Существенной характеристикой кинетики роста коллоидных центров является распределение их по размерам. Как показали исследования [1-4] для любых поглощенных доз и температур облучения, кристалл имеет характерную для него форму кривой распределения коллоидных центров по размерам. Для температур облучения, близких к комнатной, асимметричность кривых распределений с дозой меняется очень четко в виде изменения параметра формы.

Распределение частиц по размерам, определенное экспериментальным путем, описывается логнормальной функцией:

$$c_n(d, t) = F(t) \exp \left\{ - \ln^2 [d/d_{\max}(t)] / 2\xi^2(t) \right\}, \quad (10)$$

где t - время воздействия на кристалл, в итоге которого получаем агрегат диаметром d .

Распределения такого вида характеризуются следующими параметрами: диаметром коллоидного центра в максимуме распределения $d_{\max}(t)$, предэкспоненциальным множителем $F(t)$ и параметром формы распределения $\xi(t)$. При этом $\xi^2(t) < 1$, и от него в основном зависит концентрация c_n . Существенно, что параметром функции (10) является не средний радиус коллоидных центров, который, по экспериментальным данным, малочувствителен к времени (дозе), а параметр формы $\xi(t)$. Это подтверждает и сделанный нами вывод об одном порядке радиуса коллоида, размер которого определяется формулой (9), полученной нами при весьма общих предположениях.

Несмотря на сложный характер промежуточных стадий процесса накопления радиационных дефектов и процесса радиолитизации в твердых диэлектриках, существуют общие закономерности, о которых мы говорили выше. Это открывает перспективу поиска новых радиационно-стойких и радиационно-чувствительных материалов по их термодинамическим параметрам.

1. Лущик Ч.Б., Лущик А.Ч. Распад электронных возбуждений со образованием дефектов в твердых телах. - М.: Наука, 1989. - 264 с.
2. Карипбаев Ж.Т. Спектрально-кинетические характеристики легированных кислородом кристаллов вольфрамата цинка и фторида лития. - Диссер. кандидата физ.-мат. наук, Астана, 2015. - 116 с.
3. Киселева М.С. Кинетика пострadiационных процессов в оптических материалах с подвижными дефектами. - Диссер. кандидата физ.-мат. наук, Екатеринбург, 2017. - 149 с.
4. Арапов Б.А., Арапов Т.Б., Орозбаева А.А. Моделирование кинетики распада радиационно-наведенных дефектов в ионных кристаллах // Международный журнал прикладных и фундаментальных исследований, № 2, 2020. - С. 115-121.
5. Юров В.М. Термодинамика люминесцирующих систем // Вестник КарГУ, сер. Физика, 2005, № 3(39). - С.13-15.

Pylaev A.P.

Light polarization and the Brewster law

*Snezhinsk Physic-Technical Institute
(Russia, Snezhinsk)*

*doi 10.18411/gq-31-03-2021-11
idsp sciencerussia-31-03-2021-11*

Abstract

It was obtained an analytical dependance of the relative intensity of the light beam reflected from the boundary of two transparent bodies expressing the law been established experimentally by Brewster. It was found on basis of comparison of the values of parallel and perpendicular components of the electrical vectors of the incident beam wave trains to the direction of the reflected beam.

Keywords: light beam, reflection and refraction of light, area of polarization.

Introduction

So far the experimental law established by Brewster and bearing his name [1] does not have any theoretical explanation. It asserts that the intensity and polarisation of the natural light beam reflected from the boundary of two transparent bodies increase with increasing of the angle of incidence, achieve the maximal values and then decrease. These parameters achieve their maximum values at the angle of incidence φ_B (the angle of Brewster) that is concerned with the index of refraction of media n by formula

$$\sin \varphi_B / \sin \psi = n, \quad (1)$$

where ψ is the angle of refraction.

To give the explanation and to find the analytical expression of this law it is possible on the basis of the principle that explain the polarisation of a nature light beam at transiting it through a uniaxial crystal.

The natural light beam is such one that contains wave trains of all possible polarizations under which the directions of their electric vectors are implied. If such beam propagates to a definite direction then the planes of oscillations of all waves are parallel to each other. If to project the electric vectors of all waves on the plane that perpendicular to the propagating beam direction then these projections will fill the entire conditional circle as it is shown in fig. 1a.

Fig.1. Polarizations of the natural beam (a) and that part of this beam which passed by the crystal (b).

It was established experimentally that at the normal incidence of such beam upon the surface of a uniaxial crystal (for example, tourmaline) which parallel to its optical axis then the intensity of the passed beam decreases twice. This is explained by that the crystal lets pass those waves that have the electrical vectors component parallel to the optical axis which exceeding the perpendicular one. This means that the electric vectors of the passed waves were directed on the angles less then $\pm\pi/4$ to the optical axis and occupied only a half of the circle as it is shown in fig. 1b.

The polarization of the nature light beam or a part of it can be measured by the value of a half of the angular area corresponding to that part of the circle where the electric vectors of this beam were placed. In such terminology the polarization of the nature light beam is equal to $\Delta=\pi$, and the polarization of that part of the beam which was passed by the crystal is equal to $\Delta=\pi/2$. This means that the intensities of beams are proportional to the angular areas Δ of their initial polarizations. On this basis the Brewster law is considered in the present work.

Light polarization at reflection and refraction.

Let a nature light beam obliquely falls upon the boundary of two transparent media, at that the reflected and refracted beams arise. Let's consider one of the wave trains of this beam intersecting the interface. In fig. 2 by a dashed line it is shown the plane of oscillations of the

electric vector of its electromagnetic field. It is perpendicular to the direction of the refracted beam γ_p . The electric vector of this train $\mathbf{E}$ lies at angle α to the plane of incidence. By the angle α it will be characterized the wave trains polarization.

Fig.2. Plane of oscillations of a wave train.

NN is the perpendicular to the interface, AA is the interface of two media, FF is the line of intersection of the plane of incidence with the oscillations one, ψ is the refraction angle.

The component of the electrical vector that lies in the plane of incidence $\mathbf{E}_i$ and that which perpendicular to it $\mathbf{E}_n$ are correspondingly expressed by formulas

$$\mathbf{E}_i = \mathbf{E} \cos \alpha, \quad \mathbf{E}_n = \mathbf{E} \sin \alpha. \quad (2)$$

To determine whether this wave train will be moving in the direction of the refracted or reflected beam it needs to find the components $\mathbf{E}_{\parallel}$ and $\mathbf{E}_{\perp}$ of the electric vector correspondingly parallel and perpendicular to the direction of the reflected beam. From fig.3 which shows the incident γ , reflected γ_r and refracted γ_p beams it follows

$$\mathbf{E}_{\parallel} = \mathbf{E}_i \sin(\varphi + \psi).$$

Then with using (2):

$$\mathbf{E}_{\parallel} = \mathbf{E} \cos \alpha \sin(\varphi + \psi), \quad (3)$$

$$\mathbf{E}_{\perp} = \mathbf{E}_n = \mathbf{E} \sin \alpha. \quad (4)$$

Fig.3. Scheme of reflection and refraction of light at the boundary of two media.

φ - angle of incidence which is equal to the reflected angle, ψ - angle of refraction.

Let's suppose that this wave train will remain in the refraction beam if by value

$$\mathbf{E}_{\perp} > \mathbf{E}_{\parallel}, \quad (5)$$

or get to the reflection beam in the case of the opposite inequality. There are the next considerations for this presumption:

1) At the normal incidence of the nature light beam upon the interface ($\varphi=0$) all waves are physically “equal in rights” because the electrical vectors of all waves are parallel to this interface. At that practically the beam as a whole propagates into medium 2 ($\psi=0$), the intensity of the reflected beam is equal to zero, and the components $\mathbf{E}_{\perp}=\mathbf{E}$, $\mathbf{E}_{\parallel}=0$. This corresponds to (5), and from (4) it follows that angle $\alpha=\pi/2$ for all waves of the incident beam.

2) At increasing the angle φ the intensity of the reflected beam accordingly to Brewster's experiments begins to increase. This means that there some angle $\alpha_0(\varphi)$ exists, so that the waves from the angular area

$$\alpha_0 < \alpha < \pi/2 \quad (6)$$

will stay in the refracted beam, and from the area

$$0 < \alpha < \alpha_0 \quad (7)$$

get into the reflected beam. Then the angular areas of wave polarizations of the incident beam for the reflected and refracted beams are correspondingly equal to

$$\Delta_r = \alpha_0, \Delta_p = \pi/2 - \alpha_0. \quad (8)$$

The relative values of the electric vector components (3) and (4) with taking into account (1) can be expressed by formulas

$$\xi_{\perp} = E_{\perp}/E = \sin \alpha, \quad (9)$$

$$\xi_{\parallel} = E_{\parallel}/E = \cos \alpha \sin[\varphi + \arcsin(\sin \varphi/n)]. \quad (10)$$

The equation

$$\xi_{\perp} = \xi_{\parallel} \quad (11)$$

gives the possibility to find the value of the angle α_0 , and, consequently, the areas of polarization of the incident beam for the reflected and refracted beams according to (8). This equation can be solved by graphically. For example it was solved for media air – water ($n=1,33$) for angles $\varphi=25^\circ$ and $\varphi_B=53^\circ$, as it is shown in fig.4.

Fig.4. Graphical solving for two cases: $\varphi=25^\circ$ and $\varphi_B=53^\circ$.

Numbers 1 and 2 denote the areas of polarization of the incident beam which determines correspondingly the intensities of the reflected and refracted beams. In the first case ($\varphi=25^\circ$) $\alpha_0=34,5^\circ$, at that the intensity of the reflected beam less than the intensity of the refracted one, in the second case ($\varphi_B=53^\circ$) $\alpha_0=45^\circ$, at that the intensities of both beams are equal.

Substitution of expressions (9) and (10) in (11) gives

$$\text{Sin}\alpha_0 = \text{Cos}\alpha_0 \text{Sin}[\varphi + \text{arcSin}(\text{Sin}\varphi/n)],$$

or

$$\text{tg}\alpha_0 = \text{Sin}[\varphi + \text{arcSin}(\text{Sin}\varphi/n)].$$

Then the dependance $\alpha_0(\varphi)$ is expressed by the equation

$$\alpha_0 = \text{arctg}\{\text{Sin}[\varphi + \text{arcSin}(\text{Sin}\varphi/n)]\}. \quad (12)$$

Inasmuch as the intensities of the reflected and refracted beams are proportional to values of the angular areas of polarization in the incident beam then the intensity of the reflected beam relatively to the incident one can be defined as

$$I(\varphi) = \Delta_r/\Delta_\gamma = \alpha_0/\pi. \quad (13)$$

Graph $I(\varphi)$ for media air – water is presented in fig. 5.

Fig.5. Graph of relative intensity of the reflected beam in dependance on angle φ .

It is seen that the maximum of this dependence takes place at $\varphi_B=53^\circ$ that satisfies to the Brewster expression (1). So, it follows from this that the dependence (13) is the analytical expression of the Brewster law.

Conclusion

1. The obtained result shows that at falling of the nature light beam upon the boundary of transparent media the intensities of the reflected and refracted beams are proportional to the angular areas of their polarizations.

2. These areas are determined by comparison between the parallel and perpendicular components of electric vectors of the wave trains to the given direction.

3. On basis of these principals it was obtained the analytical dependance of the relative intensity of the light beam reflected from the boundary of two transparent bodies expressing the Brewster law.

1. D. Brewster. On the laws which regulate the polarisation of light by reflexion from transparent bodies. Philosophical Transactions of the Royal Society, 105, 125 – 159, 1815.
2. G. S. Landsberg. Optics, chapter XVI, PhysMatLit, 2003.