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ARTICLE

Preparation of Domestic Nuclear Detector Using Solutions of the Scintillation Materials (Acridine) and (Eosin)

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Abstract: In this work, three types of scintillation materials, Acridine orange, Eosin blue and Eosin yellow, were used to act as liquid scintillation detectors. They can be used to detect ionizing radiation, especially that of high Linear Energy Transfer (LET). This work determines the optimum concentration for each of the investigated materials to be 0.2 g/l dissolved in Methanol, added to a solution of Anthracene in Xylene of the concentration of 1.4 g/l and a solution of POPOP in Xylene of the concentration of 0.2 g/l. All samples were irradiated using radioactive sources ^{241}Am, ^{137}Cs and ^{60}Co.

Keywords: Liquid scintillation detectors; LET; Chemical quenching; Color quenching; Acridine; Eosin.

Introduction

Liquid Scintillation Solutions

A category of useful scintillators is produced by dissolving an organic scintillator into an appropriate solvent. Liquid scintillators can consist simply of these two components, or a third constituent could be added as wavelength shifter in order to tailor the emission spectrum for better matching with the spectral response of common photomultiplier tubes.

Liquid scintillators are often commercially sold in sealed glass containers and are handled in the same manner as solid scintillators. In certain applications, large-volume detectors with dimensions of several meters may be required. In these cases, the liquid scintillators are often the only practical choice from a cost standpoint [1].

Liquid scintillators are also widely applied to count radiation from a radioactive material that can be dissolved in the scintillator solution. In this case, all radiations emitted by the source immediately react with some portion of the scintillator, and the counting efficiency can be almost 100%. This technique is widely used, especially for counting low level beta activity such as that emitted by ^{14}C or tritium. In addition, liquid scintillation detectors can be applied to avoid some of the difficulties that arise when measuring low-energy beta particles or alpha particles using conventional methods [2]. The approach, sometimes called internal source liquid scintillation counting, involves dissolving the sample to be counted directly into the liquid scintillator. Under these conditions, problems relating to sample, such as self-absorption, are completely avoided [3].

A scintillator is generally a binary or ternary system composed of a solvent (donor) and one or two solutes [4]. The simplest system is a binary liquid scintillator, which consists of an organic scintillator, known as the activator or the primary solute, dissolved in an organic solvent. Typically, concentrations are less than 10 g/l. Primary

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solutes include compounds known as PPO, PBD and TP (2,5-diphenloxazol $C_{15}H_{11}NO$, 2-pheny1-5-(4-biphenylyl)-1,3,4-oxadiazole $C_{20}H_{22}N_2O$ and p-terphenly) and popular solvents are Toluene, Xylene and 1,4-dioxin [5,6].

The main requirements of the solute are that it should be an efficient scintillator and soluble in the used solvent. The solvent should be transparent to the scintillation of the solute, and should be able to dissolve not only the solute but also a wide range of source compounds and other substances that may have to be incorporated in the scintillator [7, 8].

Procedure

Sample Preparation

In this work, many chemical materials of 99% purity were used in order to obtain the best results and the largest accuracy. In addition, the solid organic material Anthracene ($C_{14}H_{10}$) was used as primary solute, as well as Xylene ($C_6H_{14}(CH_3)$) as organic solvent, while the POPOP material *{P – bis [2 - (5 - phenyloxazolyl)] benzene}* $C_{24}H_{16}N_2O_2$ was used as secondary organic solute. The latter serves to shift the wavelength of the present scintillations toward the region of the visible light.

Some organic solute materials were tested as wavelength shifters, such as Acridine orange ($C_{17}H_{19}N_3$), Eosin blue ($C_{20}H_6O_9Na_2Br_2$) and Eosin yellow ($C_{20}H_6Na_2$). All these chemical materials are also used to shift the wavelength of the present scintillators toward the region of the visible light.

Preparation of Anthracene in Xylene

In order to prepare 1.4 g/l concentration of Anthracene in Xylene, a quantity of 7 mg of Anthracene was dissolved in 5 ml of Xylene.

Preparation of POPOP {P-bis[2-(5-phenyloxazolyl)]benzene} in Xylene

The compound POPOP is considered as one of the wavelength shifters that is usually used as secondary solute, added to the photo scintillator to make scintillation light photons more appropriate for the photocathode of the photomultiplier. It was noticed that the concentration of the secondary organic solute was small compared to the concentration of the primary solute. Thus, to prepare the liquid scintillator that contains POPOP, an optimum concentration of 0.2 g/l of POPOP in Xylene was preferred, so a mass of 0.04 mg of POPOP was dissolved in 0.2 ml of Xylene, then the liquid was left for many hours after every dilution process in order to become homogenous.

The Preparation of Different Concentrations of Acridine Orange, Eosin Blue and Eosin Yellow in Methanol

In order to prepare different concentrations (0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.4 and 0.5 g/l) of Acridine orange, Eosin blue or Eosin yellow in methanol, the relation $C_1V_1=C_2V_2$ (where C_1 is the original concentration, C_2 the final concentration, V_1 the original volume and V_2 the final volume) has been applied.

Experimental Measurements

The measurement process includes the determination of the count rate during a period of 20 seconds. The measurements were performed for three replications for each sample, then the average was calculated. The net area was found by subtracting the measured value of the background, for the same time interval, from the measured value of the sample area.

The experimental measurements for all samples, and for every concentration, were performed using the experimental setup shown in Fig.1 [9, 10].

The prepared samples were irradiated by three gamma radioactive sources, namely ^{241}Am, ^{137}Cs and ^{60}Co. These sources were chosen since they emit gamma photons with low energy (59.5 keV for ^{241}Am), intermediate energy (662 keV for ^{137}Cs) and high energy (1173 and 1332 keV for ^{60}Co). Table 1 shows the nuclear data for all radioactive sources used in this work (manufactured by Amersham).

TABLE 1. Nuclear data for the used radioactive sources.

Isotope	$T_{1/2}$ (y)	$E\gamma$(keV)	$I\gamma$(%)	Activity at date of experiment (μCi)
^{241}Am	458	59.5	35.9	9.46
^{137}Cs	30	662	85.1	4.93
^{60}Co	5.2	1173	100	0.404
^{60}Co	5.2	1332	100	0.404

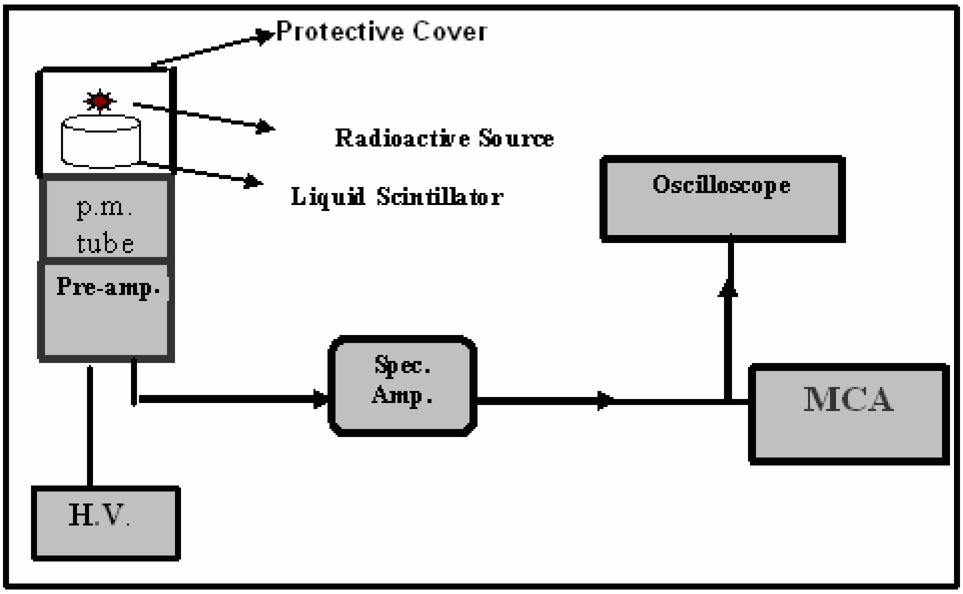

FIG. 1. Schematic diagram of the measurement system.

Results and Discussion

Tables 2, 3 and 4 list the net area under the curve of the spectrum for samples irradiated with ^{241}Am, ^{137}Cs and ^{60}Co, respectively. Note that the values within the tables represent ($N \pm \sqrt{N}$), where N = net area counts [11].

TABLE 2. Net area under the curve for samples irradiated for 20s with ^{241}Am.

Concentration (g/l)	Acridine Orange Counts	Eosin Blue Counts	Eosin Yellow Counts
0.5	240±15	552±23	275±17
0.4	295±17	615±25	390±20
0.3	380±19	750±27	470±22
0.25	550±23	875±30	610±25
0.2	690±26	1250±35	875±30
0.15	520±22	960±31	720±27
0.1	450±21	760±28	505±22
0.05	390±20	480±22	375±19

TABLE 3. Net area under the curve for samples irradiated for 20s with ^{137}Cs.

Concentration (g/l)	Acridine Orange Counts	Eosin Blue Counts	Eosin Yellow Counts
0.5	20700±144	24382±156	21500±147
0.4	22400±150	26435±163	23550±153
0.3	23700±154	28500±169	26560±163
0.25	26800±164	36600±191	29900±173
0.2	33500±183	39500±199	36200±190
0.15	26500±163	35300±188	28540±169
0.1	21250±146	32800±181	25500±160
0.05	19500±140	30900±176	22600±150

TABLE 4. Net area under the curve for samples irradiated for 20s with ^{60}Co.

Concentration (g/l)	Acridine Orange Counts	Eosin Blue Counts	Eosin Yellow Counts
0.5	5280±73	6840±83	6600±81
0.4	5500±74	7597±87	7170±85
0.3	5800±76	8104±90	7350±86
0.25	6100±78	10570±103	7900±89
0.2	7300±85	14200±119	8970±95
0.15	5730±76	11200±106	8100±90
0.1	5480±74	9520±98	7600±87
0.05	5040±71	7860±89	7200±85

The results in Tables 2, 3 and 4 are represented graphically in Figs. 2, 3 and 4, illustrating the variation of the count rate using each radioactive source with different concentrations of three different organic materials. Those figures show a gradual increase in the count rate (net area) at low concentrations of all chemical materials (Acridine orange, Eosin blue and Eosin yellow). The count rate then reaches its highest value and ultimately decreases at high concentrations.

This behavior can be explained as follows: First, the chemical quenching due to energy competition of the impurities within the sample, especially non fluorescent molecules, leads to the absorption of the transition energy originating between the solvent material and the primary solute, such that the decay from the excited state will happen without radiation. Second, the color quenching contributes to the competition process too, such that the color of the solute and the color due to the impurities will reduce the number of light photons within the sample. Third, the concentration quenching due to the increase in the molar concentration within the liquid scintillation sample will decrease the quantum efficiency of the fluorescence. The above three factors act together within the sample at the same time, such that at high concentration values, the total quenching effect reduces the fluorescence events, and the fluorescence intensity decreases.

We also notice that the optimum concentration for Acridine orange, Eosin blue and Eosin yellow that gives the maximum count rate is (0.2 g/l). The maximum count rate occurs for Eosin blue in comparison with the other materials (Acridine orange and Eosin yellow), as shown in Figs. 2, 3 and 4. However, there is no evident relation between the response of these materials at optimum concentration and the gamma energy.

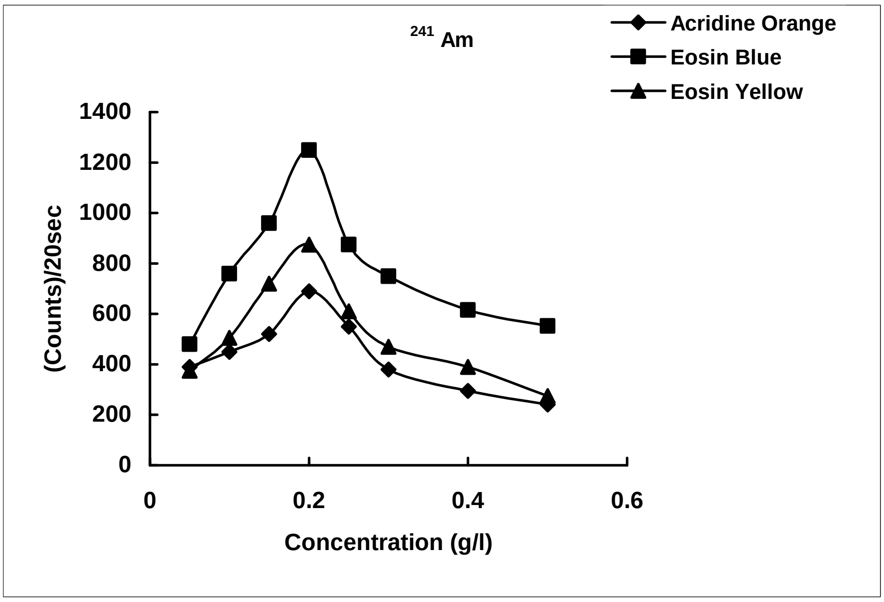

FIG. 2. The relation between the count rate, using ^{241}Am, and concentration for three different organic materials.

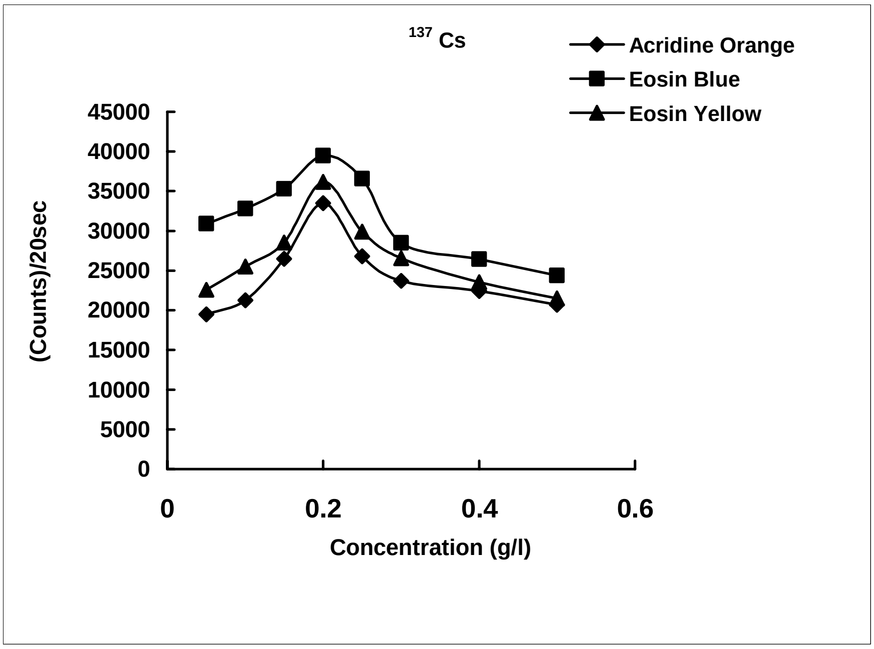

FIG. 3. The relation between the count rate, using ^{137}Cs, and concentration for three different organic materials.

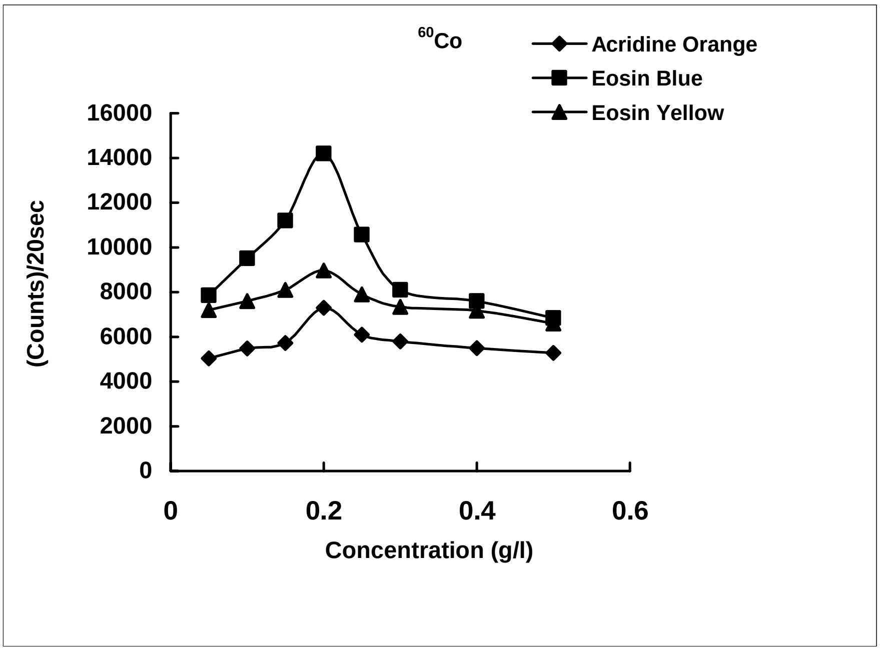

FIG. 4. The relation between the count rate, using ^{60}Co, and concentration for three different organic materials.

Fig. 5 shows the background spectrum for Eosin blue at a concentration of 0.2 g/l. In addition, Figs. 6, 7 and 8 show the spectra of Eosin blue, at a concentration of 0.2 g/l, irradiated with the radioactive sources ^{241}Am, ^{137}Cs and ^{60}Co, respectively.

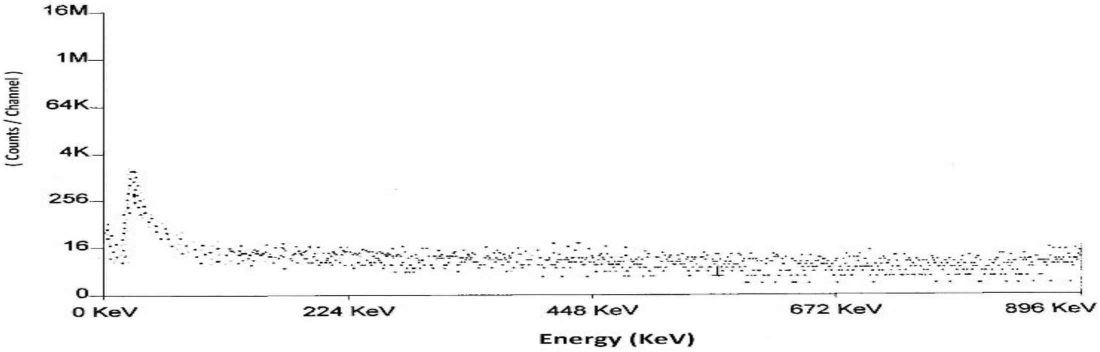

FIG. 5. The background spectrum of the Eosin blue sample at a concentration of 0.2 g/l.

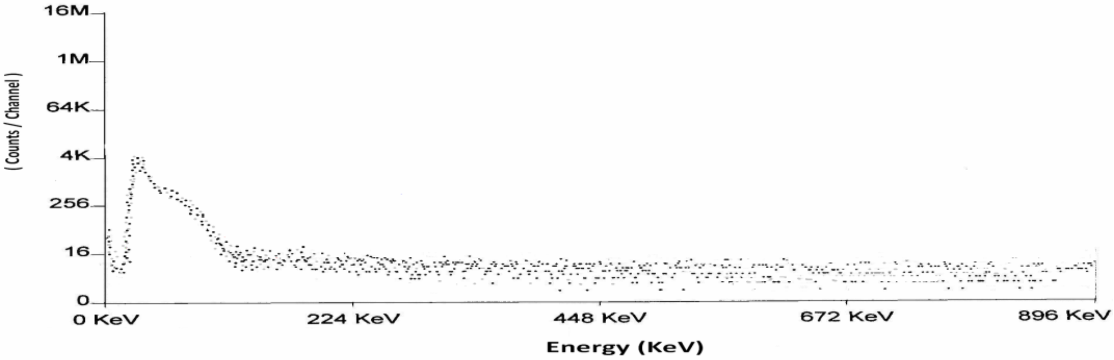

FIG. 6. The spectrum of Eosin blue sample at a concentration of 0.2 g/l irradiated with ^{241}Am.

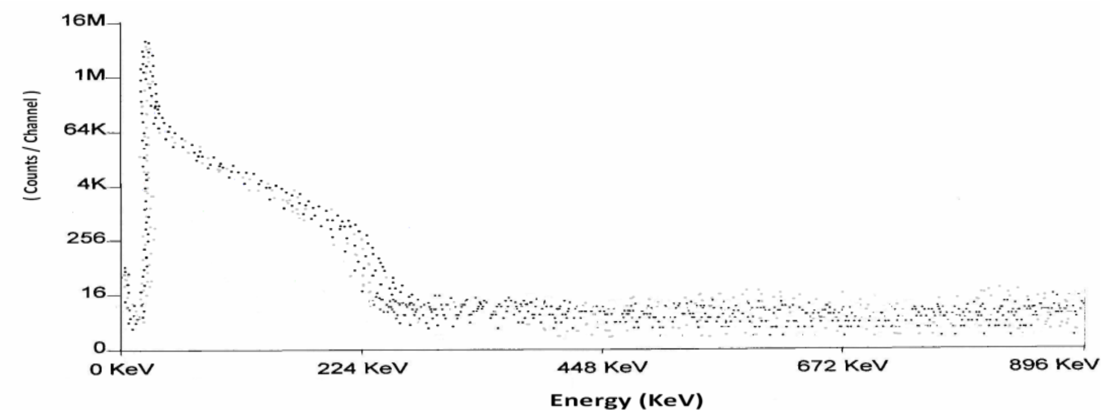

FIG. 7. The spectrum of the Eosin blue sample at a concentration of 0.2 g/l irradiated with ^{137}Cs.

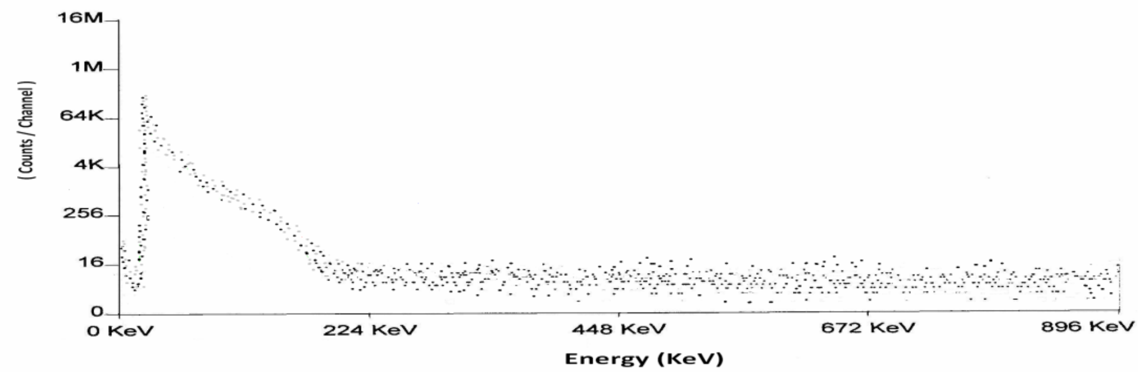

FIG. 8. The spectrum of the Eosin blue sample at a concentration of 0.2 g/l irradiated with ^{60}Co.

In order to investigate the properties of the used materials, IR analysis was performed. Fig. 9 shows the IR spectrum for the Eosin blue sample with the optimum concentration (0.2 g/l) before and after irradiation. Eosin blue was chosen due to its higher count rate as compared to the other two materials. It is clear that there is no significant difference in the spectrum before and after irradiation, implying that the irradiation time and the properties of the sources were not sufficient to produce any significant changes in the material.

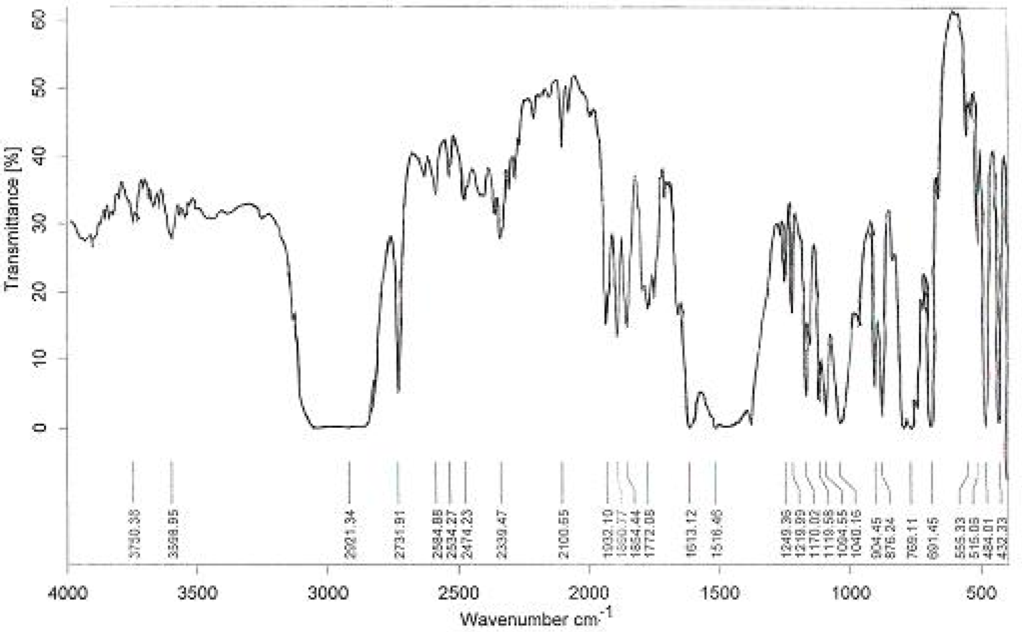

FIG. 9A. The IR analysis of Eosin blue with the optimum concentration of 0.2 g/l before irradiation.

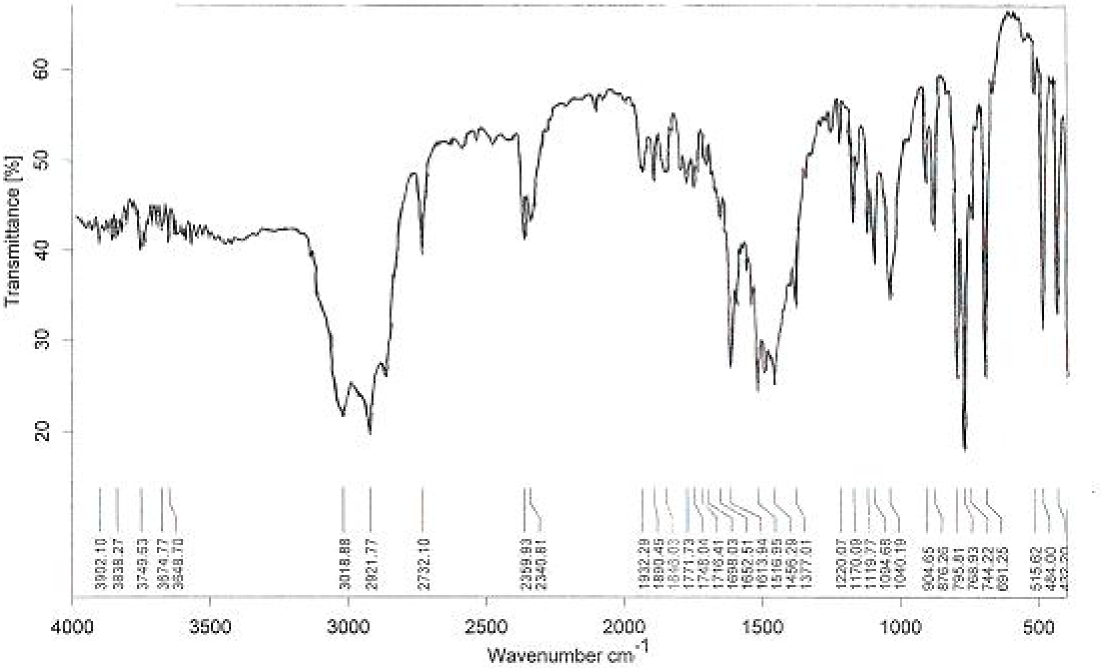

FIG. 9B. The IR analysis of Eosin blue with the optimum concentration of 0.2 g/l after irradiation.

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