INVESTIGATION OF PROCESSES OF INTERACTION RELATIVISTIC ELECTRONS WITH THE SOLUTIONS OF ORGANIC DYES

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Investigation of the processes of interaction of ionizing radiation with complex organic objects can solve a number of fundamental and applied problems in radiation physics, chemistry and biology. In this work we investigated the dose dependence (dose range $1...5\,MRad$) optical density relative concentrations of water, alcohol and glycerine solution following organic dyes: methylene blue – $C_{16}H_{18}N_3SCl$ and methyl orange – $C_{14}H_{14}N_3O_3SNa$, irradiated with an electron beam with an energy of $16\,MeV$. In the analysis of absorption spectra, it was found that water solutions of dyes have less resistance to radiation as compared with the alcohol and glycerol. Also, all solutions of methyl orange less radiation resistant than the methylene blue solution. Analysis of the spectra showed that these relationships are close to linear in the range of doses. To understand the physical and chemical processes occurring in the interaction of relativistic electrons with the studied organic objects were performed the computer simulations of the energy spectra of ions formed due to breaking the chemical bonds of molecules of dye solutions using the program $SRIM-2010$. The analysis showed that radiation - stimulated chemical processes play a major role in the destruction of the source of organic dye molecules. The remaining processes (interaction of electrons and nuclei, the cascade processes) accounts for about 10% of all molecular breaks.

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1. INTRODUCTION

Studying the mechanisms of interaction of ionizing radiation with organic and inorganic objects is necessary for a wide range of applied and basic tasks in the field of radiation physics, chemistry and biology. These tasks include: radiation-chemical protection, study and improving the sustainability of organic materials and biological systems to ionizing radiation, the development of new radioprotectors, creating new dosimeters directional change properties and radiation-chemical synthesis of materials, and the use of ionizing radiation for medical purposes [1, 2]. In this work we investigated the radiation resistance of water, alcohol and glycerine solution following organic dyes: methylene blue (MB) – $C_{16}H_{18}N_3SCl$ and methyl orange (MO) – $C_{14}H_{14}N_3O_3SNa$. Using these dyes is due to several reasons: they're available (important when creating a new economy dosimeters); colour change under the influence of ionizing radiation (it is important for ease of handling the obtained experimental data); The colour intensity of the test solution even for small amounts of solute ($1...3\,mg/cm^3$). Use of a liquid organic matrix in the study of biological objects in the one hand, allows the analysis of intact solute molecules at a much higher beam current density compared with the solid matrix, on the other hand, the dissolving fluid is often a good radioprotectors simultaneously enables to study its protective properties. The essential difference lies in the dye composition in the presence of MO, an alkali metal Na, which is a chemically active element and in case of separation from the main molecule may be involved in a number of chemical reactions.

2. THE EXPERIMENTAL TECHNIQUE

All experiments on the radiation resistance of the studied dye solutions when irradiated by an electron beam were carried out on the linear electron accelerator $LINAC-300$ KIPT. Experimental setup is shown in Fig.1.

As shown in Fig.1 electron beam through the exit foil accelerator discharged into the atmosphere, then to form passed through a lead collimator and stints on the studied target. Were used as targets water alcohol and glycerine saturated solutions of organic dyes methyl orange and methylene blue, filled in glass medical vials and tightly sealed with rubber stoppers (during the exposure to the test substance is not exposed to the ambient atmosphere).

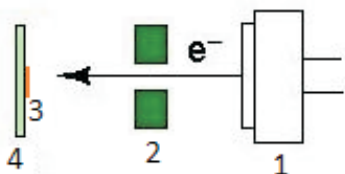*Corresponding author E-mail address: gokovsp@kipt.kharkov.ua

Fig.1. *Scheme of the experiment on the target electron beam irradiation. 1 – the output flange with foil of accelerator; 2 – collimator; 3 – film dosimeter; 4 – target*

Structural formulas of investigated dyes and their colour are presented in Fig.2.
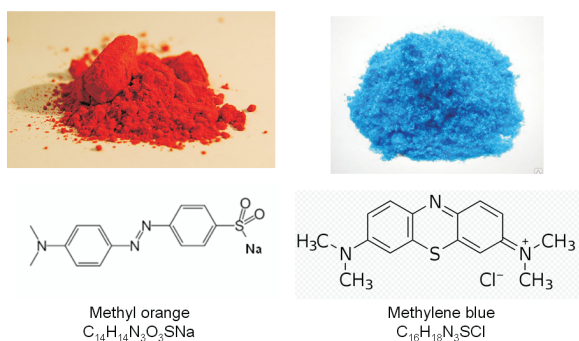

Fig.2. *Structural formulas of investigated dyes and their colour*

As seen from Fig.2 the main differences these dyes is their colours (different absorption spectra of solutions of the study) and the presence in the chemical composition of methyl orange reactive metal Na. Electron beam energy was $16\,MeV$, current density $\sim 0.5\,\mu A/sm^2$. Irradiation dose was $1...5\,MRad$. Control of the absorbed dose was performed using film dosimeters. In order to avoid thermal effects, resulting in a colour change of the investigated solutions, the sample temperature did not exceed $30°C$. Continuous monitoring of the temperature regime during the irradiation was carried out using thermocouple sensors, the adjoint directly to tubes with test solutions. Before and after irradiation, for a few hours (to no significant temporal changes in the irradiated solutions) on an automated spectrophotometer $SF-56$ produced a study of the absorption spectra of the dye solutions in the wavelength range $200...1000\,nm$.

3. EXPERIMENTAL RESULTS

In this paper we have investigated the absorption spectra of solutions of unirradiated and irradiated for three dyes absorbed dose: $1\,MRad$, $3\,MRad$ and $5\,MRad$. Fig.3-5 show the absorption spectra of irradiated solutions of dyes and related irradiated with a dose of $5\,MRad$.

From the figures, it is seen that water solutions of dyes have less resistance to radiation as compared with the alcohol and glycerol. Also, all the solutions

of methyl orange less radiation-resistant as compared with solutions of methylene blue. Fig.6 shows the ratio of the optical densities of the dye solutions before and after irradiation of the absorbed dose
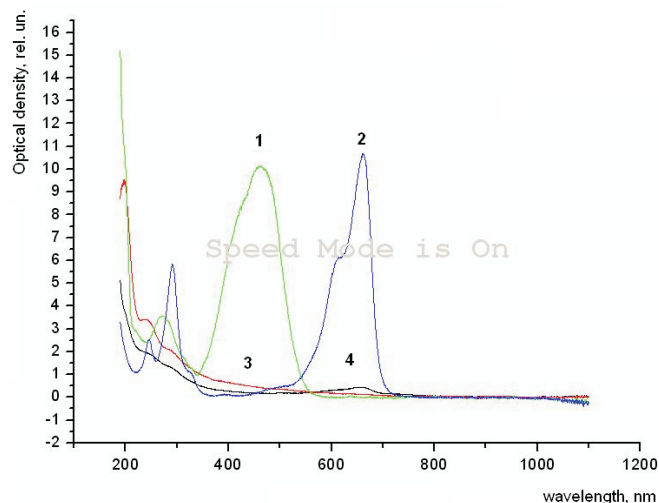

Fig.3. *Typical absorption spectra of dyes in water solutions before and after electron irradiation (dose of $5\,MRad$). Curve 1 – MO – before irradiation; curve 2 – MB – before irradiation; curve 3 – MO – after irradiation; curve 4 – MB after irradiation*

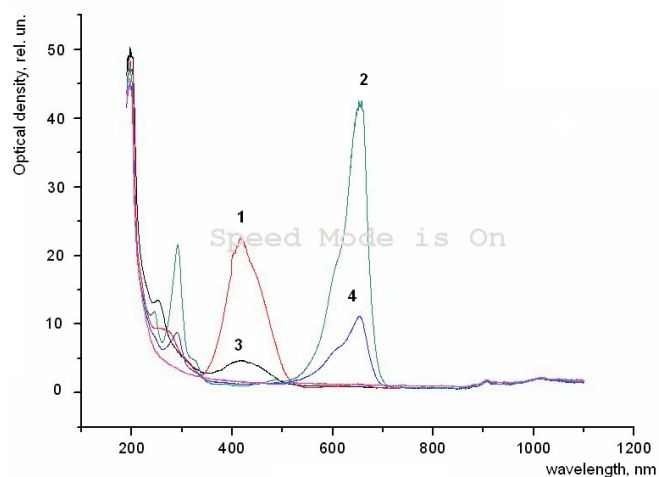**Fig.4.** *Typical absorption spectra of dyes in alcohol solutions before and after electron irradiation (dose of $5\,MRad$). Curve 1 – MO – before irradiation; curve 2 – MB – before irradiation; curve 3 – MO – after irradiation; curve 4 – MB after irradiation*

Fig.6 shows that for all solutions observed a nearly linear dependence of the optical density of the absorbed dose. Moreover, the angle of the presented dependences different for different dye solutions, which again speaks to their various radiation resistance. This experimental fact suggests that in the future it is possible the use of organic dyes such as the basis for the different sensitivity of dosimeters.
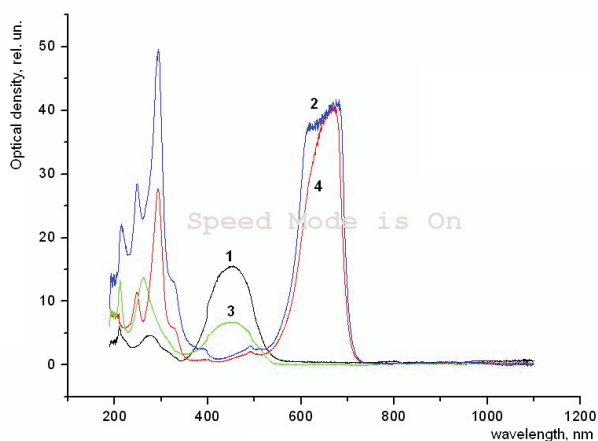
Fig.5. *Typical absorption spectra of dyes in glycerine solutions before and after electron irradiation (dose of $5\,MRad$). Curve 1 – MO – before irradiation; curve 2 – MB – before irradiation; curve 3 – MO – after irradiation; curve 4 – MB after irradiation*
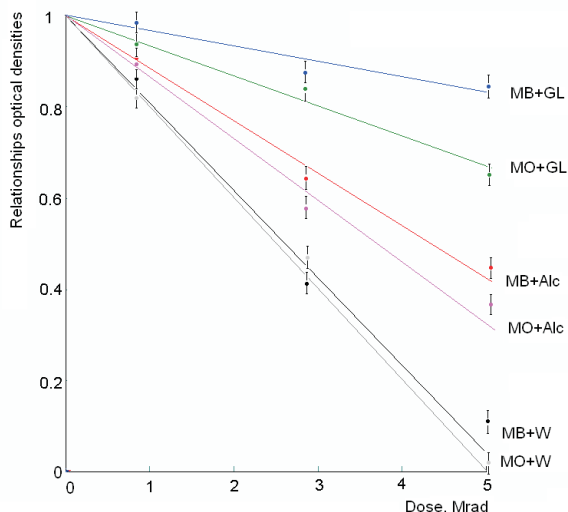

Fig.6. *Ratio of the optical densities of all dye solutions before and after irradiation of the absorbed dose*

4. MODELLING

To understand the physical and chemical processes occurring in the interaction of high-energy electrons with organic objects were investigated numerically study the energy spectra of atoms and ions formed during the collapse of the dye molecules. With the passage of a relativistic electron beam through the target as a result of electron scattering on target nuclei it is transmitted energy, resulting in the collapse of the molecules, and the formation of free atoms and ions. Further, these atoms or ions possessing an appreciable kinetic energy, compared with the binding energy of the ions and atoms in the molecule, with the other face of the dye molecules, breaking them, and forming a so-called cascade. Number of electrons

scattered by nuclei is determined by the formula:

$$N \cong n_e n_n \frac{(Ze^2)^2}{2ME'} \left(\frac{2E_0^2}{ME'} - 1 \right), \qquad (1)$$

where n_e – number of the incident electrons; n_n – number of nuclei in the target per cm^2, E_0 – energy of the electrons, Z – nuclear charge, M is the mass of the nucleus, $'E$ – electron energy transferred to the nucleus. From this formula, using the programme Maple to determine the relation N ($'E$). On the basis of the received energy spectra of ions and atoms ejected from the dye molecules with electrons of the primary beam by using programme $SRIM-2010$ was evaluated the total amount of organic dye molecules discontinuities. The calculations made it possible to determine the total number of molecular breaks (including cascade processes), which accounted for one incident electron.

5. CONCLUSIONS

In this work, we investigated the mechanisms of interaction of relativistic electrons with an aqueous alcohol and glycerine solution following organic dyes: methylene blue – $C_{16}H_{18}N_3SCl$ and methyl orange – $C_{14}H_{14}N_3O3SNa$ under irradiation with electrons. In the analysis of absorption spectra, it was found that aqueous solutions of dyes have less resistance to radiation as compared with the alcohol and glycerol. In addition, all solutions of methyl orange less radiation resistant than the methylene blue solution. For all solutions observed a nearly linear dependence of the optical density of the absorbed dose. Moreover, the angle of the presented dependences different for different dye solutions, which again speaks to their various radiation resistance. This experimental fact suggests that in the future may use such organic dyes as the basis for the different sensitivity of dosimeters. The studies were made to estimate the contribution of various processes in the destruction of organic molecules (radiation-induced chemical reactions to 90%, the direct interaction of the electrons with nuclei of up to 8%, and the impact of cascading processes and gamma – quantum to 2%) depending on the type of solvent.

References

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ИССЛЕДОВАНИЕ ПРОЦЕССОВ ВЗАИМОДЕЙСТВИЯ РЕЛЯТИВИСТСКИХ ЭЛЕКТРОНОВ С РАСТВОРАМИ ОРГАНИЧЕСКИХ КРАСИТЕЛЕЙ

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Исследование процессов взаимодействия ионизирующего излучения со сложными органическими объектами позволяет решать целый ряд прикладных и фундаментальных задач в области радиационной физики, химии и биологии. В данной работе исследовались дозовые зависимости (в диапазоне доз 1...5 МРад) оптической плотности относительных концентраций водного, спиртового и глицеринового растворов следующих органических красителей: метиленового синего – $C_{16}H_{18}N_3SCl$, и метилового оранжевого – $C_{14}H_{14}N_3O3SNa$, при облучении их электронным пучком с энергией 16 МэВ. При анализе спектров поглощения было установлено, что водные растворы всех красителей обладают меньшей радиационной стойкостью по сравнению со спиртовыми и глицериновыми. Также все растворы метилового оранжевого менее радиационно - стойкие по сравнению с растворами метиленового синего. Анализ спектров показал, что эти зависимости близки к линейным в данном диапазоне доз. С целью понимания физико-химических процессов, происходящих при взаимодействии релятивистских электронов с исследуемыми органическими объектами, было проведено компьютерное моделирование энергетических спектров ионов, образовавшихся при разрыве химических связей молекул растворов красителей при помощи программы $SRIM - 2010$. Анализ показал, что радиационно - стимулированные химические процессы играют основную роль в разрушении исходных органических молекул красителей. На долю остальных процессов (взаимодействие электронов с ядрами, каскадные процессы) приходится порядка 10% всех разрывов молекул.

ДОСЛІДЖЕННЯ ПРОЦЕСІВ ВЗАЄМОДІЇ РЕЛЯТІВІСТСЬКИХ ЕЛЕКТРОНІВ З РОЗЧИНАМИ ОРГАНІЧНИХ БАРВНИКІВ

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Дослідження процесів взаємодії іонізуючого випромінювання із складними органічними об'єктами дозволяє вирішувати цілий ряд прикладних і фундаментальних завдань у галузі радіаційної фізики, хімії та біології. У даній роботі досліджувалися дозові залежності (в діапазоні доз 1...5 МРад) оптичної щільності відносних концентрацій водного, спиртового та гліцеринового розчинів наступних органічних барвників: метиленового синього – $C_{16}H_{18}N_3SCl$, і метилового оранжевого – $C_{14}H_{14}N_3O3SNa$, при опроміненні їх електронним пучком з енергією 16 МеВ. При аналізі спектрів поглинання було встановлено, що водні розчини всіх барвників володіють меншою радіаційною стійкістю порівняно зі спиртовими й гліцеринові. Також всі розчини метилового оранжевого менш радіаційно - стійкі в порівнянні з розчинами метиленового синього. Аналіз спектрів показав, що ці залежності близькі до лінійних в даному діапазоні доз. З метою зрозуміння фізико-хімічних процесів, що відбуваються при взаємодії релятивістських електронів з досліджуваними органічними об'єктами, було проведено комп'ютерне моделювання енергетичних спектрів іонів, що утворилися при розриві хімічних зв'язків молекул розчинів барвників за допомогою програми $SRIM - 2010$. Аналіз показав, що радіаційно - стимульовані хімічні процеси відіграють основну роль у руйнуванні органічних молекул барвників. На частку інших процесів (взаємодія електронів з ядрами, каскадні процеси) припадає близько 10% всіх розривів молекул.