Modern Physics Laboratory

Experiment 431

Measurement of light absorption coefficient

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Student should be familiar with the following theoretical concepts:

1. Light as an electromagnetic wave. [10] and [32].
2. Reflection and refraction of light. [19] or [32].
3. Absorption and extinction of light. Photometry. [10] and [19].

The aim of the experiment

The aim of the experiment is to determine the light absorption coefficient of the investigated material.

Measurement method

The light beam transmitted through a material medium is always attenuated. This attenuation is caused by two phenomena: absorption and dispersion (diffusive reflection) of the light. Both these phenomena acting together are called extinction.

Part of the energy of the light beam passing through matter is changed into other forms of energy, and makes the beam intensity diminish, according to the Bouger law:

$$I = I_0 e^{-ax}, \tag{1}$$

where I_0 is the intensity of the radiation coming into the layer of thickness x, I – intensity of the radiation getting out of this layer, the constant a is called the absorption coefficient.

Part of the light beam energy is reflected on the surface of the medium the beam is getting into. This part is defined by the reflection coefficient defined as:

$$R = \frac{I_r}{I_p}, \tag{2}$$

where I_p is the radiation intensity of the incident beam and I_r is the intensity of the reflected beam. The intensity of the beam passing into the material is $I_0=I_p–I_r$. In the case of an incident beam perpendicular to the media boundary the reflection coefficient is given by:

$$R = \left(\frac{n-1}{n+1}\right)^2, \tag{3}$$

where n is relative refraction coefficient of the medium the beam is reflected from (is trying to get into), in relation to the medium the beam is coming from.

In the effect of the above mentioned phenomena the intensity of the beam passing through a plate of thickness d is given by:

$$I = I_p(1-R)^2 e^{-ad}. \tag{4}$$

The measurement of the absorption coefficient consists in measuring the relation intensity I_k of the transmitted beam, which passed through k glass plates, to the intensity of the incident beam I_p. The measurement is performed with the use of a photoresistor being one of the branches of the Wheatstone bridge.

Let's consider a bridge without the glass plates, with the photoresistor placed in some distance r_p from the light source. It is illuminated with light of intensity I_p. When there are k plates inserted, the light intensity diminishes to some value I_k. With diminishing illumination intensity the resistance of the photoresistor increases and the equilibrium of the bridge will be lost. In order to restore it, it is necessary to place the photoresistor closer to the light source – to a distance r_k, at which the illumination intensity will again have the previous value.

If some surface is to be identically illuminated by two different light sources of intensities I_p and I_k respectively, their distances r_p and r_k from this surface must satisfy:

$$\frac{I_k}{I_p} = \left(\frac{r_k}{r_p}\right)^2. \quad (5)$$

Substituting this into formula (4), and taking into account the reflections from both surfaces of the k glass plates and absorption in the layer of total thickness kd, we obtain a formula:

$$\left(\frac{r_k}{r_p}\right)^2 = (1-R)^{2k}e^{-akd}. \quad (6)$$

Taking logarithm of both sides we find out that $\ln\frac{r_k}{r_p}$ is a linear function of k. The slope (direction coefficient) of the line s is given by a formula:

$$s = \ln(1-R) - \frac{ad}{2}. \quad (7)$$

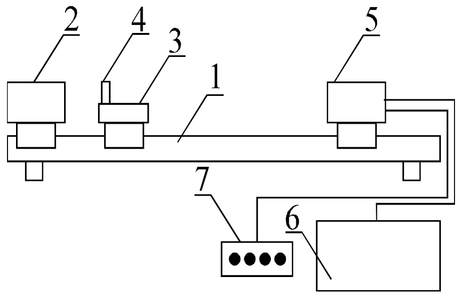
From this we obtain the following formula for the absorption coefficient:

$$a = \frac{2}{d}[\ln(1-R) - s] \ , \quad (8)$$

Into this formula we substitute the slope s determined with the use of the least squares method and R determined with the use of the formula (3).

Description of experiment

The measurements are taken with the use of the experimental setup presented in fig. 1, consisting of: the optical bench 1, light source with collimator 2, holder 3, in which the glass plates 4 will be placed, movable base with photodetector 5 and the electrical circuit of the bridge, consisting of a photoresistor (being the photodetector), the bridge with power supply 6 and indicator 7 (the bridge is in equilibrium when two center diodes are alight).



Rys. 1. Schematic of the measurement setup

Sequence of actions

1. Place the photodetector at rightmost position on the optical bench. The plate holder should be moved close to the photodetector. Switch on the light source and the bridge.
2. Moving photodetector find the bridge equilibrium and note the position r_p of the photodetector.
3. Measure the thickness d_1 of a single glass plate and insert it into the holder.
4. Moving the photodetector find the equilibrium position of the bridge, read the photodetector positon r_1.
5. Add subsequent glass plates and repeat the measurement described in points 3 and 4.
6. Note the refraction coefficient of the material of the plates.

Structure of the report

The report should contain:

1. Short description of the idea of the measurement (without description of the sequence of actions) and schematic diagram of the measurement setup.
2. Table with the measurement results:

k	0	1	2	3	4	5	6	7	8	9
d_k [m]	-									
r_k [m]										
$\ln\frac{r_k}{r_p}$	0									

where k is the number of plates and d_k is their thickness.

3. Calculation of the average thickness of plates $\bar{d}$.
4. Calculation of the slope of the line s and its error Δs performed with the use of the least squares method.
5. The plot of the $\ln\frac{r_k}{r_p}$ values versus the number of plates k.
6. Calculation of the reflection coefficient R according to the formula (3) and the absorption coefficient a according to formula (8).
7. The error calculation:
   a) the error of the average thickness is calculated using the formula:
   $$\Delta d = St_a, \tag{9}$$
   where t_a is the coefficient from the table of the Student method for the confidence interval 0.95, and S is a mean error of the arithmetic average calculated according to formula:
   $$S = \sqrt{\frac{\sum_{k=1}^{N}(d_k-\bar{d})^2}{N(N-1)}}, \tag{10}$$
   where N is the number of plates used,
   b) the error of the absorption coefficient is calculated according to the formula:
   $$\Delta a = \frac{1}{d}(a\Delta d + 2\Delta s)$$
   . (11)
9. The final result should be given in the form:
   $$a = a_{obl} \pm \Delta a,$$
   where a_{obl} is the absorption coefficient calculated according to the formula (8).
10. The comparison of the result obtained to the data from literature and discussion describing phenomena which may influence the error of the result.

Questions

1. Describe the nature of the light waves.
2. Write and explain the equation of a plane wave.
3. Formulate the laws of reflection and refraction.
4. Give definitions and units of light flux and of light intensity.
5. Formulate the Bouger (Lambert) law.
6. Derive the formula (5).
7. Explain the measurement method.
8. Expain the least squares method.