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ARTICLE

Dosimetry for low temperature irradiation using table sugar

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Recent advances in radiation treatment technologies have showed enormous advantages for irradiated goods such as marinated chicken, seafood, and biological samples, which are preserved and irradiated below room temperature to avoid the synergetic effect of heat. Table sugar is considered a promising dosimetric material for EPR and UV readings because the free radicals produced during irradiation with X- and gamma rays are stable. Most studies that employ this system are carried out at room temperature. The aim of this work is to study the behavior of table sugar when it is exposed to gamma rays at a low temperature (77 K) to investigate whether an irradiation temperature dependency exists and evaluate its possible uses as a dosimeter for low-temperature irradiations. The results obtained show that table sugar might be used as a low-temperature dosimeter because it provides a stable signal, good reproducibility, and an accessible technique for analysis.

Keywords: gamma radiation; table sugar; saccharose; conductivity; dosimeter; low-temperature; EPR

1. Introduction

Low-temperature irradiations are important in the irradiation of some commercial products and in outer-space research. Irradiation at cryogenic temperatures is increasingly being used to process commercial, biological, and pharmaceutical products. Significant errors may occur because of irradiation temperature dependency. For this reason, assessing the influence of irradiation temperature on the response of a dosimeter is important for radiation metrology.

For several years, sugar (saccharose) has been regarded as a very promising system in the field of solid-state dosimetry. Gamma irradiation generates free radicals that are stable and detectable by electron paramagnetic resonance (EPR) or by UV absorption of an aqueous solution. These effects are used for dosimetric purposes in solid-state EPR dosimetry [1]. This system has been proposed as an emergency dosimeter for any person exposed to a nuclear or radiation accident because this material retains its radiation history [2]. The advantages of this system are that the free radicals formed by irradiation are stable after irradiation; they present a stable dose-dependent EPR signal. In addition, sugar is easily available. Flores et al. [3] have made a previous report about the radiation behavior of this compound, and most recently, the electrical conductivity of aqueous solutions of gamma-irradiated solid table sugar was investigated for high-dose dosimetric purposes [4]. However, all of these studies were carried out at room temperature (298 K). Some commercial applications increased the efficiency of the reaction at low temperatures due to a decrease of free radicals in the bulk material [5]; also, experiments made to simulate the low-temperature conditions of extraterrestrial environments are increasing [6]. For these types of applications, a reliable low-temperature dosimeter is needed. This paper describes the results of irradiating table sugar with gamma rays below room temperature to test whether this system could be used as dosimeter for low-temperature irradiation. In our study, the UV spectra analysis was set at 267 nm. Other measurements were changes in the conductivity of aqueous solutions of gamma-irradiated solid sugar table cubes and the EPR spectra for gamma-irradiated solid samples.

2. Experimental procedures

2.1. Samples

The samples of sugar (*saccharose)* were purchased commercially in the form of table sugar cubes at a local market in Mexico City and were used without any purification from their original paper packaging. After irradiation, the samples were kept in a dark place and controlled humidity. The measurements were made at room temperature. For each dose, duplicate samples were irradiated and analyzed.

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2.2. Irradiation

The absorbed doses for this study were delivered by a 60-cobalt Gamma beam 651 PT facility. The absorbed doses were between 1 and 18 kGy in a fixed position with a dose rate of 232 Gy/min for samples at room temperature and 159 Gy/min for samples irradiated at 77 K (1 Gy is equal to 1 joule per kilogram). The samples were irradiated at room temperature (298 K) and at liquid nitrogen temperature (77 K) inside a Dewar flask. Few samples were irradiated at 195 K and 343 K. The dose rate was determined with a ferrous ammonium sulfate-cupric sulfate dosimeter. To pre-equilibrate the dosimeters to a specific temperature, the samples were placed in the Dewar cylinder irradiation assembly and thermally equilibrated for at least 1 h prior to placement within the gamma source.

2.3. Analysis

2.3.1 UV spectroscopy

The UV analysis was made via spectrophotometry at 267 nm of an aqueous solution, 10% weight, at room temperature with a quartz cell of 1 cm length in a Varian model Cary-100 spectrophotometer at 22 ° ± 1º C.

2.3.2 Conductivity measurements

For this measurement, the irradiated table sugar was dissolved in triple-distilled water at concentrations of 5% w/v and 10 % w/v. The change in conductivity was made at 20º C with Vernier equipment. This was calibrated with a sodium chloride solution (500 mg/L). The equipment was connected to a computer with an interface and sensor. Distilled water has an electrical conductivity of 5.5μS/m.

2.3.3 EPR measurements

The EPR analysis was carried out at the Instituto de Química–UNAM on 30 ± 0.1 mg of the sample in a quartz tube at room temperature with a JEOL JES-TE300 spectrometer operating X-Band at 100-kHz modulation frequency and a cylindrical cavity in mode TE_{011}. The external calibration of the magnetic field was made with a precision gauss meter, JEOL ES-FC5. The spectrometer settings for all spectra were as follows: center field, 336.65 ± 10 mT; microwave power, 1 mW; microwave frequency, 9.4400700 GHz; modulation width, 0.79 x 0.1 mT; time constant, 0.1 s; amplitude, 7.9 x 10; sweep time, 120 s. The readings were made at the vertical peak–peak and are given in arbitrary units.

The analyses were done at room temperature and 2 hours after irradiating samples in order to avoid any interference with the readings because of the possible presence of species that were forming but whose life spans or stability would be very short.

The samples were kept at the dark during the whole experiment. Some samples were used to monitor the stability of EPR signal over time after irradiation, and they were placed in a dark and dry place.

3. Results and Discussion

3.1. Physical aspect of the samples

The color of irradiated sugar becomes darker as more radiation is absorbed. Other observations for a solution of irradiated table sugar are as follows:

a) A change in optical rotation of the solution.
b) Decrease in pH.
c) Relation between optical density and dose is a constant.
d) The EPR signal that originally existed in the irradiated solid form disappears when it is analyzed in an aqueous solution, possibly due to a recombination or reaction of the free radicals produced.

3.2. UV Response to dose irradiation

For irradiated aqueous solution of table sugar, the response to dose irradiation in terms of optical density versus the absorbed dose at two different temperatures is shown in **Figure 1**. (Optical density [OD] is the measure of the transmission of an optical medium for a given wavelength. Higher OD means lower transmittance and vice versa). The optical density versus the absorbed dose response was linear for both temperatures but had different slopes. The dose coefficient was approximately 0.015/kGy.

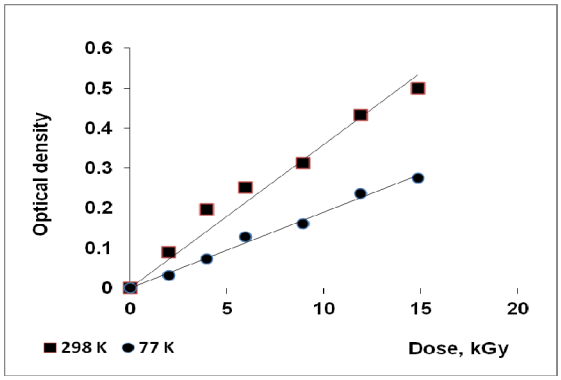

Figure 1. UV response at 267 nm of an aqueous dissolution of irradiated table sugar. Solid samples were irradiated at 298 K (■) and 77 K (●).

3.3. Conductivity measurements

The changes in conductivity showed linear behavior and at lower temperatures, the readings decreased. **Figure 2** shows the results for the conductivity at 298 K and 77 K for a 5% w/v solution.

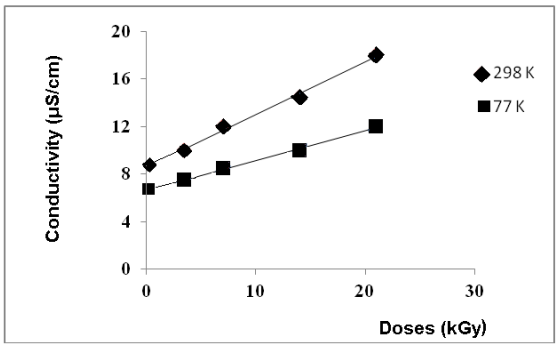

Figure 2. Change in conductivity as function of adsorbed dose for table sugar in 5 % solution at ◆ 298 K, and ▩ 77 K.

3.4. Solid samples measurements

Figure 3 shows the EPR spectra for samples irradiated at 77 K for different absorbed doses. No signal was observed when the material was not exposed to gamma radiation. **Figure 4** shows the EPR spectra of samples irradiated at 4.7 kGy at different temperatures. The response is lower for lower irradiation temperatures.

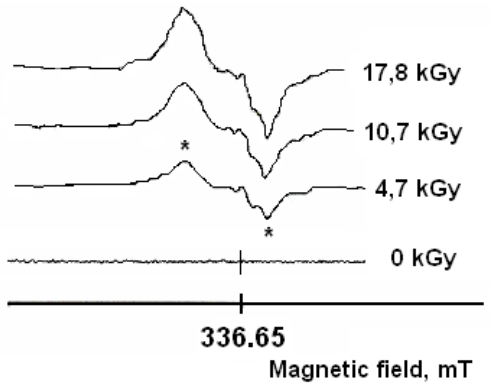

Figure 3. EPR spectra for samples irradiated at 77 K at different adsorbed doses. The asterisks represent the peaks height used for the measurement.

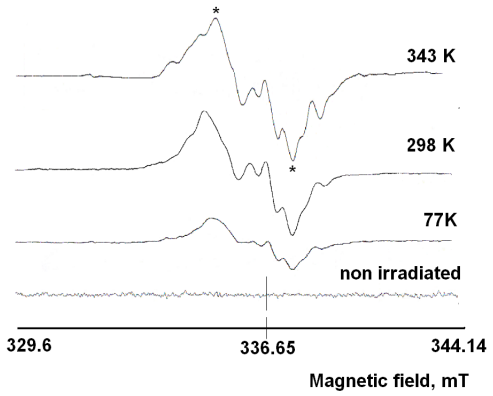

Figure 4. EPR spectra for samples of table sugar irradiated at 4.7 kGy and at different irradiation temperatures.

The EPR spectra show a broad signal consisted of several lines with constant spacing among them due to dipolar coupling. The results obtained by irradiation at low temperatures and fixed doses showed that the free radicals produced by irradiation were not affected by the temperature irradiation, and they presented the same structures. The g-factor has a value of g=2.0038, which is a typical value for free radicals observed in biological organic compounds after irradiation.

The lower signal value for temperatures below room temperature may be associated to the low mobility of the reactive species formed by irradiation in a frozen state.

Figure 5 shows the dose-response curve of irradiated table sugar at different doses and two temperatures. The response for both temperatures presented a linear behavior in the dose interval studied. The response was measured peak to peak of the first derivative of the EPR signal and normalized. Probably at higher doses the response may tend saturation. **Figure 6** presents the effect of the temperature on the response of table sugar relative to the response obtained at 298 K irradiated at fix dose (5.4 kGy). This figure suggests that the response of the sugar table is influence by the irradiation temperature.

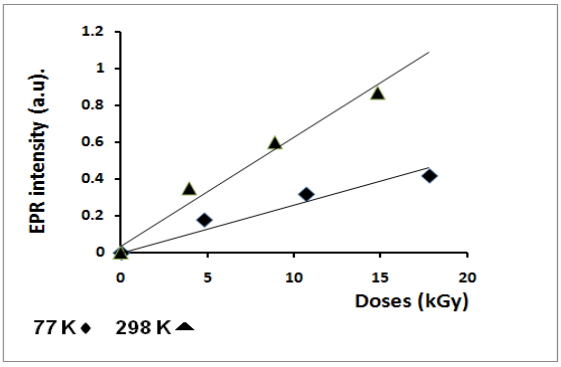

Figure 5. Dose-response curve for table sugar irradiated at two temperatures (77 K and 298 K).

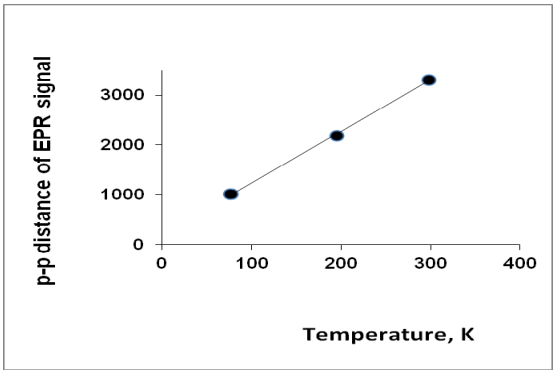

Figure 6. Response of table sugar irradiated at 5.4 kGy and at different irradiation temperatures: 77 K, 195 K, and 298 K.

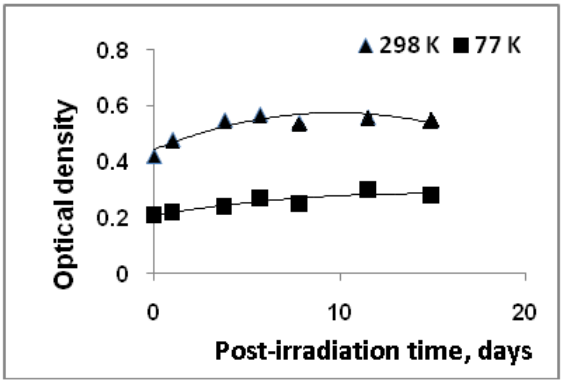

Figure 7. Post-irradiation effect for samples irradiated at 14 kGy at ▲ 298 K) and ■ 77 K and measured by UV spectroscopy.

3.5. Stability of the signals

The time stability of the irradiation-induced radicals in the samples is an important factor to consider for dosimetric purposes. In solid state, the signal remains unchanged for seven days.

3.5.1 EPR analysis

For a sample irradiated at 5.4 kGy at 298 K the EPR signal changes were monitored up to 29 days, the EPR signals varied 8 % of the original intensity.

3.5.2 UV Analysis

A study of the stability of long-term UV absorbance was performed for about two months to observe the decay or fading of the signal.

An aqueous solution prepared with irradiated table sugar, stored at room temperature and protected from light, gradually increased the value of the optical density, possibly because of a set of reactions that took place during the dissolution. **Figure 7** shows the post-irradiation response. The concentration of free radicals formed remained constant even after 15 days.

4. Conclusion

We studied the response of solid table sugar (*saccharose*) under irradiation at a low temperature. When irradiation takes place at 77 K, the concentration of free radicals formed is minor compared with that formed at a higher temperature (293 K), according to the signal strength obtained by EPR. The dose-response curve showed a linear behavior at 77 K and 298 K in the studied interval, suggesting that this material may be useful for dosimetric purposes. Besides, the EPR signal is stable for several days, and reproducible. The irradiation of this system at different temperatures showed that the response is influenced by this factor; however, it can be used as dosimeter for irradiation processes taking place at low temperature. Besides, the analysis of the sample can be done with different analytical techniques some of them common in an ordinary laboratory, like UV absorption and conductimetry. Other technique like EPR shows that the change of EPR the signal over seven days is stable and reproducible.

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