Machinery & Energetics
Vol. 13, No. 2. 2022

Journal homepage:
https://technicalscience.com.ua/en

UDC 636.082
DOI: 10.31548/machenergy.13(2).2022.102-108

Leonid Chervinsky*, Ivan Radko, Vitalii Nalyvaiko, Oleksandr Okushko

National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

The Results of Experimental Studies of the Passage of Light Energy under the Skin of Animals Along Individual Hairs

Abstract. This paper presents new scientific results of experimental studies that refute the generally accepted fact that the coat solely protects animals from the effects of solar energy. The purpose of this study was to confirm the fact of the spread of optical radiation energy under the animal's skin along individual hairs, as light guides. The authors of this study experimentally determined the optically conductive structure of an individual wool hair, the components of the transmission parameter of an individual wool hair, namely the coefficient of light transmission inside the wool hair, the coefficient of attenuation of internal light transmission by the substance of the wool hair, the coefficient of losses in the middle of the cylinder of the wool hair due to the beam scattered in the internal structure and the refractive index of its outer shell. Based on the use of methods of photometry and geometric optics, theoretically substantiated and experimentally obtained results regarding the establishment of a mathematical dependence of the total amount of optical radiation energy entering the hair cylinder on the value of the angle of incidence of the beam on the surface of the hair, the cleanliness of the inner core of the cylinder structure, the length of the light-conducting section to the surface of the skin, as well as the refractive index of its outer shell. Based on the results of experimental studies, mathematical dependencies were obtained that describe the spectral light-conducting properties of an individual hair, as well as the distribution of energy emitted in the thickness of the skin along the entire length from the point of penetration into the hair and to the follicle – the place of use of optical energy in photobiological processes. The obtained results of experimental studies of the passage of optical radiation energy along the length of a single hair into the body of an animal are of practical importance for photobiologists investigating the effect of optical radiation from the Sun on biological objects of animal origin

Keywords: solar energy, irradiation of animals, skin-fur cover, light transmission, hair

Article's History: Received: 05.01.2022; Revised: 08.03.2022; Accepted: 27.04.2022.

INTRODUCTION

Breeding of animals and birds is impossible without sunlight, which has a wide range of biological effects. Analysis of modern scientific research [1-3] shows that each of the radiation spectra has its special biological effect on the structure of the animal's body. Ultraviolet radiation has an anti-rickets and healing effect, light of the visible spectrum of assorted colours causes an exciting or calming effect, and infrared radiation causes a thermal effect and improves the physical condition of the animal and its assimilation of food [4; 5].

It is customary to believe that the main part of the Sun's energy passes into the animal's body through the skin and fur [6; 7]. Moreover, only the protective function against excess solar energy is assigned to the wool or hair cover.

It is known that the skin covering of biological objects of animal origin is divided into two main layers: the surface layer of dehydrated dead cells (epidermis) and the actual skin of the animal (corium or dermis), which consists of interconnected living cells of various functions [1; 8; 9].

Research into the ways of the influence of the Sun's energy on the skin and hair covering of biological objects of animal origin (animals and birds) has been carried out since the middle of the 20th century. The studies of several scientists [10-12] substantiated that individual hairs of the animal coat can be a kind of living light guides of optical radiation that falls on the surface of the animal and falls on the skin-fur coat and passes through the skin and along individual hairs into its thickness to the places of biologically

Suggested Citation:
Chervinsky, L., Radko, I., Nalyvaiko, V., & Okushko, O. (2022). The results of experimental studies of the passage of light energy under the skin of animals along individual hairs. *Machinery & Energetics,* 13(2), 102-108.

*Corresponding author

active subcutaneous structures, where it takes part in relevant photobiological processes.

It is known that the internal structure of individual hairs depends on many factors, which can be defined as the main ones – species, age, breed, constitutional, and seasonal [1; 13; 14].

The analysis of the results of scientific research [15-17] regarding the ways of the influence of different spectra of optical radiation upon irradiating biological objects of animal origin, namely pigs, as animals with a fur coat made of the thickest individual hairs, shows that the diameter of individual hairs (bristles) is ten fractions of a millimetre, and their optical conductivity can be measured effortlessly and accurately on modern optical spectrophotometers and other optical measuring devices.

Considering these facts, namely, the possibility of the effect of optical energy of different spectra, which indirectly passes through the wool cover, as through separate light channels, is an urgent scientific problem that is still understudied.

The purpose of this study was to establish the possibility of the passage of optical energy radiation into the biologically active structures of the skin of the body of a biological object of animal origin through individual hairs in the form of light channels. Establishing the quantitative value of the light conductivity of the wool coat during photobiological processes in the body of irradiated animals, obtaining analytical dependencies describing the processes of passage, absorption, and reflection of optical energy of various spectral composition, as well as determining the effectiveness of the effect of absorbed energy by irradiating the wool coat constitute new knowledge for understanding the full the mechanism of interaction of the energy of optical radiation of the Sun with irradiated animals.

MATERIALS AND METHODS

When conducting experimental research, individual wool (hair) of white pigs was used. Optical quantum generators (lasers) with monochromatic radiation of the near-infrared, visible, and long-wave ultraviolet spectra of biological action (630 nm, 532 nm, 445 nm) and a universal spectrophotometer of the SF-4 type were used to investigate the light conductivity of individual hairs. Registration of radiation at the exit of the end of a single hair, as a light guide, was carried out using a special device built based on a sensitive galvanometer with a photomultiplier (FEU-118A) of a wide range of sensitivity. To obtain a reliable signal regarding the measurement of the radiation that passed to the receiving window of the sensitive photoelectric multiplier, a separate hair was tightly wrapped with a rubber seal. Studies were performed in no less than tenfold repetition [18; 19].

The data of the experimental study of the light conductivity of individual wools were conducted based on the use of methods and means of fibre optics. At present, fibre optics for transmitting information over long distances is widely developed. Developed methods for calculating fibre optics [18; 19]. To find the energy of the spectrum of optical radiation affecting the body of animals through the wool cover, it is possible to use such approaches, but with certain limitations.

The optical fibre is a long cylinder with an outer coating with a high refractive index and a core transparent to optical radiation.

The main parameter characterising the efficiency of optical energy propagation in optical fibres is the spectral coefficient of light conductivity, which is determined according to the following correlation:

$$\tau = \frac{\Phi_{\lambda}}{\Phi_{\lambda 0}}\,, \tag{1}$$

where Φ_{λ} and $\Phi_{\lambda 0}$ are optical energy fluxes with a wavelength, respectively, passing inside the cylinder through the light guide and the flux falling on the surface of its cylinder from the outside.

Passing through a material medium, the intensity of optical radiation always decreases, i.e., a certain amount of it is lost. These losses in the material occur through the scattering and absorption of photons emitted by the molecules of the material structure itself.

As a rule, such losses are divided into losses in the material (substance) itself and light (optical). The more heterogeneous the structure of the light guide, the greater the radiation loss in it.

If one considers a single wool as a light guide of optical radiation, then given the above, the correlation of the transmission coefficient depending on the geometric parameters, the structure of the wool and the structure can be described by the following mathematical expression

$$\tau_0 = \tau_1 \cdot \tau_2 \cdot \tau_3, \tag{2}$$

where τ_1 is the geometric transmission coefficient, which determines the effective light transmission inside the wool cylinder.

$$\tau_1 = \frac{sin^2\psi_0}{sin^2\psi_1} \tag{3}$$

where Ψ_0 is the limiting angle of incidence of the beam on the surface of the wool, at which such a beam completely penetrates inside; Ψ_1 is the angle at which the beam is completely reflected from the surface of the animal's fur at the point of its incidence.

$$sin\psi_1 = \frac{S_0}{\sqrt{1 - L^2 \cdot D^{-2}}} \tag{4}$$

where S_0 is the area of the wool surface that is irradiated at the point of incidence of the beam itself; L is the length of the light-conducting wool particle; D is the cross-sectional diameter of the wool.

The coefficient τ_2, which characterises the weakening (scattering) of internal light transmission on the cellular structures of wool:

$$\tau_2 = 10^{-\varepsilon \cdot P}, \tag{5}$$

where ε is an indicator showing the absorption of radiation by the wool material; P is the beam path length inside the wool when it is repeatedly reflected inside the cylinder.

$$P = L \cdot sec\psi_1 = \frac{L}{\sqrt{1 - sin^2\psi_1 \cdot n_c^{-2}}} \tag{6}$$

where n_c is an indicator showing the angle of refraction of the beam that falls in the middle of the wool cylinder; L is the length of the light-conducting part of the hair.

The coefficient τ_3, which characterises the loss of light transmission inside the wool cylinder by scattering the beam itself in its internal structures:

$$\tau_3 = \rho_r^{\eta}, \tag{7}$$

where ρ_r is the coefficient characterising the single reflection of the beam from the inner surface of the wool; η is the number of reflections on single internal structures of the wool material.

If there is a core in the hair, which is observed in many species and breeds of animals, such number of reflections will be determined according to the following correlation:

$$\eta = L \cdot {D_c}^{-1} \cdot tg\psi_0 = \frac{L \cdot sin\psi_1}{D_c \cdot \sqrt{{n_c}^2 - sin^2\psi_1}} \tag{8}$$

where n_c is an indicator that characterises the angle of refraction of the incident beam; D_c is the cross-sectional diameter of the wool core.

Considering the above, the loss of light transmission of the core in the wool can be determined according to the following correlation:

$$\tau_3 = \rho_{\text{в}}^{\frac{L \cdot sin\psi_1}{D_c \cdot \sqrt{{n_c}^2 - sin^2\psi_1}}} \tag{9}$$

Having found the light transmittance components of an individual hair, it is possible to find the total light transmittance according to the following correlation:

$$\tau_0 = \tau_1 \cdot \tau_2 \cdot \tau_3 = \frac{sin^2\psi_0}{sin^2\psi_1} \cdot 10^{-\varepsilon P} \cdot \rho_{\text{в}}^{\frac{L \cdot sin\psi_1}{\sqrt{{n_c}^2 - sin^2\psi_1}}} \tag{10}$$

Thus, expression 10 shows that the amount of optical radiation energy entering the skin through a cylinder of individual wool depends on the angle of incidence of the beam on the surface of the wool, the transparency of the internal structure of its cylinder, the length of the light-conducting part and the refractive index of its outer shell.

Notably, the above correlation characterises the light conductivity of wool of a simple structure and comprises a light-conducting core and a protective cladding. In real conditions, especially in winter, in most animals, the formation of the axial core (brain) is observed inside the hair. Therefore, in the case under study, it is better to consider the wool as a fibre optic cable made of three coaxial cylinders. Furthermore, the inner cylinders will also be light conducting with different transmission coefficients (Fig. 1).

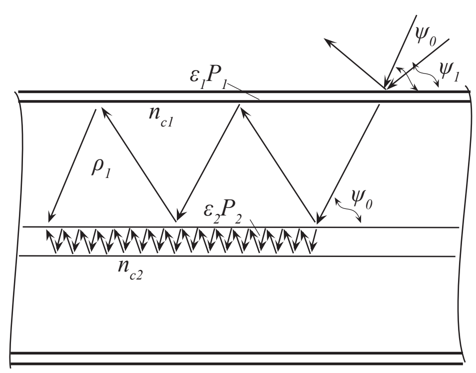

Figure 1. Schematic representation of optical radiation propagating inside a cored hair

The light conductivity of such wool will be determined by the product of the light conductivities of the "brain" core and the inner cylinder:

$$\tau = \tau_{01} \cdot \tau_{02} = \frac{sin^2\psi_0}{sin^2\psi_1} 10^{-\varepsilon_1 \cdot P_1} \cdot \rho_{\text{в}}^{\frac{L \cdot sin\psi_1}{D_c \cdot \sqrt{{n_{c1}}^2 - sin^2\psi_1}}} \times$$
$$\times \frac{sin^2{\psi_0}'}{sin^2{\psi_1}'} \cdot 10^{-\varepsilon_2 P_2} \cdot \rho_{\text{в}}^{\frac{Lsin{\psi_1}'}{D_c \cdot \sqrt{{n_{c2}}^2 - sin^2\psi_1}}} \tag{11}$$

The determination of the total light transmission coefficient of individual hairs can be performed according to the correlation (11), while this correlation is inherent in determination under the condition of conducting research on the primary mechanism of action of optical radiation that enters the follicles through these hairs.

In the conditions of the industrial use of optical radiation in the cultivation of biological objects of animal origin, namely animals and poultry, in the case when the entire skin and fur cover is exposed to radiation, then in this case it is appropriate to use simplified calculations.

Losses in the optical path comprise losses that occur at the interface between the cladding and the core. If the beam of optical radiation is of sufficient intensity I_{e0}, then in this case, the light intensity I_{el}, which propagates at a distance l from the entry point (according to the Bouguer-Lambert-Behr law), is determined according to the following correlation:

$$I_{el} = I_{e0}\, e^{-\alpha_l \cdot l} \tag{12}$$

where l is the distance from the point of incidence of the optical beam to the point from which energy is measured in the light guide; $\alpha_l – \alpha_s + \alpha_a$ is an indicator that represents attenuation during radiation in the light guide; α_s is an indicator that factors in attenuation by scattering the energy of the beam from the outside through the cladding; α_a is the rate of attenuation of the incident energy inside the light guide by its absorption.

Given that the hair is fixed in the skin at one end (follicle), and its length and diameter increase with the age of the animal, in this case, the practical interest lies only in the determination of the radiation energy that is scattered in the thickness of its skin along the entire length of the hair before it will come out of the follicle.

Such radiation, which passed through the hair cylinder into the follicle, is scattered through its spherical surface in the thickness of the skin and takes part in photobiological reactions, can be determined from the following correlation:

$$dI_s(l)=I_e(l)\cdot\alpha_s\cdot dl=I_{e0}\,e^{-\alpha_t\cdot l}\cdot\alpha_s\cdot dl \tag{13}$$

where $dI_s(l)$ is the intensity of optical radiation, which is scattered over a length dl along the surface of the wool at a distance l from the point of entry of the radiation into the cylinder of the wool.

The spectral intensity of radiation absorption along the entire length of the wool cylinder can be written as follows:

$$I_e(l,\gamma)=I_{e0}(\gamma)\cdot e^{-\alpha_t(\gamma)\cdot l} \tag{14}$$

The intensity of radiation scattering by hair into the skin environment is determined from the following correlation:

$$I_{s(l_2-l_1)\gamma}=I_{e0}(\gamma)\cdot\frac{\alpha_s(\gamma)}{\alpha_t(\gamma)}\left(1-e^{-\alpha_t(\gamma)\cdot(l_2-l_1)}\right), \tag{15}$$

and accordingly, the very intensity of radiation absorption by hair in the depth of the skin is determined by the following correlation:

$$I_{\alpha(l_2-l_1)\gamma}=I_{e0}(\gamma)\cdot\frac{\alpha_\alpha(\gamma)}{\alpha_t(\gamma)}\left(1-e^{-\alpha_t(\gamma)\cdot(l_2-l_1)}\right). \tag{16}$$

The correlations (14), (15), (16) describe the spectral light-conducting properties of hair and their distribution of radiation energy along its entire length from the point of penetration into the hair to the follicle and in the depth of the animal's skin.

RESULTS AND DISCUSSION

Experimental studies, as mentioned above, were carried out on the original setup. The results of the conducted experimental studies to determine the transmission efficiency of monochromatic laser radiation (with a wavelength of 445 nm) depending on the place of incidence of the laser beam on the surface of the fur along the entire length of the hair are presented in Figure 2 [20].

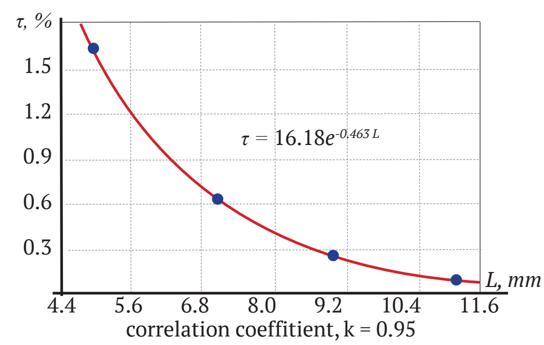

Figure 2. Experimental and mathematical correlation of the light conductivity of a single bristle on its length towards radiation and perpendicular to its side surface [20]

Figure 2 shows that the process of propagation of optical radiation inside the cylinder of individual hair has an exponential form, which indicates a complex non-linear biological structure of the cylinder core. Similar studies were conducted with the optical radiation of lasers of 630 and 532 nanometres. To find the correlation of the light transmission of a hair and the diameter of its cylinder, the study used hair from various parts of the animal's body, as well as from animals of the same breed and of different ages. As an example, the spatial image of optical radiation inside the cylinder of an individual hair depending on the wavelength of optical radiation λ and the length of the light-conducting part of the hair L is presented in Figure 3.

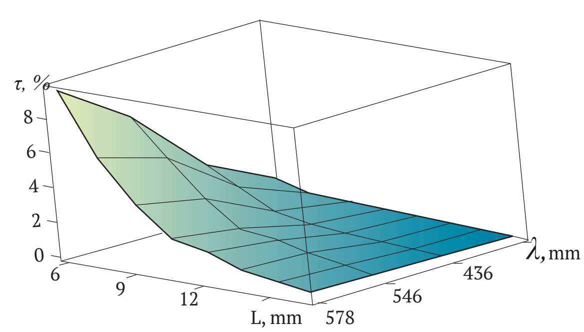

Figure 3. Expanded spatial picture of the correlation of the light conductivity of a hair on its spectral composition of optical radiation and the length of the light-conducting particle (distance to its skin) [9; 20]

The obtained results confirmed the hypothesis of some authors [8; 11; 21;22] that the fur coat of animals not only protects them from the harmful effects of the external environment but can also be a regulator of this effect. The exponential nature of the obtained correlations corresponds to the biological laws of nature and partially confirms their probability and reliability.

CONCLUSIONS

1. When studying the effectiveness of the penetration of optical radiation under the skin of a biological object of an animal origin along separate hairs, like a bundle of light guides, it is advisable to use the known laws of fibre optics in calculations and research.

2.It was experimentally established and theoretically substantiated that the light-conducting capacity of a single hair increases with the increase in the wavelength of the spectrum of optical radiation, i.e., infrared radiation has a higher penetrating power than ultraviolet radiation.

3. The closer the beam of radiant light falls on the surface of the hair to the growth area of the individual hair from the surface of the skin of the biological object of animal origin, the more optical energy will flow through the cylinder of the hair to its follicle under the skin. Thus, optical energy enters directly into the perifollicular environment of the skin, saturated with cells of nerve endings and blood capillaries. Such energy takes part in photobiological processes much more effectively than the energy that enters directly through the surface of the skin between the hairs.

4. Explanation and substantiation of the mechanism of the propagation of optical radiation energy inside the cylinder of a single individual hair is of scientific and practical importance in biological studies of the role of the skin and hair of biological objects of animal origin in their life and development and in the further study of the ways and mechanism of the influence of optical radiation energy on them, as well as for the possibility of effective dosing of optical irradiation of animals and poultry that are grown on large farms with a lack of sunlight.

REFERENCES

[1] Cooper, C.E., & Withers, P.C. (2008). Animal physiology. In *Encyclopedia of ecology* (pp. 228-237). Amsterdam: Elsevier.

[2] Lundsgaard, N.U., Cramp, R.L., & Franklin, C.E. (2021). Ultraviolet-B irradiance and cumulative dose combine to determine performance and survival. *Journal of Photochemistry and Photobiology B: Biology*, 222, article number 112276.

[3] Sousa, A.P.C., Gurgel, C.A., Ramos, E.A.G., Trindade, R.F., Valverde, L.F., Carneiro, T.S., Cangussú, M.C.T., Pinheiro, A.L.B., & Santos, J.N. (2014). Infrared LED light therapy influences the expression of fibronectin and tenascin in skin wounds of malnourished rats – A preliminary study. *Acta Histochemica*, 116(7), 1185-1191.

[4] Middelburg, T.A., de Bruijnb, H.S., van der Ploeg, A., Neumann, H.A.M., & Robinson, D.J. (2013). The effect of light fractionation with a 2-h dark interval on the efficacy of topical hexyl-aminolevulinate photodynamic therapy in normal mouse skin. *Photodiagnosis and Photodynamic Therapy*, 10(4), 703-709.

[5] Munem, M., Djuphammar, A., Sjölander, L., Hagvall, L., & Malmberg, P. (2021). Animal – free skin permeation analysis using mass spectrometry imaging. *Toxicology in Vitro*, 71, 245-251.

[6] Kim, C.-H., Cheong, K.A., & Lee, A.-Y. (2013). 850 nm light-emitting-diode phototherapy plus low-dose tacrolimus (FK-506) as combination therapy in the treatment of dermatophagoides farinae-induced atopic dermatitis-like skin lesions in NC/Nga mice. *Journal of Dermatological Science*, 72(2), 142-148.

[7] Dimaki, A., Kyriazi M., Leonis, G., Sfiniadakis, I., Theodoros, G., Papaioannou, E., Vassilios, I., & Rallis, R.M. (2019). Diabetic skin and UV light: Protection by antioxidants. *European Journal of Pharmaceutical Sciences*, 127, 1-8.

[8] Li, J., Shaoab, Y., Chenc, X., Wangab, X., Wangab, Q., Wangd, Y, Zhue, Y., Yua, H., Hanab, L., & Tianab, F. (2022). Dual-excitation red-emissive carbon dots excited by ultraviolet light for the mitochondria-targetable imaging and monitoring of biological process in living cells. *Journal of Photochemistry and Photobiology A: Chemistry*, 425, 15-23.

[9] Akhtar, S., Smedowskic, A., Masmalib, A. Alkanaanb, A., Khan, A.A., Almutle, E., Mofty, H.K., Al-Debasi, H.I., Samivel, R., & Almubrad, T. (2022). Effect of Ultraviolet-A and Riboflavin treatment on the architecture of the center and periphery of normal rat cornea: 7 days post treatment. *Experimental Eye Research*, 219, article number 109064.

[10] Maliszewska, I., & Goldeman, W. (2021). Pentamidine enhances photosensitization of Acinetobacter baumannii using diode lasers with emission of light at wavelength of λ=405 nm and λ=635 nm. *Photodiagnosis and Photodynamic Therapy*, 34, 12-21.

[11] Ivanov, V.V., Tyunina, P.S., & Savinova, M.S. (1967). Research of the permeability of the bristles of pigs of different ages to ultraviolet rays. *Bulletin of Yakutsk State University*, 7, 89-94.

[12] Butov, G.P. (1980). Optical properties of wool, feather and skin covers of animals and poultry. *Gorki, Automation and Electrification of Agricultural Production*, 63, 68-72.

[13] Graeme, E. (2021). Glass photobiomodulation: A review of the molecular evidence for low level light therapy. *Journal of Plastic, Reconstructive & Aesthetic Surgery*, 74(5), 1050-1060.

[14] Nakashima, Y., Ohta, S., & Wolf, M. (2017). Blue light-induced oxidative stress in live skin free radical. *Biology and Medicine*, 108, 300-310.

[15] Pavlov, V.F., & Melnik, I.L. (1963). Penetration of ultraviolet rays through the wool into the body of cattle and horses. In *Use of ultraviolet radiation in animal husbandry* (pp. 91-95). Moscow: Publishing House of the Academy of Sciences of the USSR.

[16] Park, I.-S., Mondal, A., Chung, P.-S., & Ahn, J.C. (2015). Prevention of skin flap necrosis by use of adipose-derived stromal cells with light-emitting diode phototherapy. *Cytotherapy*, 17(3), 283-292.

[17] Weihrauch, D., Keszler, A., Lindemer, B., Krolikowski, J., & Nicole, L. (2021). Lohr red light stimulates vasodilation through extracellular vesicle trafficking. *Journal of Photochemistry and Photobiology, B: Biology*, 220, 354-364.

[18] Chervinsky, L.S. (2020). The ways and effects of ultraviolet radiation on the human and animal body. *Tissue Optics and Photonics*, 11363, article number 113630I. doi: 10.1117/12.2552719.

[19] Sattarov, D.S. (1973). *Fiber optics*. Leningrad: Mechanical Engineering.

[20] Chervinsky, L.S. (2018). Rationale and definition of the criteria of the efficiency of the biological activity of optical radiation on animal organism. *Korean Journal of Food & Health Convergence*, 4(3), 1-5.

[21] Ripoll, J., & Ntziachristos, V. (2011). Light, sound, chemistry… action: State of the art optical methods for animal imaging Drug. *Discovery Today: Technologies*, 8(2-4), e79-e86.

[22] Bobyr, S. (2021). Theoretical Aspects of Hydrogen Diffusion in Metals. *Scientific Herald of Uzhhorod University. Series "Physics"*, (50), 31-38.

СПИСОК ВИКОРИСТАНИХ ДЖЕРЕЛ

[1] Cooper C.E., Withers P.C. Encyclopedia of ecology. *Animal physiology*. Amsterdam: Elsevier, 2008. P. 228–237.

[2] Lundsgaard N.U., Cramp R.L., Franklin C.E. Ultraviolet-B irradiance and cumulative dose combine to determine performance and survival. *Journal of Photochemistry and Photobiology B: Biology*. 2021. Vol. 222. Article number 112276.

[3] Infrared LED light therapy influences the expression of fibronectin and tenascin in skin wounds of malnourished rats – A preliminary study / A.P.C. Sousa, et al. *Acta Histochemica*. 2014. Vol. 116, No. 7. P. 1185–1191.

[4] The effect of light fractionation with a 2-h dark interval on the efficacy of topical hexyl-aminolevulinate photodynamic therapy in normal mouse skin / T.A. Middelburg et al. *Photodiagnosis and Photodynamic Therapy*. 2013. Vol. 10, No. 4. P. 703–709.

[5] Animal – free skin permeation analysis using mass spectrometry imaging / M. Munem et al. *Toxicology in Vitro*. Vol. 71. 2021. P. 245–251.

[6] Kim C.-H., Cheong K.A., Lee A.-Y. 850 nm light-emitting-diode phototherapy plus low-dose tacrolimus (FK-506) as combination therapy in the treatment of dermatophagoides farinae-induced atopic dermatitis-like skin lesions in NC/Nga mice. *Journal of Dermatological Science*. 2013. Vol. 72, No. 2. P. 142–148.

[7] Diabetic skin and UV light: Protection by antioxidants / A. Dimaki, et al. *European Journal of Pharmaceutical Sciences*. 2019. Vol. 127. P. 1–8.

[8] Dual-excitation red-emissive carbon dots excited by ultraviolet light for the mitochondria-targetable imaging and monitoring of biological process in living cells / J. Li et al. *Journal of Photochemistry and Photobiology A: Chemistry*. 2022. Vol. 425. P. 15–23.

[9] Effect of Ultraviolet-A and Riboflavin treatment on the architecture of the center and periphery of normal rat cornea: 7 days post treatment / S. Akhtar et al. *Experimental Eye Research*. 2022. Vol. 219. Article number 109064.

[10] Maliszewska I., Goldeman W. Pentamidine enhances photosensitization of Acinetobacter baumannii using diode lasers with emission of light at wavelength of λ=405 nm and λ=635 nm. *Photodiagnosis and Photodynamic Therapy*. 2021. Vol. 34. P. 12–21.

[11] Іванов В.В., Тюніна П.С., Савінова М.С. Дослідження проникнення щетини свиней різного віку для ультрафіолетових змін. *Вісник Якутського державного університету*. 1967. № 7. С. 89–94.

[12] Бутов Г.П. Оптические свойства шерстяного, перьевого и кожного покровов животных и птицы. *Автоматизация и электрификация сельскохозяйственного производства*. 1980. № 63. С. 68–72.

[13] Graeme E. Glass photobiomodulation: A review of the molecular evidence for low level light therapy. *Journal of Plastic, Reconstructive & Aesthetic Surgery*. 2021. Vol. 74, No. 5. P. 1050–1060.

[14] Nakashima Y., Ohta S., Alexander M. Wolf Blue light-induced oxidative stress in live skin Free Radical. *Biology and Medicine*. 2017. Vol. 108. P. 300–310.

[15] Павлов В.Ф., Мельник І.Л. Проникнення ультрафіолетових променів через шерсть в організм великої рогатої худоби і коней. *Використання ультрафіолетового випромінювання в тваринництві*. Київ: Видавництво АН УРСР, 1963. С. 91–95.

[16] Prevention of skin flap necrosis by use of adipose-derived stromal cells with light-emitting diode phototherapy / I.S. Park et al. *Cytotherapy*. 2015. Vol. 17, No. 3. P. 283–292.

[17] Red light stimulates vasodilation through extracellular vesicle trafficking / D. Weihrauch, et al. *Journal of Photochemistry and Photobiology B: Biology*. 2021. Vol. 220. P. 354–364.

[18] Chervinsky, L.S. (2020). The ways and effects of ultraviolet radiation on the human and animal body. *Tissue Optics and Photonics*, 11363, article number 113630I. doi: 10.1117/12.2552719

[19] Саттаров Д.С. Волоконна оптика. Ленинград: Машиностроитель, 1973. 254 с.

[20] Chervinsky L.S. Rationale and definition of the criteria of the efficiency of the biological activity of optical radiation on animal organism. *Korean Journal of Food & Health Convergence*. 2018. Vol. 4, No. 3. P. 1–5.
[21] Ripoll J., Ntziachristos V. Light, sound, chemistry… action: state of the art optical methods for animal imaging. *Drug. Discovery Today: Technologies*. 2011. Vol. 8, No. 2–4. P. e79–e86.
[22] Bobyr, S. (2021). Theoretical Aspects of Hydrogen Diffusion in Metals. *Scientific Herald of Uzhhorod University. Series "Physics"*. 2021. Vol 50. P. 31-38.

Леонід Степанович Червінський, Іван Петрович Радько,
Віталій Адамович Наливайко, Олександр Володимирович Окушко

Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна

Результати експериментальних досліджень проходження енергії світла під шкіру тварин по окремим шерстинам

Анотація. В статті наведено нові наукові результати експериментальних досліджень, які спростовують загально прийнятий факт вважати, що шерстинний покрив лише захищає тварини від впливу енергії Сонця. Метою даних досліджень є підтвердження факту поширення енергії оптичного випромінювання під шкіру тварини по окремим шерстинам, як світлопроводах. Експериментально визначено оптичнопровідну структуру окремої шерстини, складові параметра пропускання окремо взятої шерстяної волосини, а саме коефіцієнт світлопропускання усередину шерстяної волосини, коефіцієнт послаблення внутрішнього світлопропускання речовиною шерстяної волосини, коефіцієнт втрат в середині циліндру шерстяної волосини за рахунок променю, що розсіюється у внутрішній структурі і коефіцієнту заломлення її зовнішньої оболонки. На основі використання методів фотометрії та геометричної оптики теоретично обґрунтовано і експериментально отримано результати щодо встановлення математичної залежності загальної величини енергії оптичного випромінювання, що надходить по циліндру шерстинки від значення кута падіння променю на поверхню шерстинки, чистоти внутрішнього осердя структури циліндру, довжини світлопровідної ділянки до поверхні шкіри, а також коефіцієнту заломлення її зовнішньої оболонки. На основі результатів експериментальних досліджень отримано математичні залежності, що описують спектральні світло провідні властивості окремої шерстинки, а також розподіл енергії, що випромінюється в товщі шкіри по всій довжині від місця проникнення у шерстинку і до фолікули – місця використання оптичної енергії в фотобіологічних процесах. Отримані результати експериментальних досліджень проходження енергії оптичного випромінювання по довжині окремої шерстинки в тіло тварини, мають важливе практичне значення для фотобіологів, що досліджують дію оптичного випромінювання Сонця на біологічні об’єкти тваринного походження

Ключові слова: сонячна енергія, опромінення тварин, шкіряно-шерстинний покрив, світлопропускання, шерстинка