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К НАХОЖДЕНИЮ МАКСИМУМОВ В ОПЫТЕ ЮНГА

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TO FINDING THE MAXIMUMS IN YOUNG'S EXPERIENCE

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Аннотация. В литературе по физике, посвященной разделу «Оптика», рассматриваются различные схемы наблюдения интерференции, среди которых существенное место занимает опыт Юнга. Максимумы интерференции в этом опыте описываются довольно простой формулой. Расстояния между соседними интерференционными полосами, следующие из этой формулы, являются одинаковыми для любого порядка максимума. В данной работе рассматривается возможное уточнение нахождения максимумов интерференции и как это повлияет на расстояние между соседними интерференционными полосами.

Ключевые слова: *интерференция*, *ход лучей*, *условия максимумов*, *когерентность*.

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Abstract. In the physics literature devoted to the section "Optics", various schemes for observing interference are considered, among which Young's experiment occupies a significant place. The interference maxima in this experiment are described with a fairly simple formula. The distances between adjacent interference fringes, following from this formula, are the same for any order of maximum. In this paper, we consider a possible refinement of finding interference maxima and how this will affect the distance between adjacent interference fringes.

Keywords: *interference*, *ray path*, *maxima conditions*, *coherence*.

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Introduction

In 1802, Thomas Young conducted his experiment on the scattering of light. Two holes, very close to each other, were made with a pin in an opaque screen. They were illuminated by sunlight passing through a small hole in the screen. Light passing through holes in an opaque screen, expanding due to diffraction, forms two light cones. They partially overlap on the screen for observation. In the area of their overlap, one can observe the alternation of dark and light stripes. A similar experiment is carried out using narrow long slots [1]–[7].

The observation of an interference pattern means that light has wave properties (particle-wave dualism of light). Interference can only be observed for coherent light sources. It is practically impossible to create two different coherent sources, therefore all interference experiments are based on the creation of two or more secondary sources from one primary one.

This is done using various optical systems, for example using reflection or refraction. In Young's experiment, two slits in the screen serve as coherent sources. In this case, the interference pattern is observed on a screen, the distance to which is much greater than the distance between the sources (slits). An experiment similar to Young's was done by Grimaldi as early as 1665, but he used the sun as a source to directly illuminate holes in the screen. In this case, interference could not be observed due to the large angular dimensions of the Sun [1].

The conditions for interference maxima have the form [1]–[7]:

$$x_k = k\frac{L}{d}\lambda, \tag{0.1}$$

where x_k – is the coordinates of the maxima, k – is an integer, L – is the distance from the slits to the screen, d – is the distance between the slits, λ – is the light wavelength.

The distance between adjacent interference fringes is the same for any number k

$$x_{k+1} - x_k = \frac{L}{d}\lambda\,. \tag{0.2}$$

Formula (0.1) is still not exact. In this paper, we consider the question of how the refinement of the x_k maxima will affect the distance between the interference fringes.

1 Scheme of experience

In Young’s experiment, light from a source (figure 1.1) falls on a narrow slit (1), and through it, on two slits parallel to it (2). On the screen (E) in the region of overlap of the obtained coherent light beams, parallel interference fringes are observed. When using lasers that generate practically parallel beams of rays, slit (1) is not needed in Young’s experiment [1].

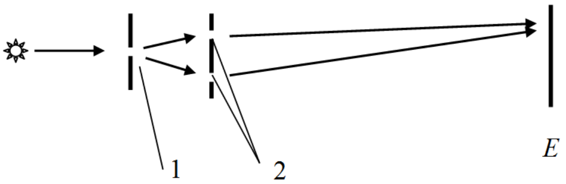

Figure 1.1 – Light from a source is incident on the screen through two slits

Two slits in the screen, which are coherent sources, will be denoted by S_1 and S_2. The path of the rays is shown in figure 1.2.

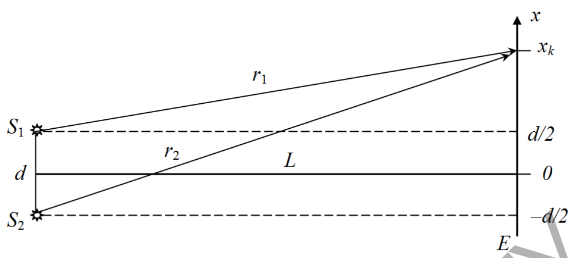

Figure 1.2 – The path of the rays from two slits to the point of observation

The difference between the optical lengths r_2 and r_1 of two beams coming from the sources S_2 and S_1, respectively, to the observation point (for vacuum, the optical length corresponds to the geometric one)

$$\Delta = r_2 - r_1. \tag{1.1}$$

The conditions for interference maxima have the form:

$$\Delta = k\lambda. \tag{1.2}$$

From the consideration of right triangles in figure 1.2

$$r_1 = \sqrt{L^2 + \left(x_k - \frac{d}{2}\right)^2}, \tag{1.3}$$

$$r_2 = \sqrt{L^2 + \left(x_k + \frac{d}{2}\right)^2}. \tag{1.4}$$

Then the conditions for the coordinates of the maxima, taking into account relations (1.1), (1.2), (1.3) and (1.4)

$$k\lambda = \sqrt{L^2 + \left(x_k + \frac{d}{2}\right)^2} - \sqrt{L^2 + \left(x_k - \frac{d}{2}\right)^2}. \tag{1.5}$$

Let's transform the ratio (1.5)

$$k\lambda = L\sqrt{1 + \frac{\left(x_k + \frac{d}{2}\right)^2}{L^2}} - L\sqrt{1 + \frac{\left(x_k - \frac{d}{2}\right)^2}{L^2}}. \tag{1.6}$$

2 Approximate analytical solution

We use several terms of the expansion of the square root in powers

$$\sqrt{1+\alpha} \approx 1 + \frac{1}{2}\alpha - \frac{1}{8}\alpha^2. \tag{2.1}$$

Considering that $L >> d$ and $L >> x_k$, from expressions (1.6) and (2.1) we obtain

$$k\lambda = \frac{x_k d}{L}\left(1 - \frac{x_k^2}{2L^2} - \frac{d^2}{8L^2}\right). \tag{2.2}$$

From the consideration of expression (2.2) it follows that the distance between the interference fringes cannot be obtained similarly to formula (0.2). That is, refining the position of the maxima x_k leads to the fact that the distance between adjacent interference fringes is not the same.

From expression (2.2) we obtain

$$x_k = \frac{k\lambda L}{d\left(1 - \frac{x_k^2}{2L^2} - \frac{d^2}{8L^2}\right)}. \tag{2.3}$$

If the expression in parentheses in the denominator is approximately equal to one, then we obtain formula (0.1). Due to the fact that the bracket in expression (2.3) is less than unity, the coordinates of the maxima following from (2.3) will be slightly larger than the corresponding coordinates from formula (0.1).

To find x_k, we reduce expression (2.2) to a cubic equation

$$x_k^3 - 2L^2\left(1 - \frac{d^2}{8L^2}\right)x_k + 2L^3\frac{k\lambda}{d} = 0. \tag{2.4}$$

The resulting cubic equation (2.4) immediately has a canonical form. To solve it, it is convenient to apply the Vieta trigonometric formula (you can also use the Cardano formula). We will carry out calculations for a particular case.

Table 2.1 – Results of calculations of maxima and distances between neighboring maxima

k	x_k, *mm*	$x_{k+1} - x_k$, *mm*	$\frac{x_{k+2} - x_{k+1}}{x_{k+1} - x_k}$
1	±2,500000325	2,50000220	1,00000149
2	±5,000002525	2,50000595	1,00000224
3	±7,500008475	2,500011575	1,00000299
4	±10,000020050	2,500019075	1,00000375
5	±12,500039125	2,500028451	1,00000449
6	±15,000067576	2,500039701	1,00000525
7	±17,500107277	2,500052827	1,00000600
8	±20,000160104	2,500067828	1,00000675
9	±22,500227932	2,500084705	–
10	±25,000312637	–	–

The results of calculations for $d = 10^{-3}$ m, $L = 5$ m, $\lambda = 5 \cdot 10^{-7}$ m are shown in Table 2.1. The second column shows the coordinates obtained from formula (2.4), and the third column shows the distance between adjacent strips.

Conclusions

From the above calculations (table 2.1) and the analysis of expression (2.3) it can be seen that the refinement of the interference maxima leads to the fact that the distance between adjacent interference fringes is not the same. This distance is slightly larger than that calculated by formula (0.2). In this case, one more regularity is traced – the distance between adjacent interference fringes increases monotonically with an increase in the order of maximum (k), although this increase is insignificant.

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