РАЗДЕЛ II. ФИЗИКА

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About the linear and elliptic polarization of light

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Abstract

On basis of the known experiments it is considered the existing conceptions about the linear and elliptic polarisation of light. It is shown that the conception of the linear polarization does not have the arguments of physical character, and the conception about existence of the elliptic polarisation was founded on mathematical formulae. Since the direct experimental proof of the light elliptic polarization is lacking it is carried out an analysis of the experimental scheme of the indirect confirmation. It is shown that this scheme cannot give such confirmation.

Keywords: light beam, polarizer, crystal plate, optical axis, polarization of light waves.

Аннотация

На основе анализа известных экспериментов рассмотрены существующие представления о линейной и эллиптической поляризации света. Показано, что представление о линейной поляризации не находит аргументов физического характера, а представление о существовании эллиптической поляризации основано только на математических формулах. Поскольку прямого экспериментального доказательства существования эллиптической поляризации не существует, проведен анализ экспериментальной схемы получения косвенного подтверждения. Показано, что эта схема не может дать такого подтверждения.

Ключевые слова: Световой пучок, поляризатор, кристаллическая пластинка, оптическая ось, поляризация световых волн.

Introduction

The conception of the linear polarization which arises at passing of the natural beam of light through a polarizer (for example, tourmaline crystal) appeared at the beginning of the nineteen century at carrying out of some experiments [1, 2].

At the natural process of light radiation tremendous numbers of atoms take part, and each of them spontaneously radiates its electromagnetic wave with a certain direction of polarization. So, if a natural beam of light passes at a certain direction then it contains electromagnetic waves of every possible polarization and in such beam the planes of oscillation of all waves are parallel to each other. If to project the vectors of electric fields strength of such beam upon the plane which is perpendicular to the beam direction then these projections will fill the whole conditional circle as it is shown in fig. 1.

Fig. 1. Wave polarizations in the natural light beam.

In work [3] it is asserted that at passing of such beam through a polarizer (uniaxial crystal) the passed part of the beam will be linear polarized, i.e. all electric vectors of this part will be directed parallel to the optical axis of the crystal.

However it is another possibility at which the waves passed the polarizer will keep their polarizations. In this case the polarization of the passed part of the beam will look as it is shown in fig. 2.

Fig. 2. Harp polarization of a light beam.

Such polarization can be named harp, it can be measured by the angle area Δ of the wave polarizations in the beam. Validity of such assumption is confirmed by work [3] in which on basis of the harp polarization it was obtained the analytical expression of the Brewster law.

Linear or harp polarization?

Let us consider well known experiments on passing the natural beam of light through a uniaxial crystal – plate of tourmaline [4]. The beam is directed perpendicular to the plate surface which is parallel to its optical axis, at that it was established that the intensity of the passed part of the beam was a half of the incident beam intensity. This result corresponds to the assumption that the plate lets pass only those waves which have parallel to the optical axis component of the electrical field strength exceeding the perpendicular to this axis component. So, the plate lets pass waves with electric vectors lying at the angle range $\pm\pi/4$ to the optical axis.

To understand which polarization has the passed part of the beam let us consider the experiment on passing the natural beam of light through two parallel plates of tourmaline with crossed axes [4] as it is shown in fig. 3. The angle between the axes is marked α .

Fig. 3. Experimental scheme with two plates of tourmaline.

If the passed through plate 1 beam has the linear polarization then the electric vectors of all waves of this beam are directed along the optical axis of this plate. Plate 2 (just as plate 1) must let pass only those waves which have parallel to the optical axis of this plate

component of the electrical field strength exceeding the perpendicular to this axis component. This means that at the angle range

$$0 < \alpha < \pi/4$$

plate 2 lets pass the whole beam that passed plate 1, but at the angle range

$$\pi/4 < \alpha < \pi/2$$

it does not let pass no one. Let us mark this dependance of the beam intensity on angle α by symbol $I_1(\alpha)$. But this dependance does not correspond to the results of the experiments: the intensity of the beam which passed through plate 2 fluently decreases at increasing angle α from 0 till $\pi/2$. To explain this result it is usually employed another rule then in the first case: the intensity of such beam is proportional to $\text{Cos}^2\alpha$ [1] (so-called Malus' law), i.e. the intensity is proportional to the wave amplitude projection square upon the optical axis of this plate. Let us mark this dependance by symbol $I_2(\alpha)$. But if to employ this rule to passing the natural light beam through plate 1 then the intensity of the passed beam will not be equal to a half of the intensity of the incident beam. So, one of these rules contradicts the results of the first experiment, another – the results of the second one.

Let us consider what will be obtained if to lay in the basis the assumption about the harp polarization of the passed through plate 1 beam. This plate let pass waves with electric vectors laying at the angle range $\pm\pi/4$ to its optical axis, i.e. at the ranges $\mathbf{E}_1 - \mathbf{E}_2$ and $\mathbf{E}_3 - \mathbf{E}_4$ as it is shown in fig. 4. Let us mark this beam as beam A.

Fig. 4. The scheme of passing the harp light beam through two plates.

From this block of waves plate 2 let pass only those ones which have electric vectors laying at the angle range $\pm\pi/4$ from axis 2, i.e. laying at the ranges $\mathbf{E}_2 - \mathbf{E}_5$ и $\mathbf{E}_4 - \mathbf{E}_6$. The range of polarizations of this area is equal to

$$\beta = \pi/2 - \alpha.$$

Let us mark this beam as beam B. The intensities ratio of beam B to beam A is equal to the ratio of the angle ranges of polarization areas of these beams, i.e.

$$I_3(\alpha) = \frac{\beta}{\pi/2} = 1 - \frac{2\alpha}{\pi}.$$

Fig. 5 shows all three dependences.

Fig.5. Three dependences of the relative intensity of the light beams passed through plate 2.

As it was said dependence I_1 does not correspond to the experimental results, dependence I_2 gives the fluently decreasing of the intensity with increasing of angle α but its wavy character does not have any physical explanation. As for dependence I_3 that is based upon the harp character of polarization, it is obtained by a natural way. So, from the fact that with using the harp conception it was obtained the analytical expression of the Brewster law [3], and from the carried out the present analysis it follows that the light polarization after passing a light beam through a polarizer must have the harp character.

Does it exist the elliptical polarization of light?

The well-known scheme of obtaining so called the elliptical polarization of light which is stated in work [4] consists in following.

Step 1. A natural beam of light is transmitted through a polarizer – uniaxial crystal analogously to that as it was described in the previous section. It is considered that at the output of the polarizer the passed beam of light is linear polarized, i. e. it presents by itself a linear polarized wave.

Step 2. Next the linear polarized wave is transmitted through a birefringent crystal whose optical axis is directed at an angle α to the optical axis of the polarizer. At that it is considered that the wave breaks up into two linear polarized waves: one (unusual) is polarized along the optical axis of the crystal, another (usual) is polarized perpendicular to this axis. So, these waves pass through the crystal to the same direction which is perpendicular to the crystal surface, but with different velocities. At the opposite face of the crystal there get out two waves with different phases of their electric vectors. Then there occurs the vector addition of electric fields of these waves, and as a result of transmitting of the summary wave its vector end describes (in common case) an ellipse in the plane that is perpendicular to the direction of the wave propagation. This is the mathematical basis of the described process.

Step 3.

How does it make sure in experiment that the electric vector of the summary wave really circumscribes an ellipse? Nobody and never observed such an ellipse in any experiment. To proof the existence of the elliptic polarization it is adopted to apply to an indirect method: the obtained at the opposite face of the crystal light beam is transmitted through a crystal plate-compensator, at that its position and thickness is chosen to compensate the phase difference of the putting together waves. At that it is considered that in result the light beam becomes linear polarized again and such polarization can be easy determined with using ordinary polarizer. Then it must be obtained the dependence been marked above as $I_2(\alpha)$. But, as it is established in the previous section such dependence does not correspond to physics.

Let us consider the described above step-by-step experiment from point of view of the harp polarization. Step 1 will give at the output of the polarizer the light beam with the structure which is shown in fig.6a. Step 2 will give at the output of the crystal plate the light beam with the structure which is shown in fig.6b. Such character of polarization at the output of the crystal plate is determined by greater velocity of waves which have polarization within the angle area $\pm\pi/4$ to its optical axis. Electrical vectors of these waves are pictured by longer

arrows. Vectors which are pictured by shot arrows correspond to waves that passed the crystal plate with less velocity. Since all the waves keep their initial polarization it does not take place any vector addition of their electric fields.

Fig. 6. Polarizations of the light beams: a) in the result of step 1, b) in the result of step 2. PP is the optical axis of the polarizer; KK is the optical axis of the crystal plate.

In general, one can say about a vector addition of electric fields only when light beams are acting upon any object, for example upon a photographic plate.

At step 3 the harp light beam is transmitted through a compensator, and in the result of this the polarization of the light beam becomes just the same which it was at the output of the polarizer at the end of step 1. The next passing of this beam through the analyzer will give dependence I_3 , which is shown in fig. 5. Thus, the experiments described above as three steps do not give any possibility to state the existence of any elliptical polarization.

As the additional consideration it can say the next: addition of electric fields is a mathematical method which gives a possibility to find the result of united acting of several electric fields at an analysis of some physical processes. For example, it permits to find the resulting strength when a charged particle is in the area of several electric fields acting, or when light beams have an influence upon a photographic plate at interference. The addition of electric fields which brings to the elliptic polarization does not have any physical consequences. It would can to consider the elliptic polarisation of light as a physical reality if some physical process existed in which just moving of the light wave electrical vector end along an elliptic trajectory gives to real experimental result. But such the process does not exist in the nature.

Conclusion

1. Light waves of the nature light beam at passing through a polarizer keep their initial polarization. The linear polarization conception does not have any physical arguments.
2. The experimental scheme of the indirect confirmation of elliptic polarization existence in reality does not give such confirmation.
3. As it does not exist any physical process in which just moving of the light wave electrical vector end along an elliptic trajectory gives the experimental result then the elliptic polarization conception needs to consider as one from unconfirmed physical hypothesis.

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