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COHERENT SCATTERING AMPLITUDE OF TUNGSTEN-186 MEASURED BY SMALL ANGLE SCATTERING

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COHERENT SCATTERING AMPLITUDE OF TUNGSTEN-186 MEASURED BY SMALL ANGLE SCATTERING

The neutron scattering cross section of ^{186}W nuclei with the first neutron resonance at $E_0 = 18.83$ eV and $\Gamma_n = 0.315$ eV[1] should be anomalously small in the thermal energy region due to the interference of potential and resonance scattering. This was confirmed experimentally[2]. It is well known that the amplitude of the neutron scattering, apart from the nuclear part, also includes an additional term which has the form $Zf(\frac{\sin\theta}{\lambda})a_{ne}$, where Z is the electron number in the atom, f - the electron shell formfactor dependent on the scattering angle 2θ and the neutron wavelength λ and a_{ne} - the neutron-electron scattering amplitude. For the mixture of tungsten isotopes containing 90.7% of ^{186}W, the contribution of $n-e$ interaction should account for about 30%; therefore this mixture is a very convenient material for precise measurements of a_{ne}. Preliminary results of the corresponding studies on this mixture performed in the JINR were reported at the Summer School on Neutron Physics at Alushta in 1969[3]. Since a very large value of a_{ne} was unexpectedly obtained and since the ac-

curacy of the measurement of a_{ne} is immediately connected with the accuracy of the coherent scattering amplitude of the isotopic mixture in use, it was extremely useful to measure the coherent amplitude by some other method. The present note gives the results of these measurements. The work was carried out at the Garching Reaktor Station (Munich, West Germany).

1. Measurement Technique and Results

The theory of small angle neutron scattering on refractive index fluctuations was developed by Weiss [4]; and the technique of measuring coherent amplitudes for powders was most fully developed at the Reaktor Station der Technischen Hochschule München [5,6]. The technique consists in the following. Using two vertical cadmium slits separated from each other by 3.3 m, a neutron flux with maximal spread in the horizontal plane 2.3′ and average wavelength $\lambda = 15$ Å was extracted from the broad flux of the curved glass neutron guide-tube. Immediately behind the entrance slit the "Christiansen-Filter" is installed and approximately 2m further there was a neutron detector whose width was sufficient to record the neutrons of the beam scattered by the filter at angles up to 1^{o} in the horizontal plane. The filter consists of a vertical cavity between glass plates filled with the powder of the substance under study. The cavity is 2mm thick in the direction of the beam and in its width it completely overlaps the beam. By means of a special vacuum installation, the space between powder grains is filled in turn with different liquids with known neutron refraction indices.

The measurement consists in observing the intensity of the small angle neutron scattering by the filter at several values of the liquid refractive index. In principle, there should be no small angle

scattering at all when the refractive index of a liquid n_L is exactly the same as that of a powder n_P and it should appear when this condition is not fulfilled. In so doing, in a certain range of n_L the scattering intensity is[6]:

$$I \sim (n_P - n_L)^2 \sim [(Na)_P - (Na)_L]^2 , \qquad (1)$$

where a is the coherent scattering amplitude and N is the volume density of atoms of a given substance.

Practically, as the difference $n_P - n_L$ grows, the neutron beam incident on the detector becomes broader as compared to the initial beam at the expense of the increase of the small angle scattering. Therefore, in order to record only the scattered neutrons, in front of the detector there was installed a cadmium catcher of such a width that it absorbed the neutrons of the primary beam, while the neutrons scattered at an angle of more than 2′ got into the detector. The ratio of the detector counting rates P with the catcher and without it was taken as a measure of the relative small angle scattering intensity. In a certain range of $n_L - n_P$ close to zero this ratio is described by formula (1).

The measurements were performed with two filters of one and the same mixture of tungsten isotopes: in filter I the powder grains were about 10–15 micron in size and in filter II about 80–120 micron. Mixtures of heavy (D_2O) and light (H_2O) water were used as liquids. In this case

$$(Na)_L = c(Na)_{D_2O} + (1-c)(Na)_{H_2O} , \qquad (2)$$

where c is the volume concentration of D_2O in the mixture. For the calculation of $(Na)_L$ we used the values $(Na)_{D_2O}$ = $=(63.399 \pm 0.005) \times 10^9 cm^{-2}$ and $(Na)_{H_2O} = (-5.61 \pm 0.03) \times 10^9 cm^{-2}$ obtained from the measurements on a gravitational refractometer in Garching[7] and corresponding to a temperature 18°C; the value of $(Na)_{D_2O}$ refers to heavy water with the enrichment of 99.75% actually used.

Fig.1 shows some values of the above-mentioned ratio of the detector counting rates P for two filters at a number of values of Na for a liquid. The solid curves connect experimental points; the points of the steeper one correspond to filter I, those of the flatter one belong to filter II. It is obvious that these measurements are not sufficient - a part of the left branches of the curves is too small. This is the main difficulty in measuring negative coherent amplitudes by the method considered, because there exists no appropriate liquid with a negative value of Na exceeding that of H_2O in its absolute value. Therefore to locate the minimum of the curve we had to restrict ourselves to measurements in a narrow range of $(Na)_L$. The results of two runs of such measurements with either filter are shown in Fig.2. The minima of both curves were located by the least squares method in which the parameters A, c_0 and B_0 in the formula

$$y = A(c - c_0)^2 + B \qquad (3)$$

were fitted to the best description of experimental values of P. Formula (3) is a natural generalization of expression (1). In this formula, c_0 is the concentration of D_2O for which the scattering is minimal and A is a constant dependent on the experimental conditions. The constant term B corresponds to finite values

of P in the vicinity of the minimum. This results from the ignored detector background, not absolutely complete overlapping of the straight beam by the catcher, scattering of neutrons by the filter and neutron guide-tube walls at large angles not in the horizontal plane and, probably, not quite ideal optical homogeneity of the filter even for $(Na)_P = (Na)_L$. The curves in Fig.2 (in Fig.1 they are dashed lines) represent the result of the fit.

The values of $(Na)_{LO}$ corresponding to the minimum were determined by formula (2) from the values of the parameter c_0 = (0.03862 $\pm$ 0.00016 and 0.03999 $\pm$ 0.00062 for filters I and II, respectively) taking into account the errors in c_0 and also in $(Na)_{D_2O}$ and $(Na)_{H_2O}$. The weighted average over two filters $(Na)_{LO}$ = $=(-2.939 \pm 0.031) \times 10^{9} cm^{-2}$. Hence, taking the density of tungsten atoms $N = 6.31 \times 10^{22} cm^{-3}$ obtained from the tungsten constant cubic lattice $\delta = 3.1647$ Å and using the condition $(Na)_P = (Na)_{LO}$, we have for the coherent scattering amplitude in $(Na)_P$

$$a = (-0,466 \pm 0,006)\, F \quad (\lambda = 15 \text{ Å}, \theta = 0^0, Zf = 74) \qquad (4)$$

2. Discussion

In the studies of the n-e scattering amplitude a_{n-e} mentioned above[3], the coherent amplitude of the same mixture of tungsten isotopes was measured by comparison of the intensity of the diffraction peak (110) obtained with a powdered mixture and that obtained with powdered natural tungsten. The coherent amplitude of the latter was taken as $(4.77 \pm 0.05)\, F$ [5]. The result was a = $=(-0.499 \pm 0.011)\, F$ ($\lambda = 1.145$ Å, $Zf = 61.3$) . (5)

The measurement conditions are given in brackets. If one takes for a the following expression

$$a = R - \frac{a\Gamma_n}{2k_0 E_0}(1 + E/E_0) + Zf \cdot a_{n-e} \qquad (6)$$

(see formula (10) in[2]) where R is a constant, $a = 0.907$ the content of the ^{186}W isotopes in the mixture, E_0 and Γ_n the parameters of the ^{186}W resonance and if one assumes that $a_{n-e} = -0.0014$ F, then the value of the amplitude (4) changed to the conditions of (5) is

$$a = (-0,475 \pm 0,006)F \quad (\lambda = 1,145 \text{ Å}, Zf = 61.3). \qquad (7)$$

Also, we obtain from (4) using (6) one more value

$$a = (-0.492 \pm 0.006)F \quad (\lambda = 1.145 \text{ Å}, Zf = 74). \qquad (8)$$

Comparing the present result (4) and its modifications (7) and (8) with the result (5) from[3], the following conclusions can be drawn:

1. The discrepancy between the values (5) and (7) obtained by quite different experimental techniques is only 5% and is less than twice the sum of their errors. Therefore the result of the present work can be considered as a confirmation of the correctness of the absolute value of the amplitude measured in[3] and the reason for the very large value of a_{ne} which was obtained in [3] should apparently be sought not in the measurement of the absolute value of the coherent amplitude in [3].

2. In principle, two values of the amplitude at one and the same neutron energy and different values of the formfactor f are

sufficient to calculate a_{n-e}. However, the very close values of Zf in (5) and (8) together with the insufficient accuracy of the measurements do not permit any reliable conclusions about the value of a_{n-e} to be drawn from these two measurements.

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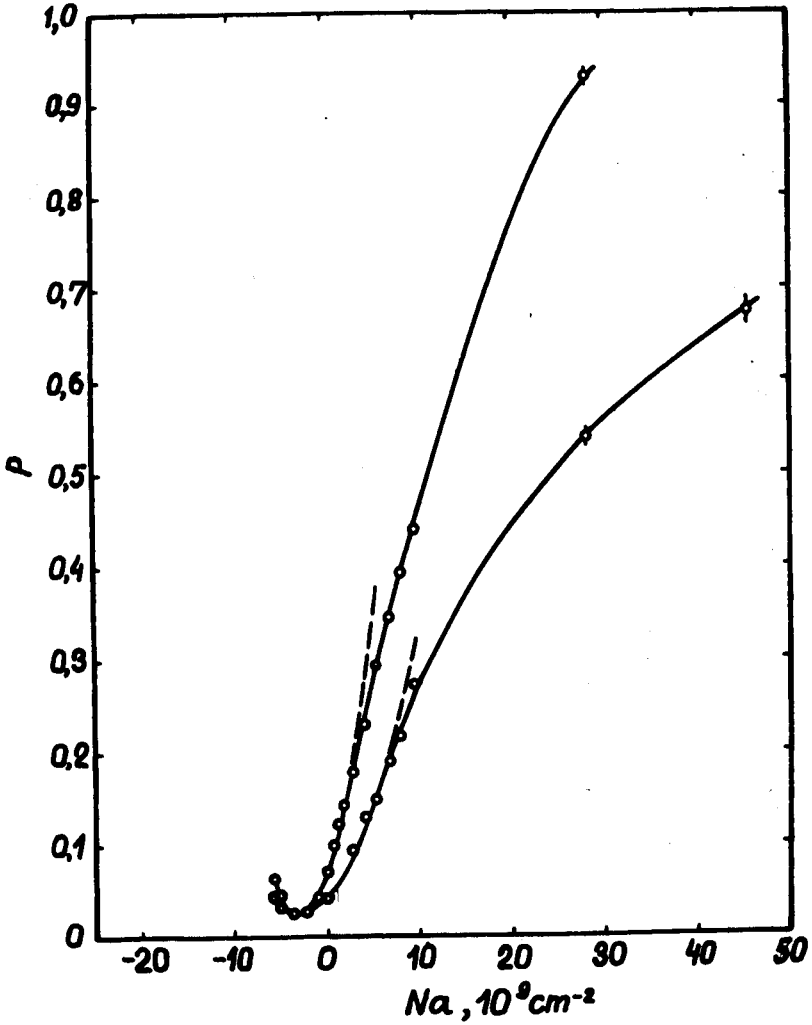

Fig.1. P vs Na for two filters

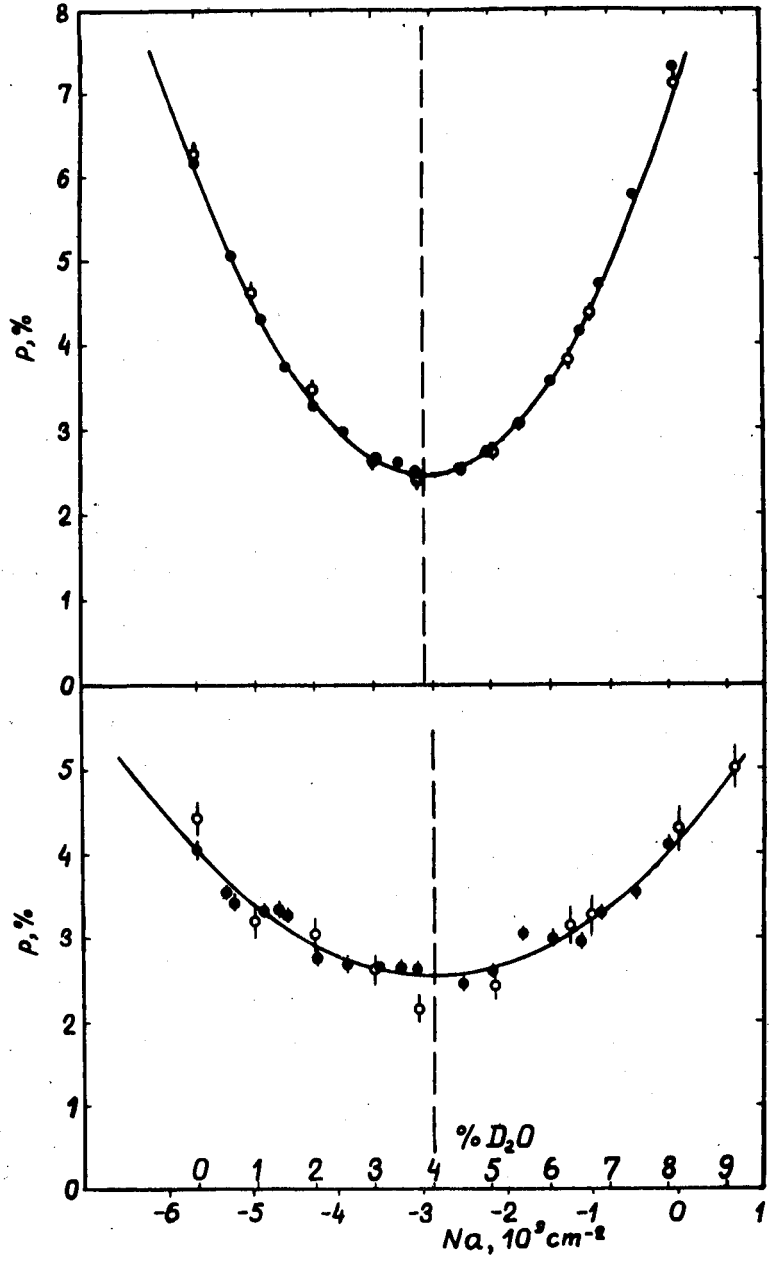

Fig.2 P vs Na in a narrow range of Na for two filters.