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КОМП'ЮТЕРНИЙ МЕТОД ВИМІРЮВАННЯ ОПТИЧНИХ І КОЛІРНОГО ПАРАМЕТРІВ ЛЮДСЬКОГО ВОЛОССЯ

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У діагностиці та лікуванні захворювань волосся та шкіри важливу роль відіграє інформація про тип і концентрацію меланіну, що в них міститься. Застосування методів математичного моделювання та комп'ютерного оброблення експериментальних даних значно спрощують аналіз вмісту меланіну в біологічних тканинах. У зв'язку з цим актуальним є розроблення та дослідження нових, більш простих методів аналізу, зокрема фізичних.

Метою цього дослідження було використання комп'ютерних методів для вимірювання діаметра людського волосся, його оптичних, колірних характеристик та оцінювання вмісту в ньому меланіну. У роботі описується запропонований авторами метод оброблення мікроскопічних зображень волосся людини, призначений для вимірювання їх оптичних параметрів. Людське волосся поміщали на предметний стіл оптичного мікроскопа BioLight 200. Для фотографування використовувалася цифрова приставка Sigeta FMA037. За допомогою програмного додатка зображення волосся було розкладено на складові трьох кольорів – червоного, зеленого та синього. Дані математично оброблено. В результаті виміряно коефіцієнти пропускання та відбиття світла в діапазонах даних кольорів. На основі отриманих даних розраховано коефіцієнт світлопоглинання волоссям, дійсну та уявну частини комплексного показника заломлення. Побудовано графіки залежності цих параметрів від кольору волосся. За допомогою методу найменших квадратів отримано формули, що описують ці залежності. Порівняння отриманих залежностей із табличними даними про вмісту меланіну у волоссі різних кольорів дозволило отримати математичну залежність вмісту меланіну від показника послаблення світла у волосині та його кольору. Запропоновано комп'ютерний метод вимірювання оптичних і колірних характеристик волосся, що дає змогу визначити вміст у ньому меланіну. Метод є набагато простішим за відомі хімічні методи, не вимагає дорогого обладнання і займає мало часу. Показано можливість використання простого та швидкого фізичного методу оперативного аналізу параметрів волосся людини та оцінювання вмісту меланіну у волоссі замість складних хімічних методів. Запропоновано комп'ютерний метод вимірювання оптичних і колірних характеристик волосся, що дає змогу визначити вміст меланіну у ньому.

Ключові слова: комп'ютерні методи, волосся, вимірювання, поглинання, розсіяння, меланін, колориметрія.

COMPUTER METHOD OF MEASUREMENT OF OPTICAL AND COLOR PARAMETERS OF HUMAN HAIR

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Background. In the diagnosis and treatment of hair and skin diseases, an important role is played by information about the type and concentration of melanin contained there. This study aimed to use of computer methods to measure the human hair diameter, its optical, color characteristics and assess the content of melanin in it.

Materials and methods. Human hair was placed on the stage of a BioLight 200 optical microscope. Sigeta FMA037 digital attachment was used for photography. With the help of a software application, the image of the hair was decomposed into components of three colors – red, green and blue. Using the least squares method, formulae that describe these dependences are obtained.

Results. The transmittance and reflection of light in these color ranges were measured. Based on the obtained data, the light absorption coefficient in the hair, the actual and virtual parts of the complex refractive index were calculated. Graphs of dependence of these parameters on hair color are constructed. Comparison of the obtained dependences with tabular data on the content of melanin in the hair of different colors made it possible to obtain a mathematical dependence of the content of melanin on the rate of weakening of the hair and its color. A computer method for measuring the optical and color characteristics of hair is proposed, which makes it possible to determine the content of melanin in it.

Conclusions. The method is much simpler than known chemical methods, does not require expensive equipment and takes little time. A computer method for measuring the optical and color characteristics of hair is proposed, which makes it possible to determine the content of melanin in it.

Keywords: computer methods, hair, measurement, absorption, scattering, melanin, colorimetry.

Introduction. Many problems in biology and medicine today require the use of mathematical methods to solve them. To do this, mathematical models of processes occurring in the studied objects are created. When developing mathematical models, in particular, those that describe the interaction of light with biological tissues, it is necessary to know the optical parameters that characterize the absorption and scattering of light.

One such problem is the application of methods of mathematical modeling and computer processing of experimental data in the analysis of melanin content in biological tissues. Its type and concentration must be known in the diagnosis and treatment of hair and skin diseases, laser hair removal etc. [1-12]. Methods of chromatography [5, 10], refractometry [11], spectral analysis [9, 12] are used to determine the content of melanin. These methods require expensive equipment and are time-consuming. Therefore, an urgent problem is the development and research of new, simpler methods of analysis, in particular, physical methods. A large number of scientific works, such as articles [1, 2, 6, 8], are devoted to this problem, although research is ongoing and the problem remains relevant.

In this article, the authors describe the use of computer methods to measure the parameters of human hair - their color characteristics, absorption and scattering of light, a complex refractive index, on the basis of which you can estimate the content of melanin. Fig. 1 shows the structure of the hair.

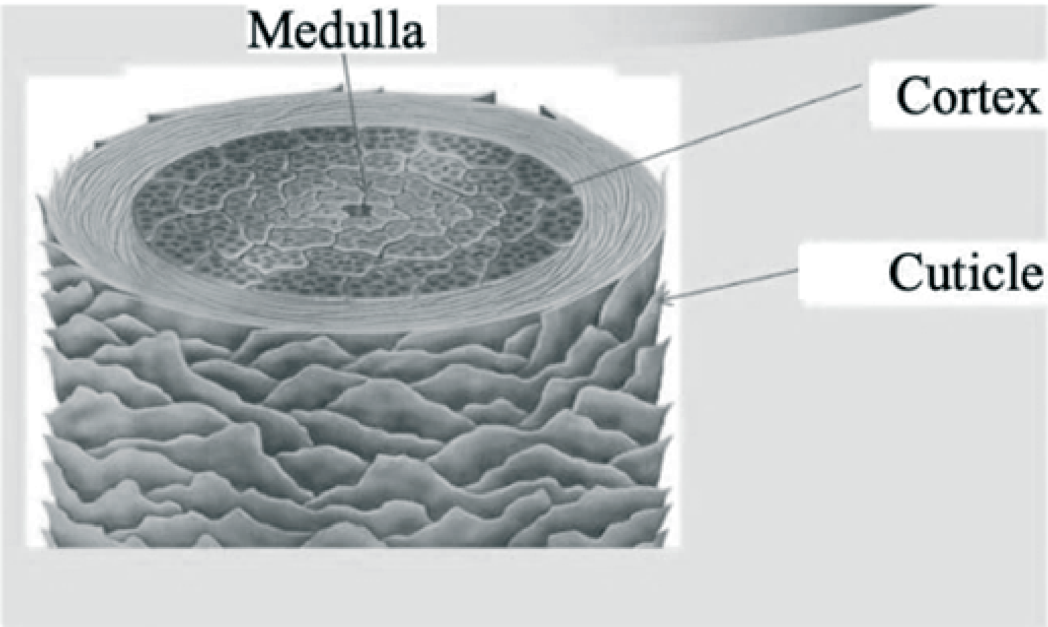


Fig. 1. Hair structure

The hair has the shape of a cylinder with a diameter ranging from 10 to 300 μm. The outer shell (cuticle) is a dense coating formed by flat cells that cover each other in the form of a "tile roof". The cells are arranged in several layers from 6 to 9. They consist of keratin and proteolipids, which form the hydrophobic shell of the hair, and also contain horny substances that provide mechanical protection of the inner layers. The organic components of the cuticle that is fats, proteins, waxy substances provide the hair with elasticity and shine.

The inner part of the hair (cortex) is formed by keratinized fibers surrounded by cells responsible for the metabolism and morphology of the hair. The cortex makes up about 90 % of the hair mass. It contains melanin granules. Hair color is determined by the concentration and type of melanin or eumelanin, which gives hair black and brown colors, as well as pheomelanin, which gives hair light shades.

In gray hair, melanin disappears because it stops being synthesized in the hair follicles, in which the amount of hydrogen peroxide increases drastically. That is, natural hair bleaching occurs through the same reagent that helps women become blonde. At the same time, a large number of air bubbles appear, which also give the hair a light shade.

Some hairs, but not all, have a central part, the medulla. Vellus hair and some other types lack it and have only the cortex and cuticle. There are no chemical processes in the medulla. Inside the medulla are microscopic air bubbles that provide good thermal conductivity of the hair.

Thus:

1. The absorption of light in the hair is determined by the amount and type of melanin.

2. Light scattering is determined by the cuticle and melanin granules located in the cortex. In gray hair, light scattering also occurs on air bubbles inside the hair, which are formed due to the destruction of melanin granules.

This work describes the results of measurements of light absorption and scattering by hair of different colors in people of a certain age. Methods of computer processing of images obtained with the help of a microscope are offered. Scattering and absorption parameters are calculated. Computerized digital image analysis allows us to assess the content of melanin in the hair.

This study aimed to use of computer methods to measure the human hair diameter, its optical, color characteristics and assess the content of melanin in it.

Materials and methods. The hair fixed in a frame was placed on a subject table of the BioLight 200 optical microscope. Lighting by means of light-emitting diodes from below and from above was used. The digital Sigeta FMA037 set-top box was used for photography, it was used to transfer the image to a computer, where it was recorded in * .bmp format. Then it was mathematically processed.

The advantages of this method are the use of equipment and software available in many laboratories, the short time required for measurements and processing of results.

Results and their discussion. Colorimetric analysis of human hair. An important characteristic of the hair substance is its absorption of light, which depends on the amount of melanin in it and its type. It is determined by the absorption coefficient α, which is included in the Bouguer formula:

$$I = I_0 e^{-\alpha l} \tag{1}$$

According to various works, for example, [2, 12] its value for the visible range is in the range from 75 m^{-1} to 7000 m^{-1}. In the work [12], the values of the scattering coefficient in the range from 3000 m^{-1} to 30,000 m^{-1} are also indicated.

To perform colorimetric analysis in this article the capabilities of software applications that enable to decompose the color image of the hair into three components - red, green and blue, and then explore them are applied. To do this, using a microscope eyepiece (Sigeta FMA037) digital photo of hair of different colors were taken. Hair samples were provided for the experiment by students of the National University of Pharmacy (Kharkiv).

The transmittance T and reflectance R of the hair were measured, and this made it possible to use Bouguer's law. In this case, the exponent includes both the absorption index and the scattering index of the medium.

Fig. 2 (a) shows a photo of fair hair and its tricolor image. The distribution of light intensity in the cross section of the hair in these color ranges in relative units is shown below the photos. The unevenness of the intensity is due to the focusing of light by the hair as a cylindrical lens. It can be seen that the red light is weaker than the green and blue. Fig. 2 (b) shows a photo of gray hair. It can be seen that the light transmission is higher here and the focus is stronger.

In addition, Fig. 2 (c) shows photos of brunette hair. The reflection (R) and transmission (T) coefficients of such hair are very small. Characteristics of blonde hair are completely different (Fig. 2 (d)). This hair transmits red light well, and transmits the green and blue ones much worse.

These data were used to determine transmission (T) and reflection (R). They were calculated by formulae:

$$T = \frac{I_T}{I_0}, \qquad R = \frac{I_R}{I_0}, \tag{2}$$

where IT and IR are the average intensity of incident and reflected light, respectively, I0 is the intensity of the background in the photos.

From these data it is possible to determine the coefficient of absorption of radiation in the hair. Part of the energy that hits the hair is reflected from it. Therefore, energy equal to (1 R) will get inside the hair. Here, the energy of the incident wave is taken equal to 1. We denote the absorption coefficient by K, and then the energy will pass through the hair:

$$T=(1-R)(1-K) \tag{3}$$

Thus, the light absorption coefficient is determined by the formula:

$$K = 1 - \frac{T}{1-R} \tag{4}$$

Fig. 3 shows the distribution of absorption in three color ranges for hair samples of an 18-year-old blonde and 18-year-old brunette. Absorption by dark hair is large in the entire visible range of about 90 %. Absorption of blonde hair is much less. It varies from 60 % in the blue part to 5 % in the red part of the spectrum. The average absorption value is 92 % in dark hair and 34 % in fair hair.

The absorption spectrum of blonde hair qualitatively coincides with the absorption spectrum of melanin.

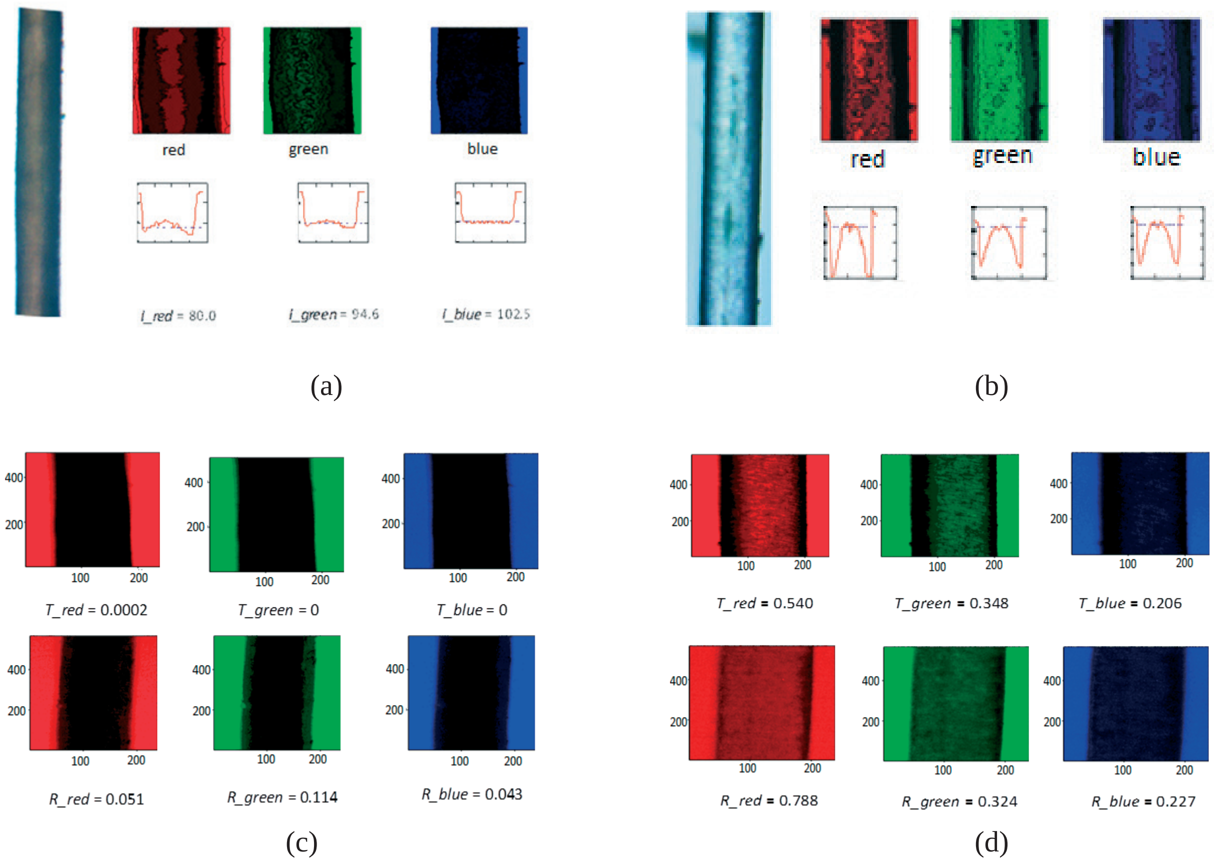
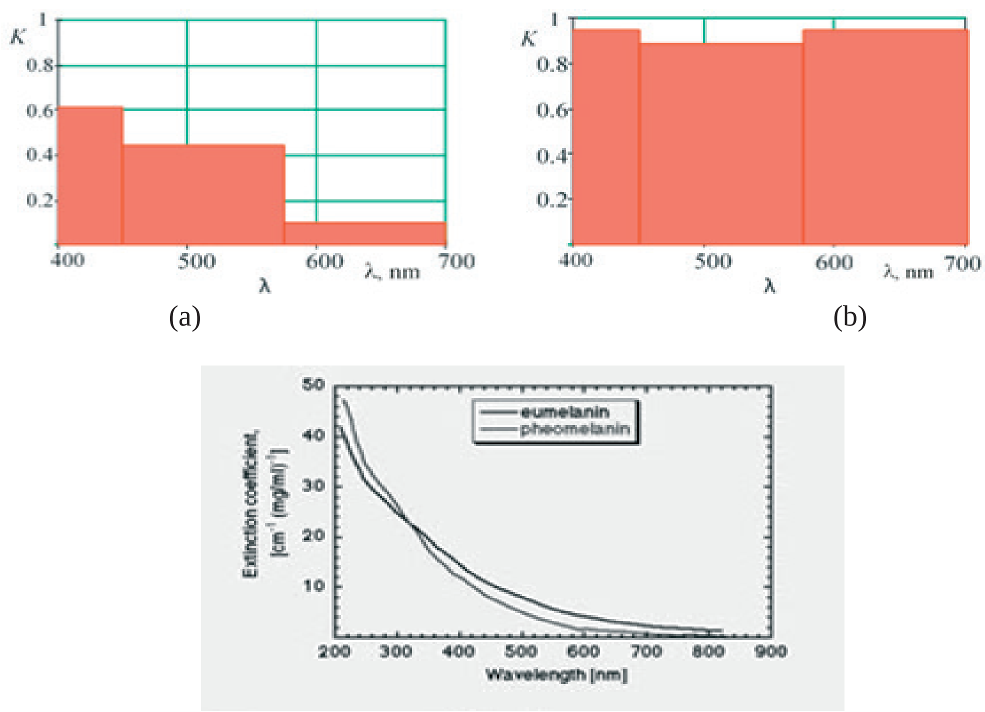


Fig. 2. Photo of fair (a), gray (b) hairs and hair of brunette (c) and blonde (d)



(c)

Fig. 3. Hair absorption of light ((a) blonde, (b) brunette), (c) melanin absorption spectrum

This confirms the correctness of the measurement technique proposed by the authors.

Formula (1) shows that the attenuation coefficient α is equal to:

$$\alpha = -\frac{\ln T}{l}, \quad (5)$$

where l is the thickness of the layer of matter through which light passes.

The measured values of absorption in several hair samples are given in Tab. 1. In the calculations, the thickness of the layer was taken to be equal to the average value of the thickness of the hair πd/4, where d is the diameter of the hair.

Table 1

Light absorption by hair

Sample	Sample characteristics	Absorption coefficient α, m^{-1}			
		red part of the spectrum	green part of the spectrum	blue part of the spectrum	average value
11	An 18 year-old brown-haired man	7.59	22.10	23.20	15.90
12	An 18 year-old blonde girl	1.43	8.08	13.20	5.75
15	An 18 year-old brunette girl	39.70	29.00	42.00	32.9
16	An 11 year-old red-haired girl	~ 0	3.55	8.82	2.05
17	A 79 year-old gray-haired man	727	288	1.18	475
18	A 46 year-old brown-haired man	6.57	19.10	19.70	14.80

The obtained values agree satisfactorily with the values obtained by other researchers, for example, given in works [1, 2].

Optics uses a complex refractive index m=n-iκ. Its actual part n determines the refraction of light at the boundary of the distribution of media, the virtual part κ is attenuation of light in the medium.

Numerous experiments have shown that the values of the actual part of the refractive index n of the hair are contained in the range from 1.5 to 1.55 [1, 6]. The values of the virtual part κ are contained in a wider range from 10 to 50.

The absorption coefficient α is related to the virtual part of the complex refractive index κ by the following ratio:

$$\alpha = \frac{4\pi\kappa}{\lambda}, \quad (6)$$

where λ is wavelength of radiation in free space.

The mathematical program separates the hair images into three components in the red, green and blue regions of the spectrum. The average value of the wavelength for these ranges was substituted into the formula for determining the parameter κ. The values of the considered wavelength ranges are taken as follows:

- blue: 400…480 nm, average energy value 420 nm;
- green: 480…600 nm, average energy value 530 nm;
- red: 600…690 nm, average energy value 680 nm.

Values κ for the studied hair samples were calculated. The results of the calculations are shown in Tab. 2.

From the indicators of the last column (average on the spectrum value of the attenuation index) it is seen that the lowest light absorption occurs in the gray hair. It is slightly greater in the red hair. It is much greater in the blonde's hair. In the hair of two brown-haired men, it is almost the same, despite the age difference. In the hair of a brunette light absorption is really great.

Graphs of the dependence of the attenuation index on the wavelength for different hair are shown in Fig. 4. Due to the small number of points, the nature of the curves cannot be determined, so they are shown in straight lines. But all the graphs show that the attenuation decreases as the wavelength increases.

Table 2

The attenuation of light in the hair

Sample	Sample characteristics	Absorption coefficient α, m^{-1}			
		red part of the spectrum	green part of the spectrum	blue part of the spectrum	average value
11	An 18 year-old brown-haired man	0.000411	0.000932	0.000849	0.000730
12	An 18 year-old blonde girl	0.000078	0.000341	0.000483	0.000301
15	An 18 year-old brunette girl	0.002150	0.001220	0.001540	0.001640
16	An 11 year-old red-haired girl	0.000001	0.000150	0.000323	0.000158
17	A 79 year-old gray-haired man	0.000039	0.000012	0.000043	0.000032
18	A 46 year-old brown-haired man	0.000356	0.000806	0.000721	0.000628

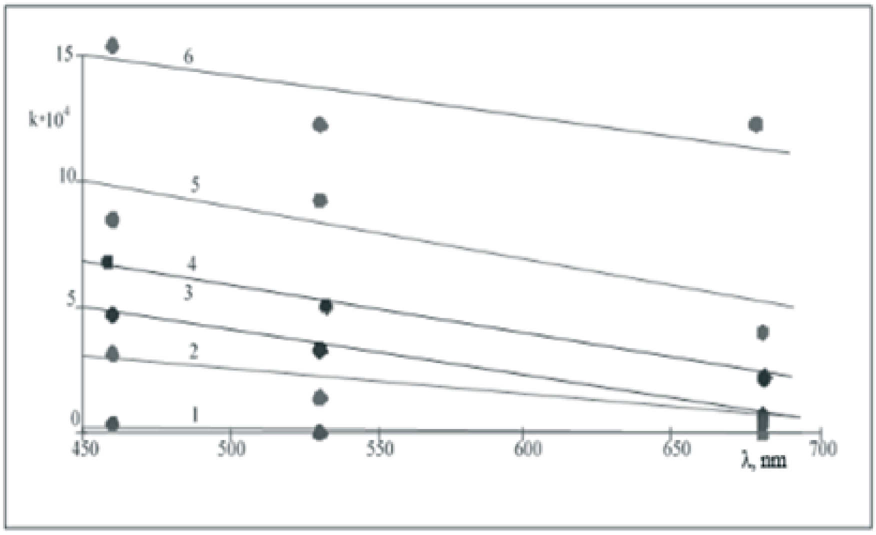


Fig. 4. Dependence of the absorption index on the wavelength of light (1 – a 79 year-old gray-haired man, 2 – an 11 year-old red-haired girl, 3 – an 18 year-old blonde girl, 4 – a 46 year-old brown-haired man, 5 – an 18 year-old brown-haired man, 6 – an 18 year-old brunette girl)

Determination of melanin concentration in hair. The rate of attenuation of light depends on the concentration of melanin in the hair. Therefore, its value can determine the melanin content. However, the optical method cannot find the absolute value of the concentration of melanin. To do this, the results obtained by chemical methods should be applied.

Reference data on the content of melanin in hair of different colors obtained by chemical analysis were taken. They are shown in Tab. 3, compiled according to [2]. The concentration of melanin is given in milligrams per 1 gram of hair mass. Data are taken from five sources. The last column shows the average values for each hair type.

Table 3

Reference data on the concentration of melanin in the hair

Hair color	The concentration of melanin, mg/g					
	1	2	3	4	5	average value
dark	13.485	-	5.37	**31,0 ± 15.0**	7.2	8.8 ± 10.4
fair (blond)	3.46 ± 0.73	-	1.165	-	2.5	2.4 ± 2.9
white (albino)	0.65	-	1.626	-	-	1.10 ± 6.20
red (different shades)	**39.85 ± 52.48**	4.065	1.90 ± 0.70	-	2.50	2.80 ± 2.80
dark brown	10.175	3.3 ± 1.5	3.2	-	5.2	5.5 ± 5.2
brown	5.55	2.64 ± 0.92	3.086	-	-	3.8 ± 3.9
light brown	-	2.065	1.605	-	-	1.8 ± 2.9
light blond	-	2.23	1.281	-	-	1.8 ± 6.0

The data in Tables 2 and 3 were used to calibrate that is to determine the relationship between attenuation and melanin concentration. The obtained dependence is shown in Fig. 5. An approximate curve was drawn through the experimental points by the method of least squares. The following formula was received:

$$C = 138\sqrt{\kappa}\ , \tag{7}$$

The concentration value C is measured in mg/g.

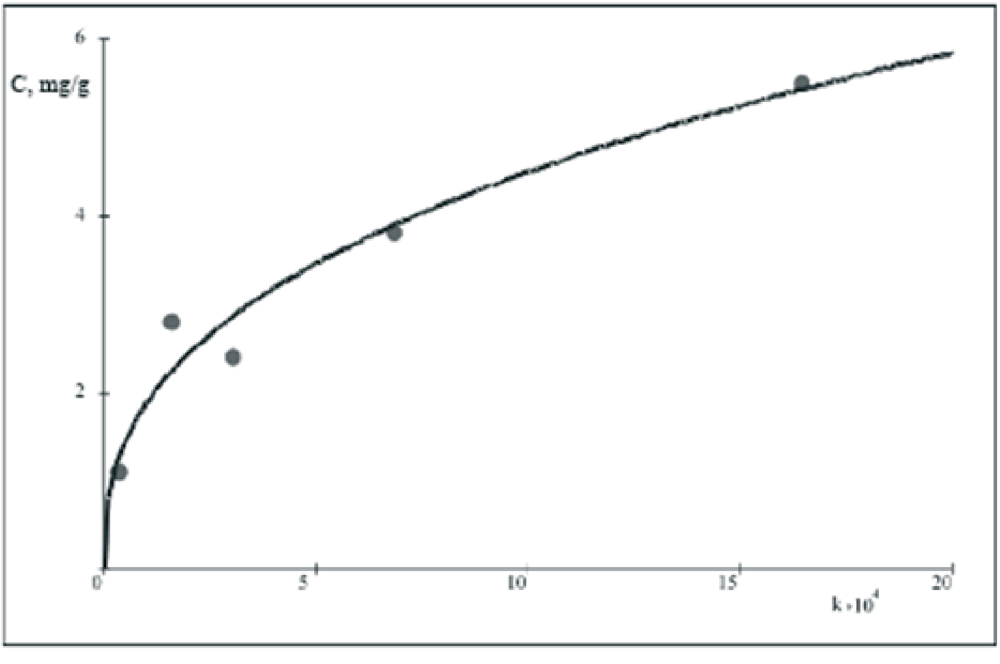


Fig. 5. Calibration curve (relationship between melanin concentration in hair and light attenuation)

The accuracy of the obtained formula is little, due to errors/deviations in the concentration values C in Tab. 3. Although the proposed method of relative measurements of this value will give better results if more accurate measurements of melanin concentration by chemical methods are used.

The proposed method of measuring hair parameters allows you to find the diameter, scattering and absorption parameters, and color characteristics with the help of a microscope with a digital nozzle. The main result of the study is the determination of the melanin content in the hair. We note that it cannot be used to determine the melanin content in milligrams per 1 gram of hair mass – the value that is usually used in such measurements. But when you calibrate the device that uses the described method at one point, then this device can be used for operational measurements and get results quickly. In addition, the method has its drawbacks – it is not absolute, but relative.

Conclusions. The possibility of using simple and fast physical method of operative analysis of human hair parameters and estimation of melanin content in hair instead of complex chemical methods is shown. A method of computer colorimetric analysis of hair is offered. Advantages of the method – analyze quickly and do not require expensive equipment. The method of measuring the value of the complex refractive index of hair samples, the value of the virtual part of which is determined by the content of melanin in the hair is proposed. The obtained results make it possible to determine the concentration of melanin in the hair.

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