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Physics

DETERMINATION OF REFRACTIVE INDEX OF HETEROGENEOUS SUBSTANCES FOR *X*-RAY RADIATION

V.Gh. MIRZOYAN[1], S. N. NOREYAN[1], K. M. GEVORGYAN[2*]

[1] *Institute of Applied Problems of Physics NAS of Armenia*
[2] *Chair of Theoretical Physics, YSU*

In this paper we suggest a method for determining the refractive index of *X*-ray radiation for a one-layer medium, having a fibrous and granular structure. It is shown that the refractive index can be calculated as the ratio of intensities, measured at the location of the substance on the path of the beam between the two-crystal *X*-ray spectrometer and behind it.

Keywords**:** *X*-ray, refractive index, *X*-ray spectrometer.

Introduction. A new rapid method for determining the refractive index of *X*-rays for non-absorbing fibrous materials first developed and implemented in the works [1, 2].

For single-layer homogeneous densely packed filaments, it was shown that the unit of refractive index decrement δ can be calculated as follows:

$$\delta = 1 - \frac{I / I_0}{\sin(\arcsin(I / I_0) + \Delta\varphi / 4))},$$

where $\Delta\varphi$ is the half-width of the Darwin table, I_0 is the intensity of the diffracted beam in the case, when the heterogeneous material is located after the blocks of *X*-ray spectrometer, I is the intensity of the diffracted beam, when the non-homogenous material is in some way oriented and placed in double-crystal *X*-ray spectrometer, where axis of threads are oriented perpendicularly to the diffraction vector.

In this paper we theoretically calculate the refractive index of *X*-rays for a medium, having a granular (spherical) structure. Calculations are made for two-crystal scheme (n,-n) on the anomalous transmission, using crystals of Ge. The subject material reacts to the *X*-rays as a diverging lens. Refracted rays, the angle of which exceeds the angle of half-width of Darwin table for Ge and for a given wavelength of *X*-rays, do not provide conditions of anomalous transmission and are fully absorbed. Thus, placing the subject material between the two crystals, we observe the decrease in intensity. The decrease in intensity occurs due to the absorption of rays, refracted in non-homogeneous materials in the second Ge crystal, that is operating in the anomalous mode. Then, to determine the fraction of

* E-mail: konstantin@iapp.sci.am

this absorption, the analyzed material is placed directly in front of the detector (outside the two-crystal system). Then, the same substance is placed into the two-crystal scheme, and intensity is re-determined (Fig. 1). The difference of intensities of the two measurements is the change in intensity due to refraction.

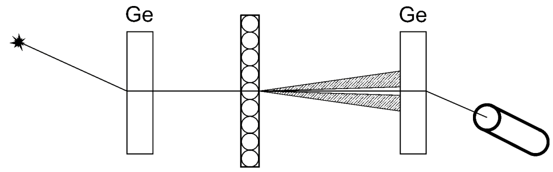

Fig. 1. Progress of beam through blocks *X*-ray spectrometer and heterogeneous material, located between the blocks.

In fact, the dependence of the refractive index decrement for non-homogeneous non-absorbing (weakly absorbing) materials, with granular structure, can be written as $\delta = f(I / I_0)$.

Calculation of the Refractive Index for a Homogeneous Spherical Substance. Assume that some part of the incident beam on the sphere has (R,α,β) radial coordinates (Fig. 2). Then, $r = R\sin\beta$, $r_x = R\sin\beta$, $r_y = R\sin\beta\sin\alpha$, where r is the projection of the sphere radius on *xy* plane, and r_x and r_y are respectively projections of r on the *x* and *y*.

Denote by *h* the distance from point *A* to the *xy* plane in the original direction of the beam. Then $\frac{\Delta r}{h} = \text{tg}\Delta\beta$, where Δr is the increase after refraction at *A*:

$$\Delta r = h\text{tg}\Delta\beta = R\cos\beta\,\text{tg}\Delta\beta,$$

$$r_x = R\cos\beta\,\text{tg}\Delta\beta\cos\alpha,$$

$$r_y = R\cos\beta\,\text{tg}\Delta\beta\sin\alpha.$$

Denote by $\Delta\beta$ the angle of refraction of the beam from its original direction. Then, the corresponding projections $\Delta\beta_x$ and $\Delta\beta_y$ on the *xz* plane and *yz* will be $\text{tg}\Delta\beta_x = \text{tg}\Delta\beta\cos\alpha$, $\text{tg}\Delta\beta_y = \text{tg}\Delta\beta\sin\alpha$. Given that in the *xz* plane the angle of refraction doesn't contribute the violation of the Bragg condition of the crystal, we consider the angle of refraction in the plane *xz*.

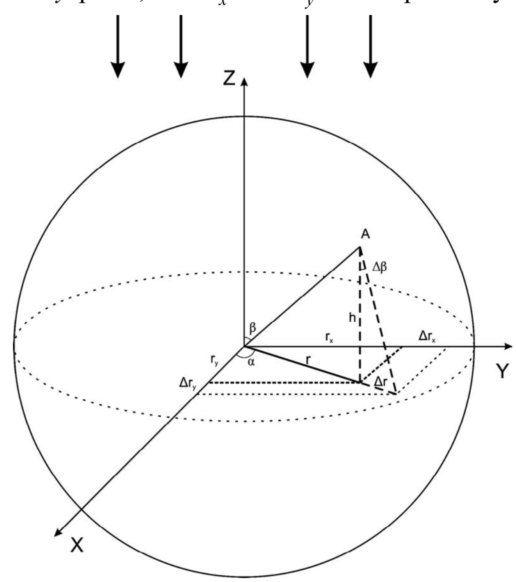

Fig. 2. *X*-ray beams falling on granular substance.

To find the geometric location on the surface of the sphere of those points that have already breached the Bragg condition, for which the expression $\Delta\beta_y = \Delta\theta$ is true, where $\Delta\theta$ is the half-width of swing curve of the crystal, we write

$$\text{tg}\Delta\beta = \frac{\text{tg}\Delta\theta}{\sin\alpha}. \quad (1)$$

From the rule of refraction, it is known that $\frac{\sin\beta}{\sin(\beta+\Delta\beta)} = n$. Hence we get

$$\mathrm{tg}^2\beta = \frac{n^2(1-\cos^2\Delta\beta)}{(1-n\cos\Delta\beta)^2}. \qquad (2)$$

From (1) we obtain $\cos^2\Delta\beta = \frac{\sin^2\alpha}{k^2+\sin^2\alpha}$, where $k = \mathrm{tg}\Delta\theta$. As $\mathrm{tg}\beta = \frac{r}{h}$, then

$$\mathrm{tg}^2\beta = \frac{r^2}{h^2} = \frac{r^2}{R^2-r^2}. \qquad (3)$$

Substituting (3) in (2), we have

$$r^2 = \frac{R^2n^2(1-\cos^2\Delta\beta)}{(1-n\cos\Delta\beta)^2 + n^2(1-\cos^2\Delta\beta)}. \qquad (4)$$

Substituting in (4) expression $\cos^2\Delta\beta = \frac{\sin^2\alpha}{k^2+\sin^2\alpha}$, we get

$$r = \frac{Rnk}{\sqrt{(\sqrt{k^2+\sin^2\alpha} - n\sin\alpha)^2 + n^2k^2}}. \qquad (5)$$

This expression represents the geometry of the projections on the equatorial plane of those points that have already breached the Bragg condition for the crystal. From Fig. 3 we can see that those beams that are refracted in the shaded equatorial plane take part in diffraction, thus, reducing the intensity of the diffracted *X*-rays due to beams, passing through the non-shaded part:

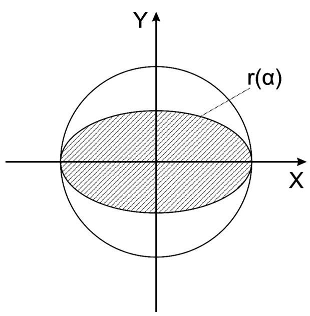

Fig. 3. Geometric allocation of points projection, described by the $r(\alpha)$ function.

$$\frac{I}{I_0} = \frac{S}{S_0} = \frac{4\int_{\alpha\to 0}^{\pi/2} r^2(\alpha)d\alpha}{\pi R^2} = F(n,k).$$

Conclusion. From obtained results it follows that with the intensities I and I_0 for a given crystal we can determine the refractive index of the substance for *X*-ray emission. To increase the accuracy of measurement of the refractive index the multichip spectrometer in anomalous mode or multiblock *X*-ray interferometer can be used. It follows from the above that one can investigate non-absorbing and homogeneous substances, such as biological objects in dynamic mode at low intensities of radiation, i.e. without radiation damage of the investigated object.

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Վ.Ղ. Միրզոյան, Ս.Ն. Նորեյան, Կ.Մ. Գևորգյան

Անհամասեռ նյութերի բեկման ցուցչի որոշումը
ռենտգենյան ճառագայթման համար

Աշխատանքում առաջարկվում է թելանման և հատիկավոր միաշերտ միջավայրի բեկման ցուցչի որոշման եղանակ: Ցույց է տրված, որ բեկման ցուցիչը կարելի է հաշվել որպես երկու ինտենսիվությունների հարաբերու-թյուն, որոնցից առաջինը ստացվում է, երբ նյութը տեղադրված է փնջի ճանապարհին ռենտգենյան սպեկտրաչափի երկու բյուրեղների միջև, իսկ մյուսը՝ դրանցից հետո:

В. К. Мирзоян, С. Н. Нореян, К. М. Геворкян.

Определение показателя преломления неоднородных веществ для рентгеновского излучения

В данной работе предложен метод определения показателя преломления однослойной среды, имеющей волокнистую и зернистую структуру, с помощью рентгеновских лучей. Выявлено, что показатель преломления можно вычислить как отношение интенсивностей, измеряемых при расположении вещества на пути пучка между двумя кристаллами ренгеноспектрометра и за ними.