REFRACTIVE INDEX AND ADIABATIC COMPRESSIBILITY OF THE OCULAR HUMOURS*

[1] IOANA MARIN, [2]ALINA GUZGĂ, [1] GEORGETA-MIRABELA COCIORVĂ, [1] RĂZVAN NAȘCU, [2] ILIE DIACONU, [1] DANA-ORTANSA DOROHOI

[1] "Al. I. Cuza" University, Faculty of Physics, Iași
[2] "Gr. T. Popa" University, Medical Bioengineering Faculty, Iași

Received September 26, 2006

The index of refraction and the adiabatic compressibility of the ocular aqueous humors in the presence of some ionic salts were determined. An Abbé refract meter and an installation that permit ultrasound velocity determination were used in this experimental study. The results could be used in teaching purposes.

1. INTRODUCTION

Ultrasounds are mechanical waves with frequencies higher then 20 kHz. The propagation space of the ultrasounds is named ultrasonic field. The ultrasounds propagate step by step, by interacting with neighbouring particles. In air and in viscous liquids, the ultrasounds are longitudinal waves, while in solids and viscous liquids the ultrasounds are transversal waves.

The ultrasonic waves modify the positions of the component particles from the propagation space, by performing mechanical work against the internal forces. The velocities and accelerations of the component atomic systems of the propagation medium depend both on the ultrasound characteristics (amplitude of frequency) and on the intermolecular interactions from the ultrasound field. In the propagation process a part of the energy transported by ultrasound can be transformed in mechanical work of the friction forces, contributing to the medium heating and/or to intensifying the thermal chaotically motion of the component particles in the propagation space.

Ultrasounds can intensify the rotation or vibration motions of the particles from the propagation space.

The ultrasound propagation velocity depends on the nature and aggregation state of the propagation medium. In the condensed media, the ultrasound velocity depends on their viscosity and density, offering information about the

* Paper presented at the National Conference on Applied Physics, June 9–10, 2006, Galați, Romania

nature of the interactions between the component particles. The ultrasound velocity values can be used for the determination of some thermodynamic parameters of the propagation medium, such as adiabatic or isothermal coefficients of compressibility, internal pressure into the propagation medium, adiabatic exponent.

The knowledge about the processes in which the ultrasonic wave is implied in the propagation process in the condensed media and finding the most suitable means for a quantitative estimation of the ultrasound effects, facilitates an efficient ultrasound application in various domains such as industry, medicine, technique, or research.

In the propagation process, the ultrasounds determine vibrating motions of the particles, whose characteristics (magnitude, acceleration, velocity) depend both on the propagation medium nature and on the ultrasound frequency and energy [1, 2]. Longitudinal or transversal character of the ultrasound waves depends essentially on the properties of the propagation medium. In viscous media and in solids the transversal waves are predominant, while in liquids (water, alcohols) the ultrasounds can be considered as being longitudinal waves.

The physical parameters used to characterize the ultrasound propagation through the tissues are: the propagation velocity; the impedance, the compressibility of the propagation medium. The coefficient of compressibility is defined as it follows:

$$\beta = \frac{1}{\rho u^2}; \quad \beta = -\frac{1}{V}\frac{\partial V}{\partial P}; \quad Z = \rho u \tag{1}$$

In relations (1), β is the coefficient of compressibility, u – the ultrasound velocity; V – the volum of the sample, P – the pressure; Z – acoustic impedance.

In biological media the ultrasound velocity depends on the protein concentration and on the nature of biological liquids that compose the biologic tissue. Concomitantly it depends on the internal pressure. The influence of the external factors on the ultrasound propagation velocity also depends on temperature.

From the physical parameters characterizing the ultrasound propagation in tissues important information about anatomical functions of the biological tissues or the foreign bodies and tumors can be evidenced. So, the study of the propagation process is very important for Biology, Biophysics and Medicine. On the other hand, the domain of the ultrasounds bond vast fields of knowledge from Physics, Biology, Chemistry or Bioengineering which contribute to the understanding of the complex phenomena of ultrasound interaction with living systems.

In this paper a study on the ultrasound propagation in the pig ocular humours was performed in the context of trials to explain the human eye accommodation process.

2. THEORETICAL NOTIONS

The eye is a transparent, convergent optical system which forms the images of the objects on the retina surface. Having a fixed length, the optical system of the eyes must form the final image in a fixed place. The accommodation process of the human eyes consists in the change of the ocular convergence in such a way that the final image through the eye component is achieved at the level of macula lutea on the retina surface. So, for the objects placed at different distances in front of the eyes, the eye focal distance must be variable in order to ensure a fixed position for the final image.

If one considers the eye as being equivalent with a centred optical system [3], which could be replaced by a convergent lens with the image focal distance *f*, one can write an approximate formula for the object-image conjugated points.

$$\frac{1}{x_2} - \frac{1}{x_1} = \frac{1}{f} \tag{2}$$

In a first approximation, the focal distance of the crystalline eye is given by:

$$\frac{1}{f} = \left(n_r - 1\right)\left(\frac{1}{R_2} - \frac{1}{R_1}\right) \tag{3}$$

In relations (2) and (3), x_1 and x_2 are the distances object-cornea and cornea-retina and f is the image focal distance of the eye, given by formula (3); n_r is the relative index of refraction of the crystalline surrounded by the ocular humours. From relation (3) it results that, in a first approximation, the crystalline curvature and its relative index are determinant for the focal distance of the eyes.

As it results from relation (3), the eye focal distance, f, depends on the relative refractive index of the crystalline related to the internal eyes humours, n_r, and on the crystalline curvature radii R_1 and R_2. As a consequence, the eye convergence could be changed if the curvature radiuses R_1 and R_2, or the crystalline relative index of refraction are modified by a quick mechanism.

It is known the fact that the radii of the crystalline are quickly modified in mechanical process. Supplementary information shows that the persons having a low percentage of calcium in their blood have problems in the eye accommodation.

3. MATERIALS AND METHODS

The pig eye is quite similar with the human eye. This is the reason we made some experiments on the pig ocular humours. The internal pig ocular humours were obtained by eliminating the covering foils of the pig eyes and the crystalline. Solutions of the humours with different amounts of calcium chloride were made. Their concentration was in the range $4\cdot10^{-5}$–$10\cdot10^{-5}$ mol/l.

The weightings were carried out using a Mettler MD B5 digital balance with 10-5 g precision. The measurements were made in vitro, at normal pressure and at room temperature. The refractive index of the eye humours has been determined by using an Abbe refractometer. A piknometer of accuracy about 0.5 kg/m^3 has been used for the density determination.

The ultrasound velocity of the pure pig ocular humours and of those solutions with different $CaCl_2$ salt amounts has been measured. The calcium chloride concentration was expressed in mole/l. The values of the ultrasound velocities were measured by an interferometric method, using a device (Fig. 1) projected and realised in the Labs of the Bioengineering Faculty of "Gr. T. Popa" University of Medicine and Pharmacy from Iași [4, 5].

In Fig. 1 the transducer Q has a frequency of $f = 1$ MHz, the reflector *R* can be moved with a micrometric device M, having the precision of 10^{-2} mm. The transducer has double role in this device:-emitter and receiver of the ultrasounds. The space between the transducer and the reflecting surface is filled with the studied liquid. The longitudinal ultrasound waves emitted by the transducer with a fixed frequency are reflected by the ultrasound mirror O moved by the micrometer M. Let be d the distance between transducer and the mirror R. For distances that satisfy the condition;

$$2d = n\lambda; \qquad n = 1, 2, 3, \dots \tag{4}$$

One obtains minima of vibration amplitude of *u* (maxima of ultrasound pressure) at the level of the transducer surface. When on the transducer surface a null for the magnitude of vibration appears, the reflected wave is in opposite phase with the emitted one. The ultrasonic pressure has maximum value; in this situation the transducer is blocked in its vibration and a maximum of the electric

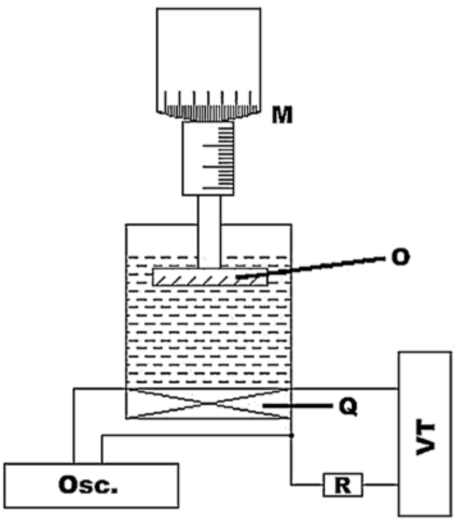

Fig. 1 – Ultra-acoustic interferometer.

current will be measured in the alimentation electric circuit by the micro ammeter μ*A*. The similar situations are realized when the mirror *R* is moved by a distance equal with a semi-wavelength. The measurements between *q* maxims, for a distance *D* increase the precision for the wavelength evaluation.

$$\lambda = \frac{2D}{q-1} \tag{5}$$

The wavelength measured permits the evaluation of the ultrasound velocity, *u*, as function of the ultrasound wavelength and frequency.

The ultrasound has been used in order to determine the adiabatic coefficient of compressibility that determines the degree of association of the molecules in the studied liquids. Ultrasound velocity, density and adiabatic compressibility for pig ocular humours with a variable $CaCl_2$ concentration were estimated (see Figs. 2, 3 and 4).

3. RESULTS AND DISCUSSIONS

The human eye accommodation has been explained by two essential processes. The most known is the modification of the curvature of the spherical surfaces that separate the crystalline from the internal ocular humours.

The second process that can change the eye convergence is the modification of the ionic composition of the eye humours that could modify the relative refraction index, determining in conformity with relation (1), the eye focal distance. This process is less studied and there are ophthalmologic centres in which this problem constitutes a fundamental research topic. We studied the ultrasound propagation through the pig eye humours because the values of the ultrasound velocities can give us information about the adiabatic compressibility of the eye humours and about the eye accommodation process. From Figs. 2 and 3 it results the increasing in the ultrasound velocity and in the ocular humours density with the increasing salt concentration in the humours.

The adiabatic compressibility decreases with the salt concentration (Fig. 4), proving a pronounced clusterization of the water molecules around the positive ions in solution. The ions come from the ionization of the salt molecules in the ocular humours. The refractive indices measured with an Abbe refract meter, for each solution, show values placed between 1.371 and 1.375.

The variation produced in the adiabatic compressibility and in the refractive indices demonstrates that the focal image distance of the eye given by relation (2) could be influenced by the concentration of salts in our blood cells. It results that the ionic salts concentration in the blood cells influences the eye accommodation power.

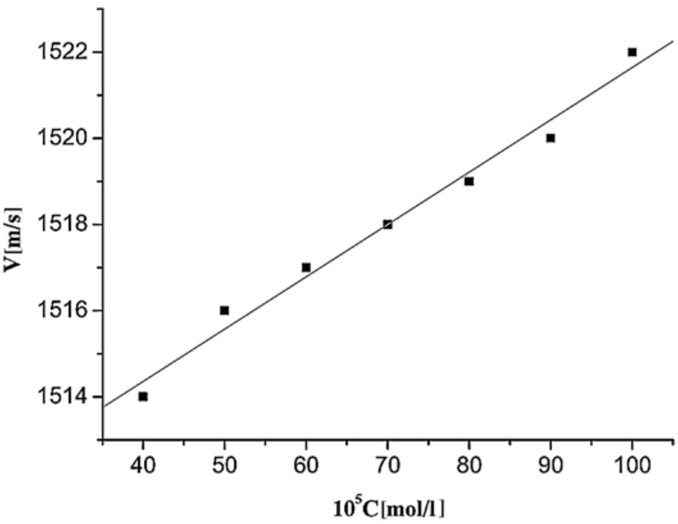

Fig. 2 – Ultrasound velocities of ocular humours *versus* $CaCl_2$ concentration.

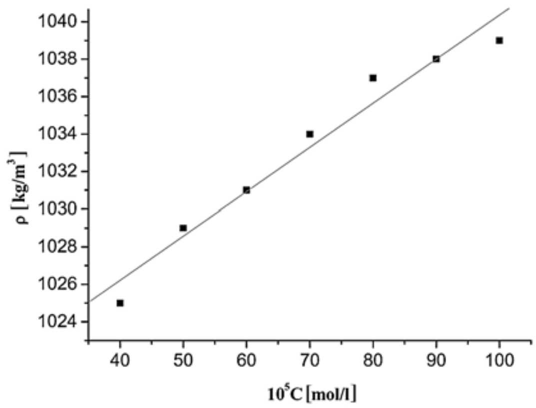

Fig. 3 – Density of ocular humours *versus* salt concentration.

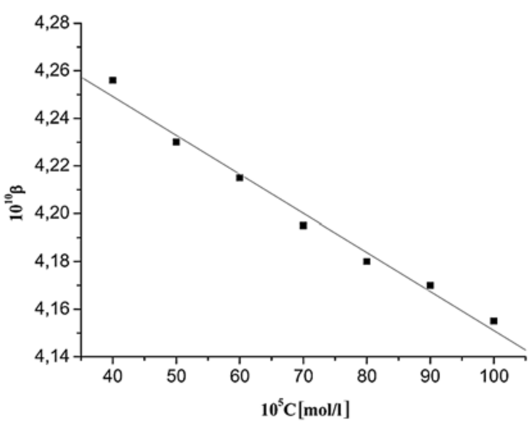

Fig. 4 – Adiabatic compressibility *versus* salt concentration.

Our researches were made in order to give new arguments for the explanation of the accommodation process both by the modification of the crystalline radii and by the modification of the relative refractive index of the crystalline.

4. CONCLUDING REMARKS

Increasing ion concentration in eye humours it can be seen an increasing of n and u, and the adiabatic coefficient decreases, that proves the increase in the intermolecular interactions, meaning the decrease in the compressibility capacity. From our experiments it results that the presence of the salts influences the physical parameters of the ocular humours determining the focal distance of the eyes.

REFERENCES

1. J. Tonnelat, *Biophysique*, Ed. Masson, Paris, 1968.
2. D. Mărgineanu, *Biofizica,* Ed. St. Enciclop., București, 1985.
3. V. Pop, *Bazele Opticii*, Ed. Univ. Al. I. Cuza, Iași, 1988.
4. I. Diaconu, D. Dorohoi, *Ultrasunetele. Aplicații în medicină*, Ed. Technopress, Iași, 2005.
5. D. V. Vasilescu, N. I. Nagy, *Ultrasunetele in medicină*, Ed. Medicală, București, 1984.
6. G. Gheorghieș, A. David, S. Budeanu, D. O. Dorohoi, Adamachi, vol. XIII, Nr. 1–4, p. 92–93, 2005.