonance (A) neutrons.

As shown in Figs. 2a,b. the shape and magnitude of the measured excess counts for thermal and resonance neutrons can be approximated by Eq. (4) both for elements and compounds. The reproducibility of the data points does not exceed ±10% for the Bitatron measurements. However, the statistical error in the case of resonance neutrons was about ±15%. The reflector materials and their physical data studied in this experiment are summarized in Table 1. Letters B and A in Table 1. denote the data measured with the Bitatron and the activation method, respectively.

Table 1.

Reflector	Σ_β	R_0	R_i	Mass (g)	Density (g/cm^3)
Graphite (B)	0.597	0.589	1.5	1090	1.66
Graphite (A)	0.584	0.724	0.4		
Paraffine (B)	0.628	3.808	1.7	560	0.87
Paraffine (A)	1.054	1.187	0.6		
H_2O (B)	0.527	3.494	1.6	648	1.0
H_2O (A)	0.775	1.103	0.5		
Zeolite (B)	0.685	0.509	0.25	648	0.98
Sugar (B)	0.516	2.22	1	607	0.96
SS. steel (B)	1.07	0.586	0.27	4465	7.79
Lead (B)	0.505	0.455	0.19	6128	10.58

Some new results and proposals deduced from these investigations are as follows:

1. The values of Σ_β, R_0 and the inflection point, R_i of the R(x) function obtained for the samples used in these measurements are given in Table 1. It should be noted that the Σ_β, R_0 and R_i are semi-exact data, their values depend on the elemental composition of the reflector and the geometrical circumstances of the measurement. The Σ_β values given in Table 1. are averaged over the bulk samples used as reflectors. As it shown in Table 1. the Σ_β values are higher obtained by the activation method (A) than those for thermal neutrons (B).
2. The shape and magnitude of the yield of reflected neutrons could be approximated by a simple analytical expression both for thermal and resonance neutrons (see Figs. 2a,b).
3. A comparison of the R_0 values indicate that the interrogated region for the detection of explosives and illicit drugs differs significantly for thermal and resonance neutrons. The activation method is less sensitive and more time consuming as compared to the Bitatron arrangement.
4. Further investigations are needed to clear up the possible correlation between the values of Σ_β and the macroscopic elastic

scattering cross sections, Σ_{EL} averaged over bulk samples both for thermal and resonance neurons.

5. Determination of the spectral yield, $\Phi(E_n)$ of reflected neutrons beyond the 0.55 eV Cd cut-off energy is also recommended. For example, the activity of ^{198}Au is low in spite of the high value (1560±40)b of its resonance integral [15] at 4.90 eV.

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