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ON SOME PECULIARITIES OF SCATTERING OF SLOW NEUTRONS BY TUNGSTEN

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ON SOME PECULIARITIES OF SCATTERING OF SLOW NEUTRONS BY TUNGSTEN

Александров Ю.А., Игнатович В.К. Е3-6294

О некоторых особенностях рассеяния медленных нейтронов на вольфраме

Анализируются эксперименты по дифракции нейтронов на монокристалле вольфрама-186 и рассеянию нейтронов на малые углы на порошке того же изотопа.

Существование небольшого дополнительного когерентного рассеяния нейтронов на вольфраме могло бы объяснить эти эксперименты.

Сообщение Объединенного института ядерных исследований
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Alexandrov Yu.A., Ignatovich V.K. E3-6294

On Some Peculiarities of Scattering of Slow Neutron by Tungsten

Experiments on the diffraction of neutrons by a single ^{186}W crystal and the small-angle scattering of neutrons by powder of ^{186}W are analysed.

The occurence of a small additional coherent scattering of neutrons by tungsten could explain these experiments.

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Dubna, 1972

1. In ref. /1/ a single crystal made of a mixture enriched with the ^{186}W x/ was used in studying $n-e$ interaction by the neutron diffraction method.

Integral intensity of the $(hk\ell)$ Bragg reflection per a single crystal plane:

$$N_{hk\ell} = C\{(a_{nuc} + z f_{hk\ell}\, a_{ne})^2 + \gamma^2 ctg^2\theta_{hk\ell}(1-f_{hk\ell})^2\}\frac{A_{hk\ell}\exp(-2w_{hk\ell})}{\sin 2\theta_{hk\ell}} \quad (1)$$

where C is a constant, $\theta_{hk\ell}$ the Bragg angle, a_{nuc} the coherent nuclear scattering amplitude, $f_{hk\ell}$ the atomic structure factor, a_{ne} the neutron-electron scattering amplitude, $A_{hk\ell}$ the absorption factor, $\exp(-2w_{hk\ell})$ the Debye-Weller factor, $\gamma^2 ctg^2\theta_{hk\ell}$ the term taking into account the Schwinger scattering /2/.

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x/ For a mixture containing approximately 91% of ^{186}W, coherent scattering amplitude $b_{coh} \simeq -0.05 \times 10^{-12}$ cm, while for a natural tungsten isotope mixture $b_{coh} = +0.477 \times 10^{-12}$ cm.

The quantity

$$\left[\frac{N_{hkl}\,\sin 2\theta_{hkl}\,\exp(2w_{hkl})}{A_{hkl}\,C} - \gamma^2 \mathrm{ctg}^2\theta_{hkl}\,(1-f_{hkl})^2\right]^{1/2} = a_{nuc} + zf_{hkl}a_{ne} = b \quad (2)$$

must linearly depend on zf .

The measurements performed with a single ^{186}W crystal for eight reflections (100), (200), (220), (310), (400), (330), (420), and (510) with neutrons, the wave length of which $\lambda = 1.45$ Å, show that such a linear dependence does not hold /1/ (Fig.1). Let us assume that the violation of the linearity is due to the additional scattering, which makes a contribution to the Bragg peaks. We shall write the expression (1) as follows:

$$N_{hkl} = C\,\{(a_{nuc}+zf_{hkl}a_{ne})^2 + \gamma^2\mathrm{ctg}^2\theta_{hkl}(1-f_{hkl})^2 + p^2\}\,\frac{A_{hkl}\exp(-2w_{hkl})}{\sin 2\,\theta_{hkl}}, \quad (3)$$

where p is the additional scattering amplitude. Taking for a_{ne} the value $a_{ne} = -1.46 \cdot 10^{-16}$ cm, corresponding to the zero value of the mean square electric radius of the neutron /3/, it is possible to determine the quantity p^2 which is presented in Fig. 2 x/ as a function of $\frac{\sin\theta}{\lambda}$. For the employed mixture the ratio $p^2/b^2 \sim 7-10\%$, therefore the coherent additional scattering effect is not practically revealed by the natural isotope mixture measurements.

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x/ Measurements performed with a mixture of another isotopic composition ($b_{coh} > 0$)/1/ confirm this dependence.

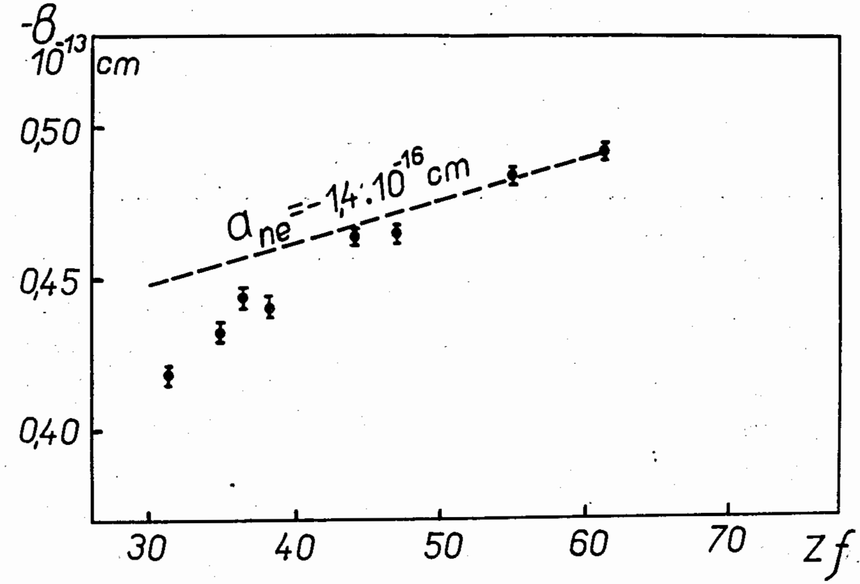

Fig. 1.

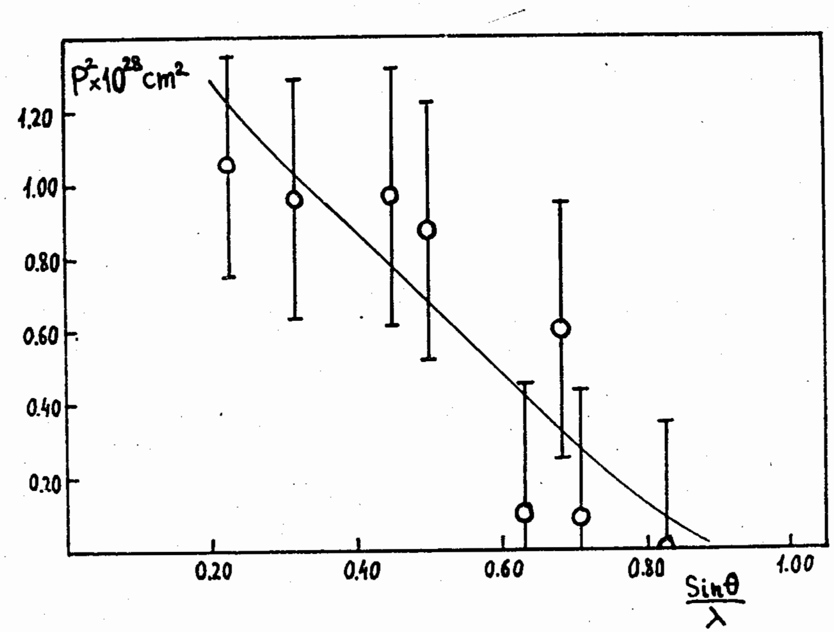

Fig. 2.

2. Another experiment which confirms the existence of the amplitude p is the small-angle scattering which makes it possible not only to determine the quantity p but also to find the dimensions of the correlation domains which account for the additional scattering. In measuring the ^{186}W amplitude by the method of the Crisiansen-filters /4/ one has never succeeded in obtaining the total disappearance of the small-angle scattering. This means that the tungsten powder investigated was not homogeneous from the point of view of the neutron scattering x/. The inhomogeneity can be estimated from the aperture angle of the residual small-angle scattering. The size of the domain a which scatters the waves with the wave vector $\vec{k}$ within the angle θ is $a \sim \frac{1}{k\theta}$. The experiment /4/ gives for the value $\theta \sim 10^{-3}$ rad. and at $\lambda = 15$ Å the size of the domain is $a \sim \frac{15.10^{-8}.10^{3}}{2\pi} \sim 0.25 \mu m$. The scattering intensity for a separate grain of the powder is defined by the magnitude of the differential cross section:

$$\frac{d\sigma}{d\Omega} = \overline{\left(\sum_{\nu=1}^{N} p_\nu \exp\left(i\vec{q}\vec{r}_\nu\right) \right)^2} \sim N_0 \overline{\left(\int dv \exp\left(i\vec{q}\vec{r}\right) p(\vec{r})\right)^2} = \tag{4}$$

$$= N_0^2 p^2 v \int_v Q(\vec{\rho}) \exp\left(i\vec{q}\vec{\rho}\right) d^3\rho \ ,$$

where v is the volume of the grain, N_0 -the number of the nuclei per unit volume of the grain, $\vec{q} = \vec{k} - \vec{k}_0$ -scattering vector, $p^2 Q(\vec{\rho}) = \overline{p(\vec{r})\, p(\vec{r}+\vec{\rho})}$ - the amplitude correlation function. The line means the averaging over the grain volume. If we assume that $Q(\rho) = \exp(-\rho^2/4a^2)$ then

$$\frac{d\sigma}{d\Omega} = N_0 p^2 v (2a)^3 \pi^{3/2} \exp\left(-q^2/a^2\right) . \tag{5}$$

In ref. /4/ a beam striking the pattern comes from a gap located at a distance L=1800 mm from the detector, the width of the beam being d = 0.75 mm. The pattern of thickness ℓ (along the beam direction) was placed near the gap. The relative number of the neutrons obtained from the direct beam as a result of a small-angle scattering is

$$\delta = 2\sqrt{\pi}\, n_1 v \ell a \lambda^2 N_0^2 p^2 \left[1 - \Phi\left(ka\frac{d}{L}\right) \right] \tag{6}$$

where n_1 is the number of grains per unit volume of the pattern, $\Phi(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-y^2} dy$ - the error function.

Knowing δ, from (6) it is possible to get p^2. Using the data of ref. /4/ we obtained from (6) $p^2 \simeq 10^{-28}$ cm^2 which corresponds in the order of magnitude with the value of p^2 obtained from diffraction measurements. We can also find the angular distribution:

$$\frac{I(\theta)}{I_0} = 4\pi n_1 v (N_0 p)^2 a^2 \ell \lambda \exp\left(-k^2 a^2 \theta^2\right) . \tag{7}$$

This expression makes it possible to determine the values of a and p more accurately. Unfortunately special experiments aimed at the measurement of the angular distributions of the small-angle scattering have not been performed in ref. /4/.

3. It may be assumed that the observed additional scattering is due to, for example, concentration inhomogeneities. Putting the amplitude of the mixture to be

$$b_m = C' b_{nat} + (1 - C') b_{186}\ , \quad \text{where} \quad C' \sim 0.1\ ,$$

b_{nat} and b_{186} are the scattering amplitudes for the na-

x/ It is interesting to note that the small-angle scattering disappeared completely or almost completely in the scattering by diamagnetics of Sb, Si, Te and appeared for paramagnetics of Al, Nb, Ta /5/.

tural tungsten and the ^{186}W isotope, we find the amplitude fluctuations

$$\Delta b = p = \Delta C \; (b_{nat} - b_{186}) \simeq \Delta C \; 0.5.10^{-12},$$

where ΔC is the concentration fluctuations. Since $p^2 \sim$ $\sim 10^{-28}$ cm^2 we find that

$$(\Delta C)^2 \sim 4.10^{-4}.$$

The thermodynamic fluctuations cannot account for such a large value since for them $(\Delta C)^2 \sim C'/N$, where N is the number of particles in the fluctuation region. Since the dimension of the region is $\sim 0.25.10^{-4}$ cm then $N \sim 4.10^8$. It is also unlikely that the concentration fluctuations are due to the technology of preparation of the pattern. Moreover, the hypothesis about concentration inhomogeneity cannot explain the angular dependence of p^2. It may very likely occur that p has the magnetic nature, however to draw definite conclusions about the nature of p, further experiments should be set up.

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