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Passive protection capabilities of selected sunscreen materials against the carcinogenic UV-solar radiation

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The extinction coefficient of various materials and industrial products used most frequently in practice as the measure of the passive protection capability against the UV-solar carcinogenesis in humans has been measured in the whole ultraviolet wavelength spectrum range 200–400 nm. The measured data were correlated at the most dangerous carcinoma wavelength $\lambda = 300$ nm, where the carcinoma action spectrum has its maximum.

1. Introduction

Ultraviolet radiation of the sun is the predominant factor causing the skin cancer in humans. Besides the skin cancer, also other diseases can result from the UV-irradiation, such as cataract, elastosis, erythema, photokeratitis, conjunctivitis, *etc.* Repeated small doses of UV-irradiation can cause cutaneous desquamation, associated with the decrease of the stratum corneum layers and loss of the transepidermal water, leading to the rapid photoaging. Now, harmful effects of the UV-irradiation on plants, plankton and various industrial products are being studied [1]–[3].

Two basic forms of the cutaneous cancer predominate: the squamous and the basal cell carcinomas. The solar ultraviolet radiation produces 90% of the carcinomas of these two types, but only 7% of the skin carcinoma of the melanoma type. The melanoma carcinoma, however, is the most dangereous, causing 80% of death of the skin cancer.

The rate of the skin cancer occurrence has been increasing dramatically from year to year. For example, in the Czech Republic, a 2% annual increase of the new cases has been reported. The skin cancer has occurred most frequently (about 15%) besides the lung cancer in men and the breast cancer in women. The annual costs of treatment of the cancer diseases are estimated at 8.3 milliard Kc. In other countries, the situation is similar. The skin cancer is also the most common type of cancer in the USA, with more than 500,000 new cases recorded each year [4], [5].

The most effective wavelengths causing the solar carcinogenesis lie in the vicinity of the wavelength $\lambda = 300$ nm, where the carcinoma action spectrum has its maximum. Most researchers suppose that the curve of the action spectrum is very similar to that of the ultraviolet erythema. From $\lambda = 300$ nm upwards, the curve of the carcinoma action spectrum sharply decreases so that the probability of inducing the skin cancer lesion is very small. The carcinogenesis effect of the shorter wavelengths lying below $\lambda = 300$ nm is still not clear and is under the intensive discussion [6].

Both ultraviolet B (290–320 nm) and A (320–400 nm) solar radiations reach the surface of the Earth, while the ultraviolet C (200–290 nm) is fully filtered out by the ozone layer surrounding the Earth. The maximum ozone concentration is at the altitude of 20–25 km and reaches approx. 500 $\mu g/m^3$. At the Earth's surface the atmospheric interaction with the radiance reflected from the surface must be considered. This interaction depends on the aerosol concentration, solar zenith angle, velocity and direction of the wind, temperature and pressure, the type of vegetation, soil, desert sand, water and snow. The scattering of the solar ultraviolet radiation caused by air molecules and clouds represents a very complicated mathematical problem. The radiation of the daylight is polarized.

Since 1933, when the first research laboratory experiments confirming the induction of the ultraviolet solar carcinogenesis in hairless mices were made [7], several effective protection means have been designed, such as ultraviolet-B absorbing sunscreens, some dietary foods, enriched with vitamin C, retinoids, *etc.* Some clothing and glass products are also sufficient protective materials against the dangerous solar ultraviolet irradiation. This paper presents the results of the measurement of the extinction coefficient of various selected materials often used in practice in the whole ultraviolet spectral band. The emphasis is put on the protection capability of these materials against the harmful solar ultraviolet radiation.

2. Measurement of the ultraviolet extinction coefficient

The extinction coefficients of various selected materials in the whole ultraviolet spectrum, ranging from 200 to 400 nm, were measured.

The measuring set-up is shown schematically in Fig. 1. The optical source was the Tesla mercury-arc Hg-75 W lamp with the discrete ultraviolet emission spectrum of 200–400 nm. The peak emission $I_{0\max} = 100\%$ (= 273 $\mu W/cm^2$) was at the wavelength $\lambda_0 = 369$ nm. The boundary spectral wavelengths were $\lambda_a = 196$ nm and $\lambda_b = 403$ nm with the intensities $I_a = 41\%$ and $I_b = 96\%$, respectively. The radiation wavelengths and intensities in the ultraviolet spectral band were $\lambda_1 = \lambda_a$, $\lambda_2 = 228$ nm, $\lambda_3 = 254$ nm, $\lambda_4 = 278$ nm, $\lambda_5 = 302$ nm, $\lambda_6 = 330$ nm, $\lambda_7 = \lambda_0$, $\lambda_8 = \lambda_b$, $I_1 = I_a$, $I_2 = 45\%$, $I_3 = 96\%$, $I_4 = 76\%$, $I_5 = 91\%$, $I_6 = 84\%$, $I_7 = I_{0\max}$ $I_8 = I_b$, respectively (see Fig. 2). The lamp thermal radiation of the visible and near infrared wavelengths was filtered out by means of the filter (FT). The grating spectrophotometer SPM–2 (SP) was used for separation of the different spectral lines

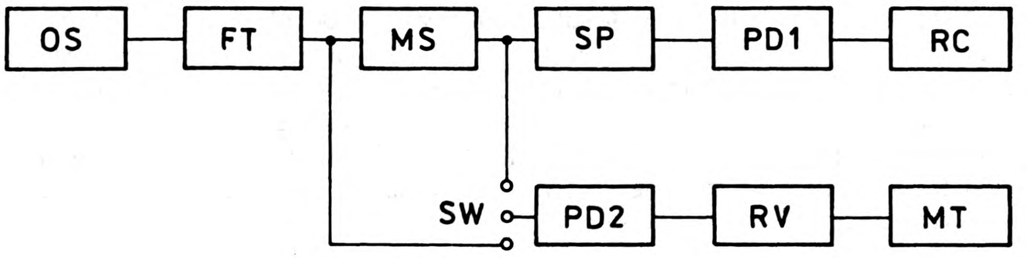

Fig. 1. Scheme of the measuring set-up. OS — optical source, FT — optical filter, MS — measured sample, SP — spectrophotometer, SW — electrical switch, PD — photodetector, RV — radio voltmeter, RC — recorder, MT — monitor

of the lamp. The blaze grating had 1302 lines/mm. The measuring bandwidth was 200–610 nm. The spectrophotometer spectral bandwidth was 2 nm. In order to make the spectrophotometer entrance slit width the same as during calibration, it was necessary to attenuate the light from the lamp by a neutral density filter whose spectral transmittance curve was accurately known. Two photodetection systems were used for detection of the beams being measured. The main detection system (PD1) used the sensitive lock-in nanovoltmeter amplifier. A low-noise active-elements preamplifier was connected to the photomultiplier input with a frequency response at short wavelengths. The beam splitter reflected a portion of the incoming radiation to the monitor using the other detection system (PD2) with a silicon photodetector. The recorded signals were corrected for the reflectance of the mirrors and the transmittance of the filters. The ratio of the corrected signal to the corresponding spectral radiance of the lamp gave the relative spectral response of the measuring system at the given wavelengths, needed for the evaluation of the extinction coefficient.

The extinction coefficients of the selected materials and industrial products were measured in the ultraviolet wavelength spectrum range shown in Fig. 2. The extinction coefficient a is given by

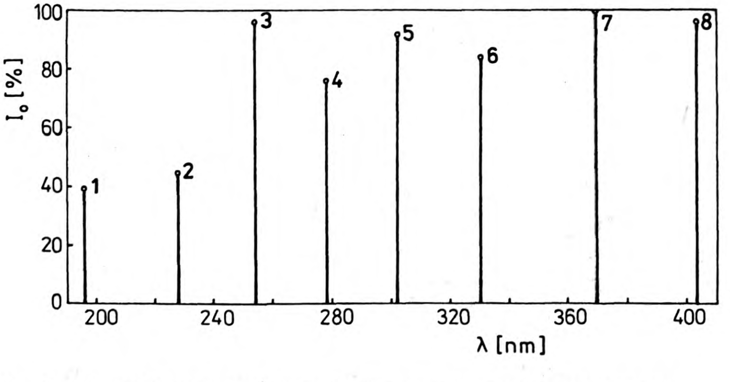

Fig. 2. Ultraviolet spectral lines in the experimental measurement

$$a = 1/d \lg(I_0/I)$$

where d is the length of the optical path of the measured sample, and I_0 and I are the incident and outcoming light intensities, respectively. The measuring error was less than 5%, in the whole spectral range considered. Nevertheless, the measured values of the extinction coefficients may differ due to the various chemical composition of products resulting from application of different methods of processing. Silica-glass cuvettes of various lengths were used for the measurement of the liquids and sunscreen creams.

3. Protection-absorption capabilities of various materials and products

Various representative materials and industrial products were gathered in the following five groups. The first group includes ordinary window glass, silica glass, optoelectronic fused-silica glass, Perspex, and plastic foil. The representative materials of the second group are the ordinary and photochromatic glasses, contact lenses, and welding safety glasses (with blue and green filters). The third group comprises the cloth-fibre materials, such as wool, cotton, silk, nylon, and the semiartificial plastic material "Tesil". In the fourth group the following liquids were chosen: distilled water, petrol, acetone, paraffin oil, and industrial alcohol. The fifth group comprises several cosmetic creams known under their trade names as Moisture Balance Cream, Night Cream, Eye Cream, Colla Cream (with ultraviolet filter), and Miami Gold Cream (Factor 12).

The measured extinction coefficients of these materials in the whole ultraviolet wavelength spectrum are shown in Figs. 3–7. The attenuation of industrial products made of these materials at the most dangerous ultraviolet carcinoma wavelength $\lambda = 300$ nm is summarized in Fig. 8.

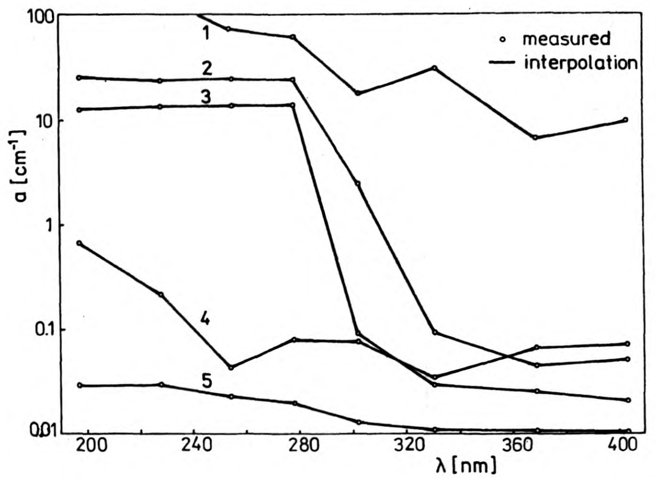

Fig. 3. Curves representing the extinction coefficients in the ultraviolet spectral waveband. 1 – plastic foil, 2 – window glass, 3 – Perspex, 4 – ordinary silica glass, 5 – optoelectronic fused-silica glass

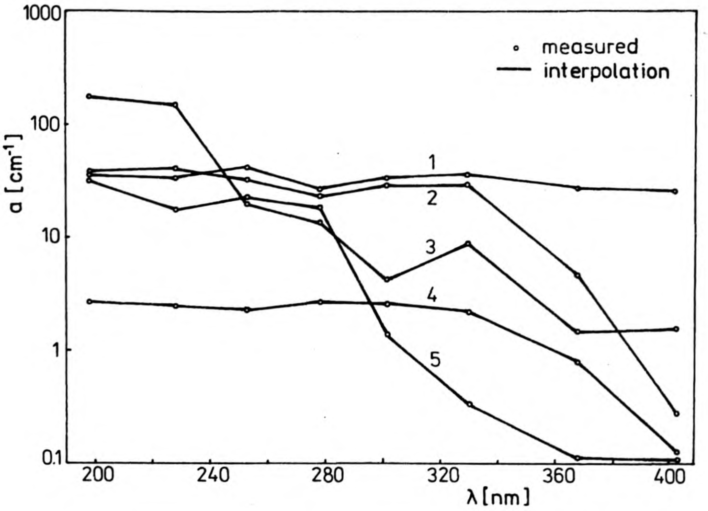

Fig. 4. Curves representing the extinction coefficients in the ultraviolet spectral waveband. 1 — welding safety glasses with a green filter, 2 — welding safety glasses with a blue filter, 3 — contact lens, 4 — photochromatic glasses, 5 — ordinary glasses

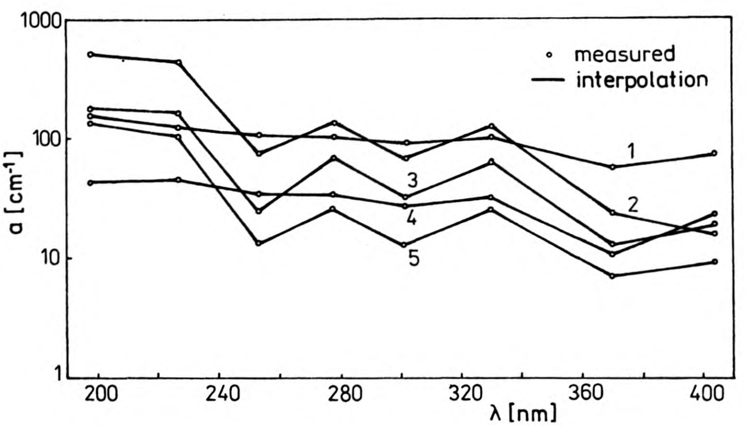

Fig. 5. Curves representing the extinction coefficients in the ultraviolet spectral waveband. 1 — semiartificial material "Tesil", 2 — silk, 3 — cotton, 4 — wool, 5 — nylon

4. Discussion and conclusions

The carcinogenesis protection capabilities of the sunscreen materials and products depend on their inherent absorption and thickness. The absorption is given by the chemical composition of the material. It usually varies with the changing wavelength. The optical attenuation depends on the thickness of the material according to the exponential law

$$I = I_0 \exp(-ad).$$

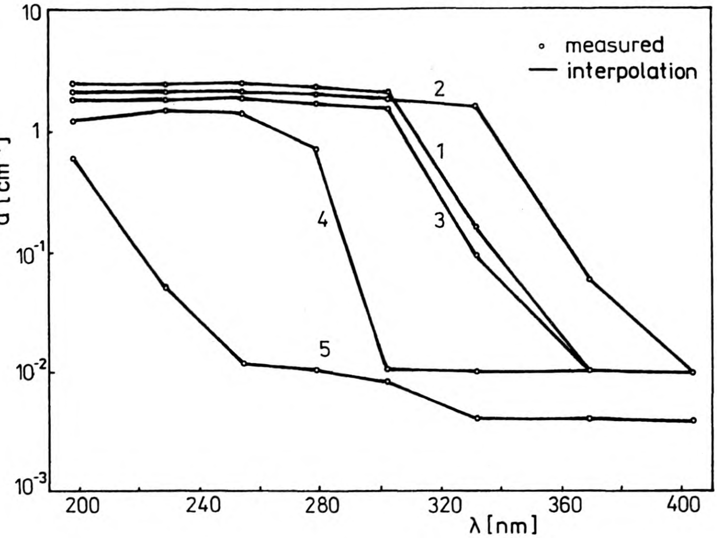

Fig. 6. Curves representing the extinction coefficients in the ultraviolet spectral waveband. 1 – paraffin oil, 2 – petrol, 3 – acetone, 4 – industrial alcohol, 5 – distilled water

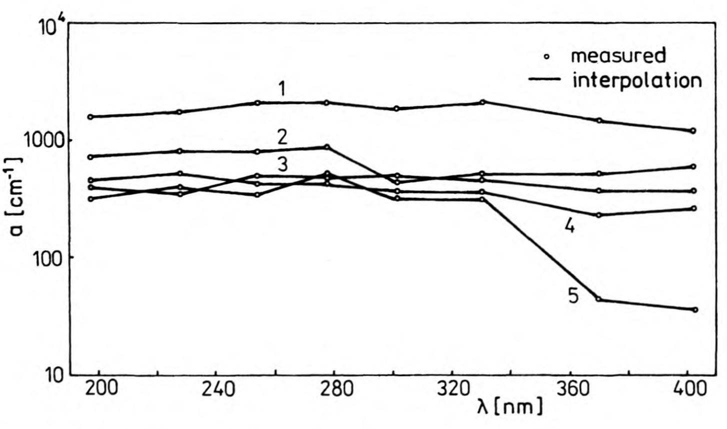

Fig. 7. Curves representing the extinction coefficients in the ultraviolet spectral waveband. 1 Miami Gold Cream (Factor 12), 2 – Eye Cream, 3 – Moisture Balance Cream, 4 – Night Cream, 5 – Colla Cream

It is obvious that the attenuation decreases much more rapidly with d than is the direct proportionality. If, for example, $d = d_0 m$ (d_0 is the original thickness, $m =$ const), the resulting attenuation will be

$$I_m = I_0 \exp(-ad) = I_0 \exp(-amd_0)^m = I_0 \exp(-ad_0)^m.$$

Thus, the protection capabilities of the sunscreen materials increase with the thickness exponent of the original material attenuation. The measured material attenuations increase or are constant with decreasing wavelength (see Figs. 3–7).

The UV-solar carcinogenesis protection effect of the ordinary window glass has been known for a long time [7]. However, the attenuation is much larger at optical

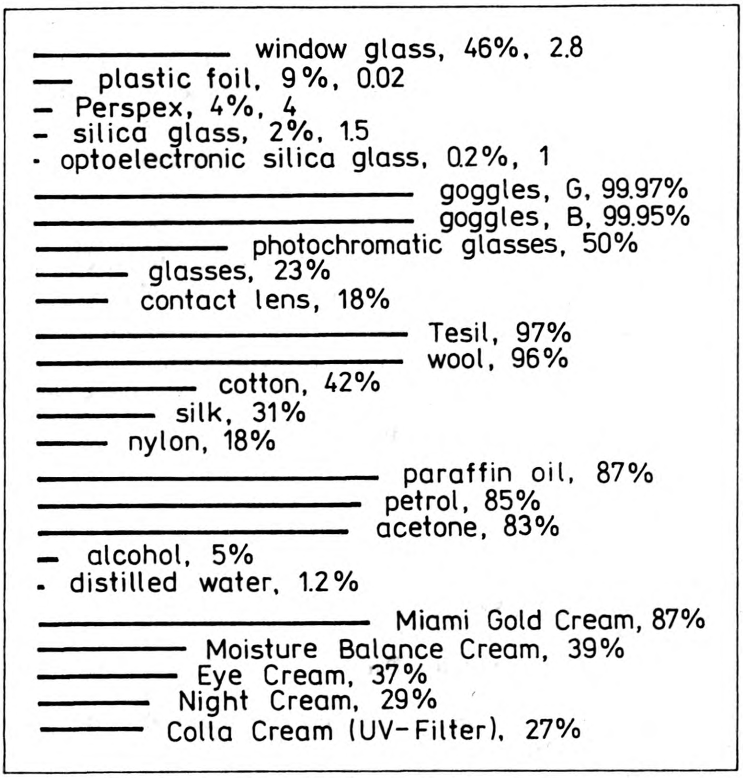

Fig. 8. Optical attenuation of the selected materials and industrial products at the most dangerous skin carcinogenetic wavelength $\lambda = 300$ nm of the ultraviolet waveband. Optical attenuations are in percents, the thickness of the samples in millimetres, G — green filter, B — blue filter, the thickness of the liquid-cuvette is 1 cm, the thickness of the cream-cuvette is 10 μm

wavelengths shorter than $\lambda = 300$ nm (see Fig. 3). Despite of the very high values of the extinction coefficients of the plastic materials at shorter wavelengths, the plastic foils provide the persons with a very bad protection due to their very small thicknesses of only several tens of microns (see Fig. 8). The optoelectronic fused-silica is a very good transparent material at ultraviolet wavelengths.

Although the self-protection effect of the human eyes against the ultraviolet radiation is well known (the eye lens and cornea filter out the light wavelengths of the range 295–400 nm from the incidence on the retina [8]), the malignant tumours of the eyes caused by the ultraviolet irradiation have been observed [9]. According to the measured data, an absolute protection (more than 99% at the wavelength $\lambda = 300$ nm) is perhaps offered by the welding goggles. The photochromatic glasses are protective with 50% efficiency, the ordinary glasses 23%, and the contact lenses – 18%.

The occurrence of the skin cancer prevails in the white population and in the sunbelt countries where the sunscreen protection against the dangerous solar irradiation is of primaty importance. The silk and nylon clothes do not protect very much in comparison with, for example, wool or semiartificial material "Tesil",

"Tesil", having the attenuation above 95%. Among the items of this group, the cotton products occupy a middle position with the attenuation of 42%.

In the fourth group, several liquids most frequently used in practice are included. The highest value of the extinction coefficient was found with the paraffin oil, followed by petrol, acetone and spirit. The distilled water has very low extinction coefficient up to the wavelength $\lambda = 254$ nm.

Nowadays, there is a large variety of the sunscreen creams, offering the protection of the woman skin against the ultraviolet irradiation. Unfortunately, most of them are not wavelength selective and attenuate the solar radiation in the whole optical spectrum. All of the creams measured showed the ultraviolet protection effect. However, only the Colla Cream, declared as the UV-cream, was selective with the very high attenuation at the wavelengths below $\lambda = 330$ nm and very good transparency at the wavelengths above $\lambda = 369$ nm (see Fig. 7).

References

[1] KNESTRICK G. L., CURCIO J. A., Appl. Opt. **9** (1970), 1574.
[2] SHI W., CUI T., SIGEL G. M., SPIE **1422** (1991), 62.
[3] VAN DER LEUN J. C., Photochem. Photobiol. 39 (1984), 861.
[4] FENYJO M., Opt. Laser Technol. **16** (1984), 209.
[5] PARRISH J. A., JAENICKE K. F., Photochem. Photobiol. **37** (1983), 643.
[6] KAIDBEY K. M., NONAKA S., *ibidem* **39** (1984), 375.
[7] ROFFO A. H., Bol. Inst. de Med. Exer. para el estudy y trata del cancer **10** (1933), 417.
[8] DILLON J., Photochem. Photobiol. **47** (1988), 94S.
[9] LEV R. D., APPLEGATE L. A., FRY R. J. M., STUART T. D., *ibidem* 45S.

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