Measurement of Reflection Coefficients of Organic and Non-Organic Media and Materials in UV Spectrum

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ABSTRACT

Measurements of the diffuse reflection coefficients of organic and inorganic materials and media in solid, granular and liquid forms were made in the UV field of 230-400 nm. A single channel spectrometer with an integrating sphere was used. Relation between diffuse reflection coefficients and the structure and composition of the samples is discussed. These data allow us to estimate the prospect of machine vision systems application for the UV range in such areas as biology, geology, remote control of materials and media.

Key words: UV spectrum, integrating sphere, optically dense scattering and absorbing media, organic and inorganic materials, remote sensing methods, machine vision.

1. INTRODUCTION

High level of development of remote sensing methods and tools for study of the atmosphere as an absorbing, reflecting and scattering media allows solving of important industrial problems as well as issues in other spheres of human activities. One of the prospective lines for investigation is customization of methods that apply scattering, reflection and absorption effects for remote sensing of optically dense media. Physically such investigations are based on knowledge of absorption, scattering and reflection spectra of organic and non-organic samples and media. Thus one of the important steps for development of the remote sensing methods is hard research of scattering, reflection and absorption spectra.

In this paper investigation of reflective properties of different materials is described.

2. EXPERIMENTAL PLANT DESCRIPTION

Measurements of diffuse reflection factor have been made using a spectrometer with integrating sphere (Fig.1).

A photometric spherical integrator made by Carl Zeiss Jena Inc. of 110 mm in diameter has been used as an integrating sphere. The sphere had quite a big exit window (about 50 mm) for photocell placement. For improvement of UV range reflective properties of the sphere the exit window was decreased to 5mm using a washer made of ground silica glass. Sample installation window was 30 mm in diameter.

The registered signals had high “signal-noise” ratio (in the range $\lambda=250-300$ nm, at time-averaging of $\sim 1$ second the ratio of PMT dark noise to a signal was less than 1%). In this case the major source of experimental errors was spatial inhomogeneity of reflective properties of the samples and differences in placing the samples to the sphere working site. Possibly some influence was also caused by instability of light source parameters as each measurement session of 30 samples lasted about 3-4 hours. Dispersion of absolute diffuse reflection factors in repeated measurements for wavelength $\lambda=350$ nm reached 7% for samples with high diffuse reflection factor and 20% for samples with low diffuse reflection factor. Thus we suppose that major measurement errors occur due to reference calibration errors.

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3. METHODS AND TECHNIQUE OF REFLECTION COEFFICIENT MEASUREMENTS

Measurements of reflection coefficients using a spectrometer with an integrating sphere require adjustment and calibration of the sphere. In this work we used two reference samples for calibration – an absolutely black body and a white body.

Measurements of reflection coefficients have been made using two methods:

a) “Recording of spectrum of one sample in the whole range”. Three reflection spectra have been recorded consequently in a certain spectral range from $\lambda_1$ to $\lambda_2$: spectra of the “white” body, of the “black” body and of the study sample. Reflection coefficient on the $\lambda_i$ wavelength within the range was calculated using the following formula:

$$K_{\text{sample}} = K_{\text{black}} + (K_{\text{white}} - K_{\text{black}}) \times \frac{(U_{\text{sample}} - U_{\text{black}})}{(U_{\text{sample}} - U_{\text{white}})}$$

where $K_{\text{black}}, K_{\text{white}}, K_{\text{sample}}$ – reflection coefficients of “white” and “black” reference samples and a study sample, $U_{\text{sample}}$ and $U_{\text{white}}$ – signals of “white” reference sample and a study sample calculated from zero signal level. Zero signal level corresponds to automatic recorder indications when the light flux from the lamp is cut off by the blind. Then the measurements were repeated for the next spectral range from $\lambda_2$ to $\lambda_3$ with correction of $U_{\text{white}}$ value, and so on.

b) “Recording” of PMT signals using “white” reference sample $U_{\text{white}}$ and “black” reference sample $U_{\text{black}}$, with monochromator set up on one of UV range wavelengths. These records allowed plotting a calibration curve for this wavelength by two points. Reflecting coefficient of the samples $K_{\text{sample}}$ for this wavelength was a function of value $U_{\text{sample}}$ on the calibrating curve.

4. MEASUREMENTS RESULTS AND DISCUSSION

4.1. Non-transparent and turbid media

Metals are considered to be optically non-transparent medium. Absorption and reflection of light occurs in a very thin surface layer of the metal. Reflection coefficient in this case is mostly dependent on surface roughness and electrical conductivity of the metal.
Optical characteristics of metals are well studied. Optical characteristics of metals at relatively low frequencies (IR rays) are mostly dependent on behavior of unbounded electrons. But when the frequencies change to visible and ultraviolet light, bounded electrons that possess their own frequency in a range of shorter wavelengths start playing a prominent part. Participation of these electrons is responsible for so called non-metallic optical characteristics of the metals. This proves that if the wavelengths are shorter than 400 nm, forced oscillations of bounded electrons in ions that form lattice of the metal (Great Encyclopedia of Oil and Gas http://www.ngpedia.ru/id413104p2.html) start playing essential part in optical characteristics of the metals.

Fig. 2a shows diffuse reflection spectra of some metals and alloys that have been obtained in the present work. Reflection coefficient values for alloys of different metals are quite different depending on alloy composition. Rolled ferrous metal has the least reflection. Aluminum has higher reflection coefficient, over 0.5 within all range under investigation. Mat duralumin (aluminum alloy with 4% of copper) has the highest reflection coefficient of all studied samples. Spectra of pure metals and metal alloys differ in intensity and spectral curve shape.

Water solution with organic impurities has been used as a turbid medium sample. Milk has been chosen as a study object. From the scattering theory viewpoint, milk is a multi-component (water, carbohydrates, fats, protein etc.) highly-scattering medium, turbid in UV range.

Milk contains milk fat in a form of fat blobs of 0.5-10 µm in size, coated by lecithin-protein cover. Covers of fat blobs consist of phospholipid and protein compounds (lipoproteins) and are basically a lecithin-protein complex. Milk fat has an absorption band of 200-300 nm with a wide peak in a range \(\sim 220\text{÷}240\) nm that is caused by conjugated diene bonds [1, 2]. Absorption bands of milk sugar are in ranges of 240÷250 nm and 300÷320 nm [3]. Figure 2b shows milk scattering spectrum that forms a complex waveform. This spectrum conforms well with milk reflection spectra, shown in [2]. Milk spectrum is not monotonous. We can observe correlation between milk reflection spectrum and absorption spectra of milk components – albumin (absorption maximum is on \(\lambda=279.06\) nm), glucose albumin (absorption maximum is on \(\lambda=310.44\) nm), milk fat (220÷240 nm). The albumin absorption spectrum is shown in [5]. The glucose absorption spectrum is shown in [2].

4.2. Biological materials

Wood (spruce, cedar, aspen, birch) has low reflection coefficient that does not exceed 20% and grows up to 30% in a 400 nm range. Aspen bark has nearly the same low reflection coefficient within all the UV range under investigation. Aspen leaves and bark, wood and packaging board have similar reflection bands in a range about 260-280 nm. In this range reflection depends on complex composition of organic substances – chlorophylls, porphyrins, lignin, proteins, nucleobases, etc.
Birch bark reflection in a range of 230 nm is mostly defined by betulin. Content of betulin in birch epiphloem - birchbark makes from 10 to 40% depending on the birch specie, tree origin, age and other conditions [6].

Figure 3 shows reflection spectra of biological materials: figure 3a – green plant leaf, front and back sides; figure 3b – birchbark and aspen bark.

![3a](image1) ![3b](image2)

Fig. 3a. Plant leaf reflection. 1- front side, 2- back side. Fig. 3b. Tree bark reflection. 1 – aspen bark, 2 – birch bark.

4.3. Construction materials.

Figure 4 shows reflection spectra of composite construction materials - silicate and common red brick, concrete, asbestos cement. Composite materials have complicated physicochemical composition. Thus, for example, silicate brick consists of about 90% lime, 10% sand and a small part of admixtures. Red brick is made of clays. Chemical composition of red brick is defined by ratio of different oxides: Al₂O₃, SiO₂, Fe₂O₃, CaO, Na₂O, MgO and K₂O. Admixtures (quartz, mica, feldspars, calcite, magnesite and others) that are components of clay as well as clay minerals are added to decrease brick plasticity. Reflection spectra of construction materials look complicated as they have complex physicochemical composition.

![4a](image3)

Fig 4a. Reflection spectra of construction materials. 1 – silicate brick, 2 – red brick, 3 – concrete, 4 – asbestos cement.
4.4 Minerals

Reflection spectra of mineral samples in solid and free-flowing states have been obtained. The reflection coefficients of mineral samples under investigation are much dependent on wavelengths. Usually minerals contain a certain amount of admixtures, the most common of which are iron, tantalum, niobium, titanium, and manganese. It is generally thought that most of these impurities are contained in minerals in a form of microinclusions. These inclusions are less than 1µm in size, they are semi-transparent, dyed, and they greatly influence on formation of optical characteristics of the metals. Intensive light absorption in UV and neighboring visible spectral ranges is generally connected with these microinclusions [4]. Samples of jadeites and feldspars were studied in a free-flow form. Size of the particles was 1-2mm.

Fig 4b. The reflection spectra of minerals. 1 - quartz, 2 - K-feldspar, 3 - calcium-sodium feldspar (plagioglas), 4 - brown feldspar (dolomite), 5 - jadeite gray-green, 6 - bright green jadeite.

5. CONCLUSION

In this study measurements of reflection coefficients of over 50 samples of different materials are presented. These are surfaces of some metals, needles and leaves of green plants, tree wood and bark, composite construction materials. It is demonstrated that physicochemical construction of matter occurs in reflection and absorption spectra in UV range.

It is shown that UV range reflection spectra have characteristic features, so that allows designating samples under investigation to a certain class of objects.

Thus, spectra of pure metals and metal alloys differ in intensity and spectral curve shape depending on sample composition. The examined minerals have typical spectrum shapes, individual in each case. It is widely known that in visible range reflection coefficients of front and back sides of green plant leaves are different. The same dependence continues in UV range. It is important to note that we found only a few papers devoted to study of leaves reflection coefficients in UV spectral range. Reflection spectra of construction material samples under investigation are easily distinguished by intensity and shape of spectral curves.

Modern multichannel spectral systems provide measuring of absolute and relative values of reflection coefficients of organic and non-organic samples in UV range, from 190 nm and above. Reflection spectra that are described in this paper have resolution of 10 nm. That is enough for identification of particular materials in laboratory environment. But it is not enough for remote investigations, when several objects can get into field of sensing, and the sensing emission passes through the atmosphere thickness.

Investigation of detailed reflection spectra of different objects with high spectral resolution (~1÷3 nm) with a reflection spectra database at hand will allow more precise discrimination of different objects. Special methods of database processing, such as, for example, Principal Component Analysis [7-8], can be used for spectra identification.

REFERENCES


