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Liquid–crystalline detectors for ionizing radiation

A progress in radiative isotopes utilization and in nuclear power engineering as well as persisting the hazard of the nuclear war implies the necessarity of perfection in dosimetric methods.

Selection of a dosimetric method depends on the measurement task (i.e. measurement of the exposure dose or absorbed dose, dosage, monitoring the energy distribution in radiation beam), on the kind of radiation examined and its parameters as well as on the economical, technological and ergonomical factors. It can be stated generally, that no universal methods of dosimetry exist.

Search for the new dosimetric systems, is conducted in direction of looking for the new physical affects as well as for the new materials to use in the known investigation sets.

Liquid-crystals, used for a long time in information display devices, can also be used in detection of variety physical quantities. It is due to the fact, that relatively small changes in physico-chemical parameters results the relatively large variation in the internal structure of the L.C., thus in its physical properties, first of all in its optical properties.[1]

It was expected that in the case of ionising radiation due to radiation decomposition products of molecules of L.C. substance would create a mixture changing the physical properties of the L.C., which as known depends strongly on the chemical composition. This suggestion resulted in selection the cholesteric L.C. (Ch.L.C.) as the subject of interest, the optical parameters of which are strongly sensitive to the composition variation. Ordering of molecules in Ch.L.C. is shown schematically in Fig. 1.

A helical spatial structure of Ch.L.C. results in creation the effect similar to the Bragg's diffraction on the spatial structure of solid crystals. The incident wave penetrate the thin layer of Ch.L.C. excluding the narrow interval $\lambda_s \pm \Delta\lambda_s$ where $\lambda = \bar{n}$ p, and $\bar{n}$ is the mean value of refractive index of the Ch.L.C. layer.

The value of p, hence also of λ_s depend on the chemical composition of the substance. Particularly, when the compound has also the liquid-crystalline smectic phase, near the

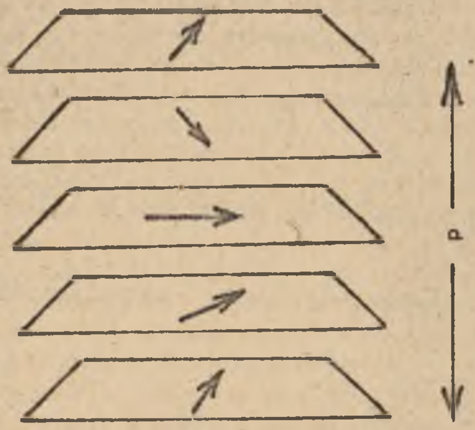

Fig. 1. A molecular ordering in cholesterol L.C. The arrows indicate the ordering direction of the long molecular axis, p is the structure step(period)

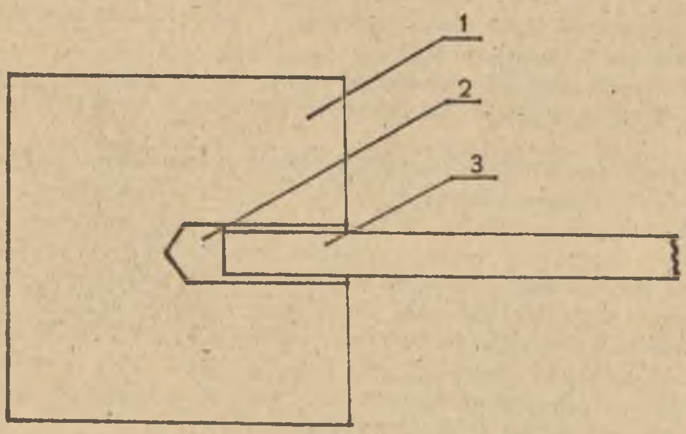

Fig. 2. The plate for visual determination of colour response parameters in ChLC

temperature of phase transition smectic-cholesteric a quick reorientation of the cholesteric ordering occurs with the temperature rising. As the effect the values of p and λ_s , increase. This is referred to as the thermo-optic effect, in another words the temperature of colour response, and occurs in the interval of the single degrees, but the change in λ_s usually occurs in the range corresponding to the colour change from violet, through blue and green to red (with temperature decreasing). Since temperature of occurance the smectic — cholesteric phase transition depends on the chemical composition, hence also the temperature of occurance of the colour response and its parameters (the temperature of occurance of each colour intensity, saturation and others) depend on the chemical composition of Ch.L.C.

That is why, the measure of the ionising radiation dose, is the change in parameters of colour response, which can be visually observed or monitored using the proper devices. In all published to date papers the cholesterol esters have been used in this direction as the investigation material. The choice has been related by the low cost, availability of these substances and advantages of theirs functional parameters. Morever, the cholesterol esters are the compounds showing the low chemical and photochemical stability [2], the similar effects have been expected in the case of interaction of ionising radiation. Irradiation of cholesterol esters can be realized in few basical investigation systems.

The first possibility relies on the use of diluted cholesterol esters solutions in organic solvents [3]. After irradiation the solvent is subjected to evaporation to maintain the temperature below 343 K. Then temperature of the phase transitions is measured using a polarization microscope with the heating stage or by measurement of the parameters of colour response using the device shown in Fig. 2.

The chemical composition of the dry remainder differs from the initial composition of the L.C. substance, it is due to the presence in the sample the stable radiolise products, mainly of the solvent. This results in a change (lowering) of the phase transition temperature, mainly that of clearance and S-Ch, and a change in colour response parameters.

The results obtained depend on: the solvent kind, the kind of L.C. substance and the concentration of solution. Examples of dose-temperature characteristies are shown in Fig. 3.

The set described above can be used in the laboratory measurements, owing to time and read out technique and it enables to measure the exposition doses within the interval of 8×10^{-2}–30 C/kg (350–12000 R). In the commercial sets no deoxidaton of samples are used due to occuring in this case decrease of dose sensitivity $\eta = T/D_e$ measured in kg/K or K/R.

Repeativity of the measurement results mainly depends on carefulness in performance of the solvent evaporation, since overheating of the samples can result in uncontrolled evaporation of more violatile products of radiolise or thermal degradation of L.C.

The second possibility in dose measurement with the aid of ChLC, is making use of bulk detectors from solid cholesterol esters of liquid–crystalline phase [6]. The measurements are performed in the same manner as in the above described method, however the solvent evaporation stage is omitted. Fig. 4 shows the examples of temperature — dose dependences in this case.

The dose sensitivity obtained in this case depends on the substance kind and the gamma radiation energy, however is independent of the exposition dose.

The longer molecules of L.C. substance are, the lower dose sensitivity is. It is firstly due to effect of the light scattering by large molecules without the bound breaking. Secondly, the influence of admixture on the temperature of phase transition increases with increasing the ratio of the linear dimensions of admixture and L.C. substance molecules

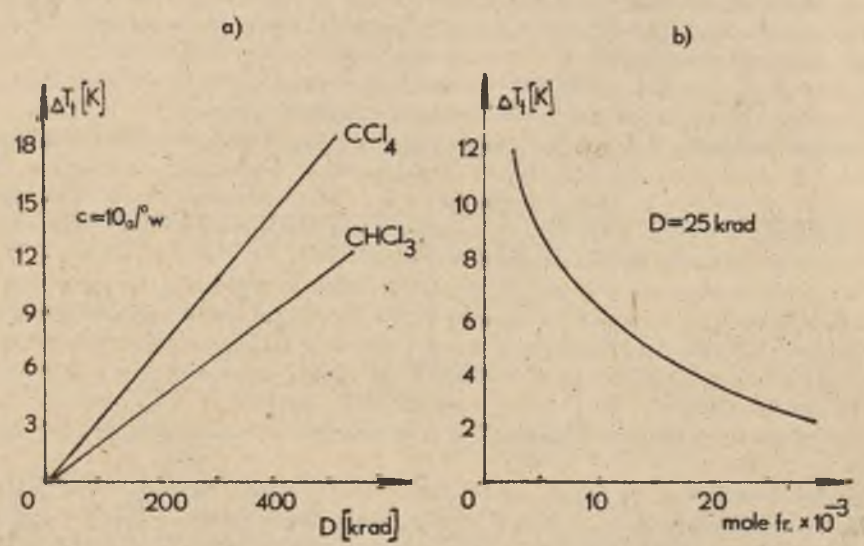

Fig. 3. Influence of exposure dose D_e of gamma radiation on the liquid-crystalline properties of cholesterol nonanoate irradiated in organic solutions. a) The change of clearance temperature ΔT_k vs D_e in CCl_4 and $ChCl_3$ solutions [4], b) ΔT_k vs concentration of hexane solutions [5]

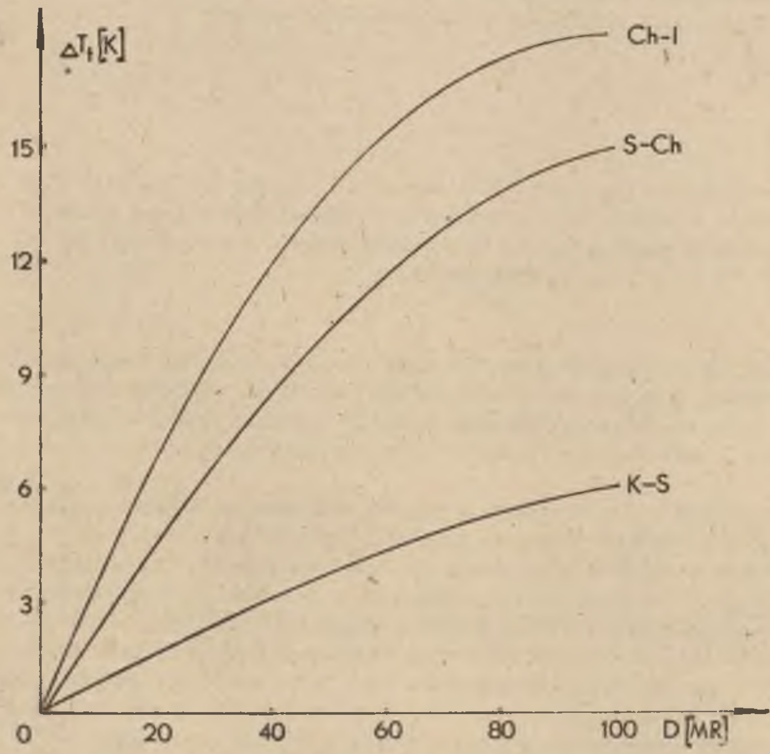

Fig. 4. Dependence of change in temperature of phase transitions on exposition dose for cholesteryl nonanoate irradiated at a solid state by gamma radiation

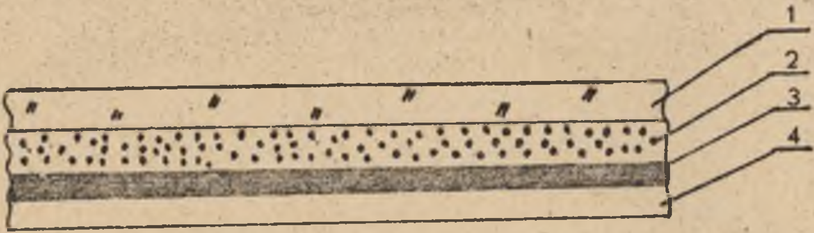

Fig. 5. Cross section of hermetized ChLC layer [1]: 1 – washer foil (polyester of polyethylene), 2 – the ChLC layer suspended in a colloidal form in a film creating material, 3 – the black masking layer (a film creating material + a black dye), 4 – the hermetizing layer

and with the globularity degree of admixture molecules. Since radiative destruction of the cholesterol esters mainly on the breaking of the ester bond, thus the influence of created in such a way admixtures on the phase transition temperature of L.C. is found to be less for further terms in homology series of cholesterol esters and in carboxyl aliphatic acids.

Insignificant increase in dose sensitivity is observed with decrease in gamma radiation energy at a ratio of 3%/100keV within the range of 0,2 to 1,25 MeV.

The largest dose sensitivities are observed for cholesterol halides. The variations in the clearance temperatures and smetic-cholesterol phase transition are found to be the most pronounced and the reverse is true for melting temperature. As a result of this effect with increase of the absorbed dose the narrowing of temperature range appears in which the L.C. phase occurs. The individual phases are found to be monotropic and for doses exciting 100 MR all liquid-crystalline properties disappear for most of the compounds The dose-temperature characteristics are found usually to be linear up to about 20 MR, and for higher doses are nonlinear.

The examination of products of cholesterol esters radiolyse show [7], that the radiative decomposition usually occurs on the carbon atom 3 — β of steroide core, thus with the break of ester bound or carbon halide bound.

In the case of cholesterol ester mixtures it is observed about 10 to 40% increase in dose sensitivity with respect to the single esters. It is due to the possibility in occurring more chemo-radiative reactions. The use of specially prepared mixtures or containing radiative sensitive nonmesoge-neous admixtures enables to achieve the dose sensitivity of one order of magnitude higher than in the case of singular compounds.

The third system to be studied, was chosen to be the polymer layers containing hermetically closed the L.C. colloid. This system appears to be most close to the commercial form of L.C. dosimeter. The processes that occur in it, basically perform identically as in mixtures of L.C. compounds. The possibility to take part in chemo-radiative reactions

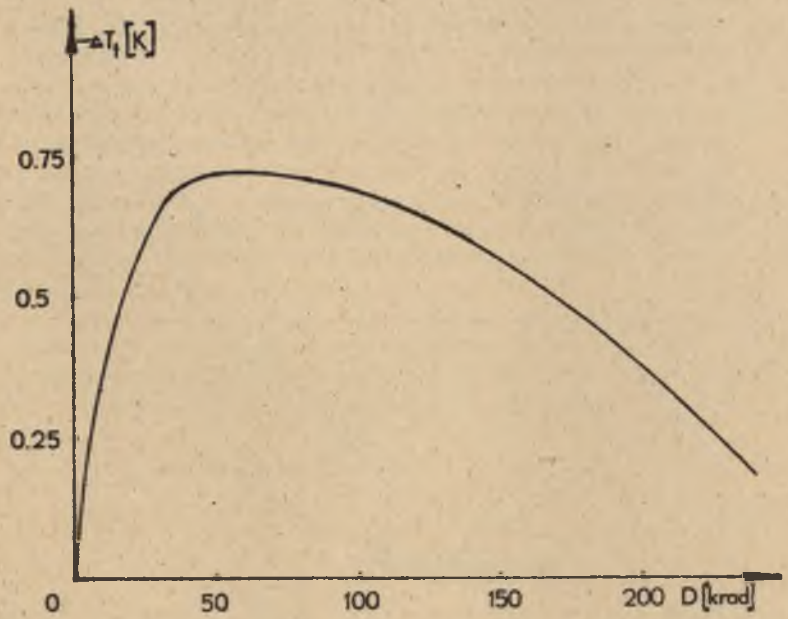

Fig. 6. The change in temperature of clearance for cholesterol esters subjected to the action of fast neutrons (E=5.5 MeV) vs absorbed dose

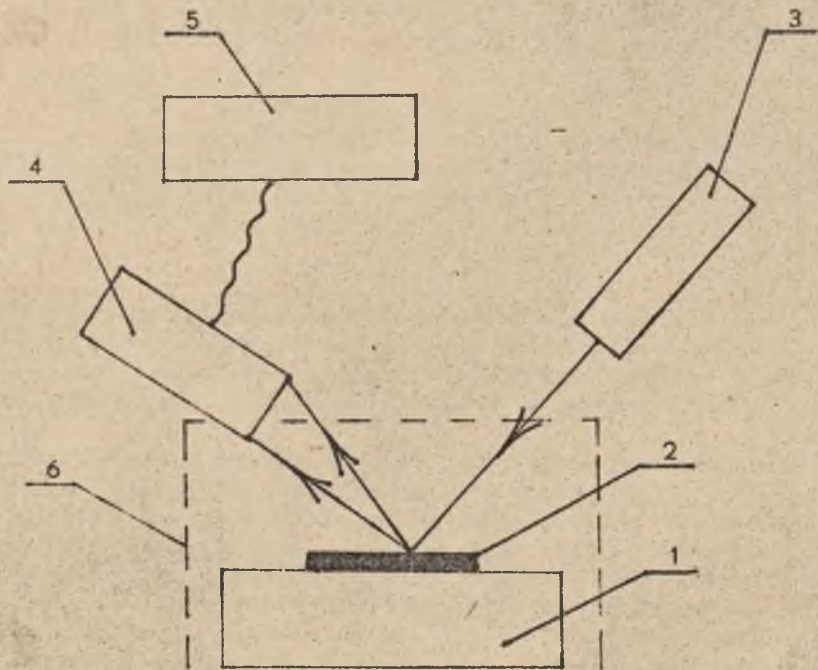

Fig. 7. A block scheme of reading device for L.C. dosimeters [1]. 1 – the thermostative plate (T=Q,1K), 2 dosimeter (hermetized layer), 3 – source of light i.e. laser or LED, 4 – detector of the reflected light, 5 – the reading and recording system, 6 – the thermostating housing

of nonreacted compositors of the substance appears to be the only difference. The cross section of such the layer is shown in Fig. 5.

The range of exposition doses, which can be measured by using the cholesterol derivative mixtures, hermetized as well, is found to be 40 kR to 100 MR.

Massurements of dose of another kinds of ionization radiation: neutron, proton, alfa and beta, occur to be the separate problem. In the case when cholesterol esters are subjected to neutron or proton irradiation [8], it is found the strong nonlinear dependence of the clearing and S–Ch phase transition temperature variation on the absorbed dose (Fig. 6).

The observed effects in this case are considerably weaker than for gamma radiation, and mechanism of the effects occurring is found to be more complicated. As least two competitive processes run in this case. The problem is under intensive investigations. In the case of proton irradiation the L.C. samples were observed to behave in the similar way. The extremum of $\Delta T_p = f(D_p)$ dependence occurs for the lower doses and posses the higher value, the longer molecules of cholesterol esters are. The absorbed doses which can be measured to date were observed to lie within the range of 20–250 kR.

As was pointed at the beginning, the final task to be achieved are the measured quantities being the colour response parameters. In order to make measurements more objective and more sensitive instead of read-out the photoelectrical reading device can be used. In Fig. 7 is shown an example of the block scheme of this kind of the realing device.

It is apparent that at present, L.C. dosimetric systems enable the measurement of irradiation doses met in the radiative technique. However, regarding the low cost of theirs, the interesting properties and the short investigation period, it follows that the substances appear to be much perspective for the dosimetry needs.

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