Optical studies of fast neutron irradiated composites of poly(vinyl alcohol) and bovine serum albumin

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ABSTRACT

The proposal in this study was to evaluate the optical properties of different biopolymers films before and after irradiation with fast neutrons. The materials used were: poly(vinyl alcohol) (PVA) and bovine serum albumin (BSA). PVA/BSA blends were prepared by casting technique. The effects of different BSA concentrations (2.5-15 wt%) on the optical properties by near infrared and transmittance in the spectral region 400–2500 nm of the PVA/BSA films were studied before and after irradiation with fast neutrons of fluence 1×10^7 n/cm². Transmittance spectra were used for the determination of the optical constants. The results indicate that variation in the optical band gap was derived from Tauc's extrapolation with the BSA contents. The results obtained by the effect of different weight percent of BSA were compared with that detected by the effect of fast neutron.

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KEYWORDS

INTRODUCTION

The categories of materials that are used as biomaterials include metals, ceramics, carbons, glasses, modified natural biomolecules, synthetic polymers and composites consisting of various combinations of these material types[1]. Detailed studies of doped polymer with different dopant concentrations allow the possibility of choice of the desired properties[2,3].

PVA is a water-soluble poly-hydrogel polymer, one of the few linear, no halogenated aliphatic polymers. PVA has a two dimensional hydrogen–bonded network sheet structure. The physical and chemical properties of PVA depend to a great extent on its method of prepa-

ration[4]. Poly(vinyl alcohol) is used in surgical devices, sutures, hybrid islet transplantation, implantation, blend membrane[5], in synthetic cartilage in reconstructive joint surgery[6], as a new type of soft contact lens developed from PVA hydrogel prepared by low temperature crystallization technique[7], as sheets to make bags for premeasured soap, for washing machines, or to make longer bags used in hospitals[8]. PVA was selected in the present study, as the hydrogel component based on its favorable water-soluble, desirable physicochemical properties and its biocompatibility[9]. Furthermore, chemically crosslinked PVA hydrogel has been gaining increasing attention in the field of biomedics[10].

Bovine serum albumin (BSA) is cheap and plen-

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tiful, owed to the fact that it is a natural byproduct of the cattle industry[11]. This makes it ideal in vaccine production, medical research, and food additives. BSA is essentially a plasma protein that can be used to grow cells, test the proteins of other cells, and be added to a variety of food products. BSA is quite stable, which makes it ideal for scientific measures. BSA is often used in restriction digest to stabilize some of the enzymes during the digestion of DNA for study. It is ideal for determining the quantity of other proteins present. These days, BSA is just as likely to be in a lab as a kitchen. It can be used to test DNA structure as well as supplement various meat products. Stable and safe, bovine serum albumin can help measure the quantities of other proteins, serving as a model to begin the comparison.

Previous investigations reported the intermolecular interactions between bovine serum albumin and certain water-soluble polymers at various temperatures[12] and the release of model proteins with net-positive (histone) and net-negative charge (BSA) from various scaffolding surfaces and from encapsulated microspheres in the presence of ions, proteins, and cells[13].

In the present study, a trail will be carried out to produce the best product of PVA/BSA blends. Variations in the group coordination in the near-infrared region were followed. The effects of BSA concentrations on the optical properties of the PVA films were studied by performing VIS/NIR analysis before and after irradiation with fast neutrons of fluence 1×10^7 n/cm^2, which give an evidence for understanding energy band diagram and optical parameters which is relatively affected by processing conditions. The study has been also extended to calculate the extinction coefficient (K) for the investigated films.

EXPERIMENTAL

Materials and sample preparation

Poly(vinyl alcohol) (PVA) granules with molecular weight of 125 kg/mole was supplied from El-Nasr Company, Cairo, Egypt. The viscosity of 4% aqueous solution of the polymer at 20 °C ranges from 4.5 to 5.4 cP. The residual poly(vinyl acetate) takes the value of 0 to 3%, the ash has maximum value as 0.75%. Bovine

serum albumin was supplied by Biomark, India and the component is normally free from impurities (min. 98.5%) has Helical structure.

The solution method[14,15] was used to obtain film samples. This method depends on the dissolution, separately, the weighted amounts of PVA granules and BSA powder in double distilled water. To prepare thin films of the blend of PVA and BSA with different weight percentages 100/0, 97.5/2.5, 95/5, 92.5/7.5, 90/10, 87.5/12.5 and 85/15 wt/wt%, the solutions were mixed together at 50 °C with a magnetic stirrer. Thin films of appropriate thickness (about 0.01 cm) were cast onto stainless steel Petri dishes (10 cm diameter). The prepared films were kept at room temperature (about 25 °C) for 7 days until the solvent completely evaporated and then kept in desiccators containing fused calcium chloride to avoid moisture. The samples were measured at room temperature as solid films (slabs) of dimensions 1 x 4 cm.

The prepare thin films of the blend of PVA and BSA were irradiated with fission neutrons with mean energy of approximately 4.2 MeV from Americium-Beryllium (^{241}Am-Be) neutron source of activity 5 Ci (185 GBq) and with emission rate 0.87×10^7 n/s at the Physics Department, Faculty of Science, Al-Azhar University, Cairo, Egypt. During irradiation the prepared samples were fixed in positions that neutrons were incident approximately normal. The irradiation temperature was adjusted to be about 25 °C. The films were exposed to neutron fluence 1×10^7 n/cm^2. The neutron fluence were measured using a calibrated TLD-700 Thermoluminescence detector at the location of the sample.

VIS/NIR spectroscopic measurements

The measurements in the visible region from 400 to 700 nm and NIR region from 900 to 2500 nm for PVA/BSA blends before and after irradiation with fast neutrons were carried out using a Shimadzu (UV/VIS/NIR) Double Beam Spectrophotometer with standard illuminant C (1174.83), has a serial number B44360512, Model V-530 and band width 2.0 nm covers the range 200-2500 nm with accuracy ±0.05%.

Optical and color parameters

The absorption coefficient (α) of the present mate-

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rials strongly depends on optical transmission, reflection and thickness of film which is evaluated using the relation[16,17]:

$$\alpha = (1/d) - \ln (1-R)^2/T \qquad (1)$$

Where T is the transmittance and d is the thickness of the sample in cm (the reflectance, R is neglected in this calculation). The optical energy gap (E_g) of the thin films has been determined from absorption coefficient data as a function of photon energy (hυ in eV). According to the generally accepted model proposed by Tauc for higher values of absorption coefficient where the absorption is associated with interband transitions, it yields the power part which obeys the Tauc[18] and Mott and Davis[19] relations as:

$$\alpha \, h \upsilon = B \, (h\upsilon - E_g)^n \qquad (2)$$

Where B is the slope of the Tauc edge called the band tail parameter and n is the type of electronic transition responsible for absorption, being 0.5 for direct transition and 2 for indirect one. In the low absorption region the absorption coefficient (α) shows an exponential dependence on photon energy (hv) and obeys the Urbach relation[16]:

$$\alpha = \alpha_0 \exp (h\upsilon / E_b) \qquad (3)$$

Where α_0 is a constant and E_b is the Urbach energy, interpreted as the width of the tails of localized states in the band gap. The absorption edge (E_e), the band tail (E_b), the direct energy gap (E_d) and the indirect energy gap (E_{ind}) were also calculated from the graphs of: α versus hv, $\ln \alpha$ versus hv, $(\alpha hv)^2$ versus hv and $(\alpha hv)^{1/2}$ versus hv, respectively.

The extinction coefficient (K) is important parameters characterizing photonic materials. Value of K can be calculated from transmission and reflection spectra using the relation[17]:

$$K = \alpha\lambda/4\pi \qquad (4)$$

Where λ is the wavelength and α is the absorption coefficient. The decrease in the extinction coefficient with an increase in wavelength shows that the fraction of light lost due to scattering.

The color parameters: relative tristimulus values (x_t, y_r and z_t), the brightness (L), the color constants (A) and (B), the whiteness index (W), the yellowness index (Ye) and the calculation color differences (total color difference, ΔE, the difference in chroma, ΔC and the difference in color hue, ΔH) are estimated using the CIE relations as reported previously[15,20,21].

RESULTS AND DISCUSSIONS

Near infrared (NIR) spectral analysis of PVA/BSA blends

The transmittance spectra and the assignments of the most important bands in the near infrared region 900-2500 nm for PVA/BSA blended samples before (a) and after (b) irradiation with fast neutrons fluence 1 x 10^7 n/cm², respectively, are shown in Figure 1. TABLE 1 illustrates the variation of the peak positions as well as the bond vibration and chemical structure for PVA/BSA blended samples before and after irradiation with fast neutron[22]. It is clear from Figure 1 and TABLE 1 for PVA/BSA blended samples that a slight variation has been observed in the transmission bands. In addition, it is noticed that strong local interaction between albumin and other groups to different chains in PVA will take place at the expense of the intermolecular interaction between these chains[23]. This in turn can be directly correlated with variations in the mechanical behavior of the polymer[24,25].
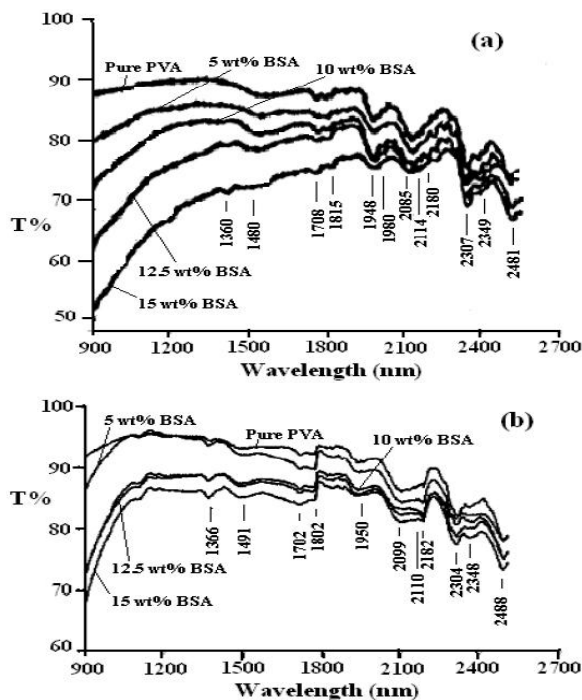

Figure 1 : Variation in NIR spectra of PVA/BSA blends before (a) and after (b) irradiation with fast neutrons fluence 1 x 10^7 n/cm²

Visible analysis

The study of optical transmission spectra provides essential information about the band structure and the

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energy gap in crystalline and non-crystalline materials. Analysis of the transmission spectra in the energy part (1.77-3.1 eV) gives information about atomic vibra-

tions. Hence, the study of optical properties in the visible region can help in a better understanding of the optical material constants[26,27].

TABLE 1 : Positions and chemical assignments of the most NIR absorption bands for PVA/BSA blends before and after irradiation with fast neutrons fluence 1 x 10^7 n/cm^2

Wavelength (nm)		Assignments and chemical structure	
Before irradiation	After irradiation	Bond vibration	Chemical Structure
2481	2488	C-H stretching + C-C stretching	= CH group
2349	2348	CH$_2$ symmetric stretching + =CH$_2$ defromation	HC=CHCH$_2$
2307	2304	C-H stretching + C-H deformation	CH$_2$ or CH$_3$
2180	2182	2x amide I + amide III	Protein
2114	2110	N-H symmetric stretching + amide III	CONH$_2$, CONHR
2085	2099	O-H stretching + O-H deformation	ROH, Sucrose
1980	1985	N-H assymmetric stretching + amide II	Protein
1948	1950	C=O stretching overtone O-H stretching + O-H deformation	CO$_2$R H2O
1815	1802	O-H stretching + 2(C-O) stretching	Cellulose
1708	1702	O-H stretching first overtone (intermole. H-bond) N-H stretching first overtone	Glucose CONH$_2$
1481	1491	C-H stretching first overtone	CH$_2$
1360	1366	2x C-H stretching + C-H deformation	CH$_3$

Figure 2 shows the transmission spectra of PVA/BSA blends in the wavelength range 400-700 nm before (a) and after (b) irradiation with fast neutrons fluence 1 x 10^7 n/cm^2, respectively. It is clear from the figure

that the spectrum for pure PVA is higher than those for PVA/BSA blend compositions in all wavelength range. The decrease in the transmission values of the blend samples with increasing the concentration of BSA up
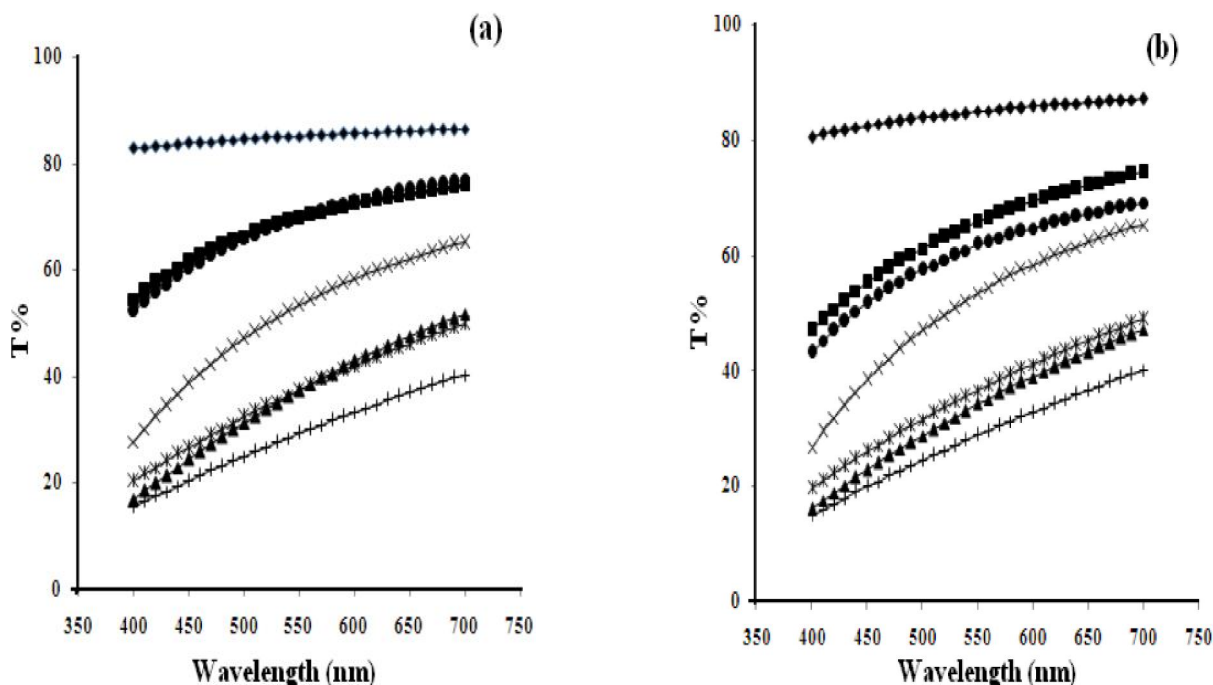

Figure 2 : The transmission spectra of PVA/HPMC blends before (a) and after (b) irradiation with fast neutrons fluence 1 x 10^7 n/cm^2: (♦) 100/0, (■) 97.5/2.5, (●) 95/5, (x) 92.5/7.5, (*) 90/10, (▲) 87.5/12.5 and (+) 85/15 (wt/wt%)

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to 15 wt% as well as by irradiation with fast neutrons may be attributed to the fact that increasing the concentration of BSA and/or irradiation with fast neutron decreases the transparency of the sample which may be due to that there is a change in the molecular configuration which leads to the formation of new color centers[14,15,28].

Optical parameters of PVA/BSA blends

The total transmission spectral response (i.e., the absorption coefficient, α) for PVA/BSA blends were calculated in the visible wavelength range from 400 to 700 nm and in the photon energy range 1.77-3.10 eV.

Figure 3 shows the relation between the absorption coefficient (α) as a function of wavelength in the visible range for PVA/BSA blended samples before (a) and after (b) irradiation with fast neutrons fluence 1 x 10^7 n/cm², respectively. It is clear from figures 3a and 3b that the absorption coefficient (α) increases gradually with increasing BSA content as well as with fast neutron fluence. The increase in α with the increase in the BSA content and/or neutron irradiation may be attributed to the change of the molecular configuration which indicates to the formation of new color centers as previously mentioned and reported[14,15].
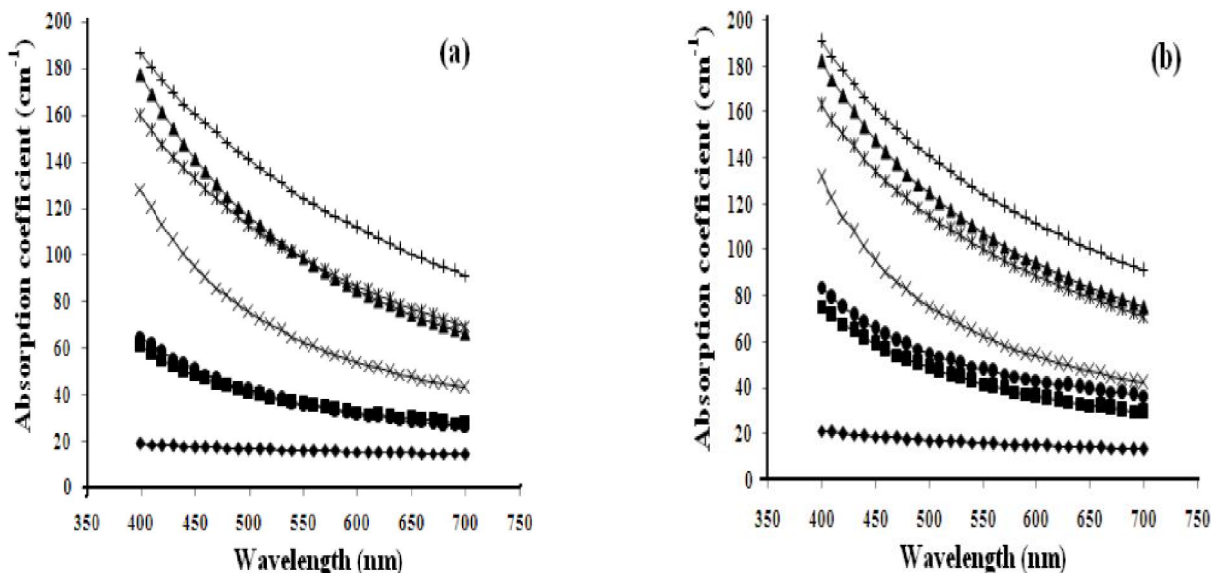

Figure 3 : The absorption coefficient (α) of PVA/BSA blends as a function of wavelengths in the visible range before (a) and after (b) irradiation with fast neutrons fluence 1 x 10^7 n/cm²: ($\blacklozenge$) 100/0, ($\blacksquare$) 97.5/2.5, ($\bullet$) 95/5, (x) 92.5/7.5, (*) 90/10, ($\blacktriangle$) 87.5/12.5 and (+) 85/15 (wt/wt%)

The fundamental absorption edge is one of the most important features of the absorption and transmission spectra of crystalline and amorphous materials. The increased absorption near the edge is caused by the transition of electrons from the valence band to the conduction band[22]. Figure 4 illustrates the plot of absorption coefficient against photon energy (1.77-3.10 eV) for PVA/BSA blend samples before (a) and after (b) irradiation with fast neutrons fluence 1 x 10^7 n/cm² respectively. It is clear that the absorption coefficient values increases with increasing photon energy and exhibits a steep rise near the absorption edge and a straight line relationship is observed in the high α-region. The intercept of extrapolation to zero absorption (i.e., $\alpha = 0$) with photon energy axis was taken as the value of

absorption edge (E_e) and the values obtained are listed in TABLE 2. It is clear that the values of the absorption edge (E_e) for BSA dopent concentration and fast neutron irradiation are higher than that for pure PVA. This may reflect the induced changes in the number of available final states according to the blend composition.

In amorphous as in crystalline materials some useful information can be deduced from absorption edge. For many amorphous materials an exponential dependence of absorption coefficient on photon energy is found to obey an empirical relation due to Urbach equation[14]. Figure 5 shows the relation between $-\ln \alpha$ and $h\upsilon$ for PVA/BSA blended samples in the visible range before (a) and after (b) irradiation with fast neutrons, respectively. The straight lines obtained suggest that the

absorption follows the quadratic relation for interband transitions and the Urbach rule is obeyed[19]. The values of band tail energy (E_b) can be deduced from the slopes of the straight lines and are listed in TABLE 2. The values of E_b increase with increasing BSA concentration up to 7.5 wt% as well as with fast neutron irradiation and then decrease and show fluctuation values up to 15 wt% BSA but still higher than the values of the pure PVA. The tail states are generated due to disorder in the system and these variations may be due to the variation in the internal fields associated with structure disorder in the system[19].
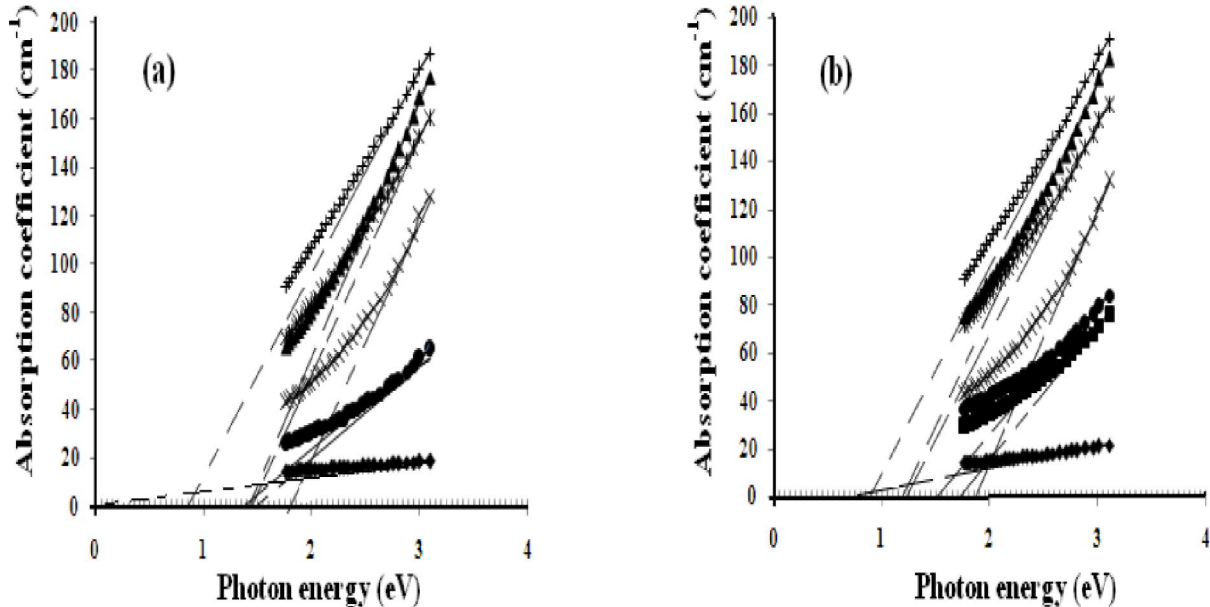

Figure 4 : The absorption coefficient (α) of PVA/BSA blends as a function of photon energy (hυ) in the visible range before (a) and after (b) irradiation with fast neutrons fluence 1 x 10⁷ n/cm²: (♦) 100/0, (■) 97.5/2.5, (●) 95/5, (x) 92.5/7.5, (*) 90/10, (▲) 87.5/12.5 and (+) 85/15 (wt/wt%)
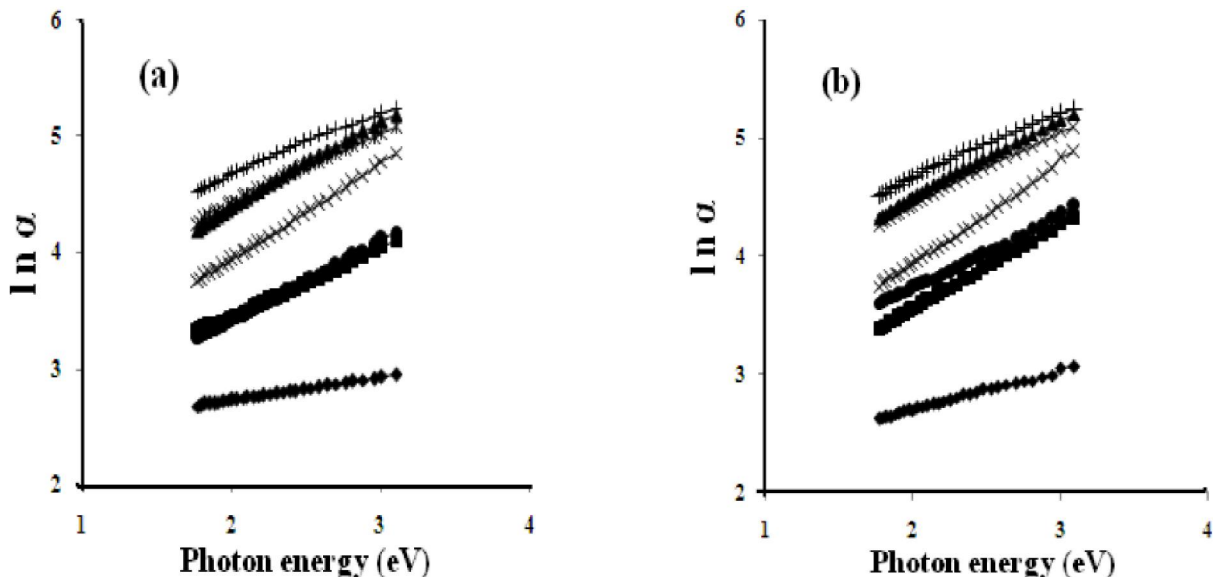

Figure 5 : Urbach law plots for PVA/BSA blends as a function of photon energy (hυ) in the visible range before (a) and after (b) irradiation with fast neutrons fluence 1 x 10⁷ n/cm²: (♦) 100/0, (■) 97.5/2.5, (●) 95/5, (x) 92.5/7.5, (*) 90/10, (▲) 87.5/12.5 and (+) 85/15 (wt/wt%)

Figure 6 shows the dependence of $(\alpha h\upsilon)^2$ on hυ for PVA/BSA blended samples before (a) and after (b) irradiation with fast neutrons fluence 1 x 10⁷ n/cm², respectively. From the figure, the allowed direct energy

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gap (E_d) is determined by extrapolating the linear parts of the curves to zero absorption and the values of E_d are listed in TABLE 2. It is clear from the table that, the values E_d increases nearly gradually with increasing BSA concentration up to 7.5 wt% as well as by irradiation with fast neutron and then decrease and show fluctuation values up to 15 wt% BSA but still higher than the values of the pure PVA.
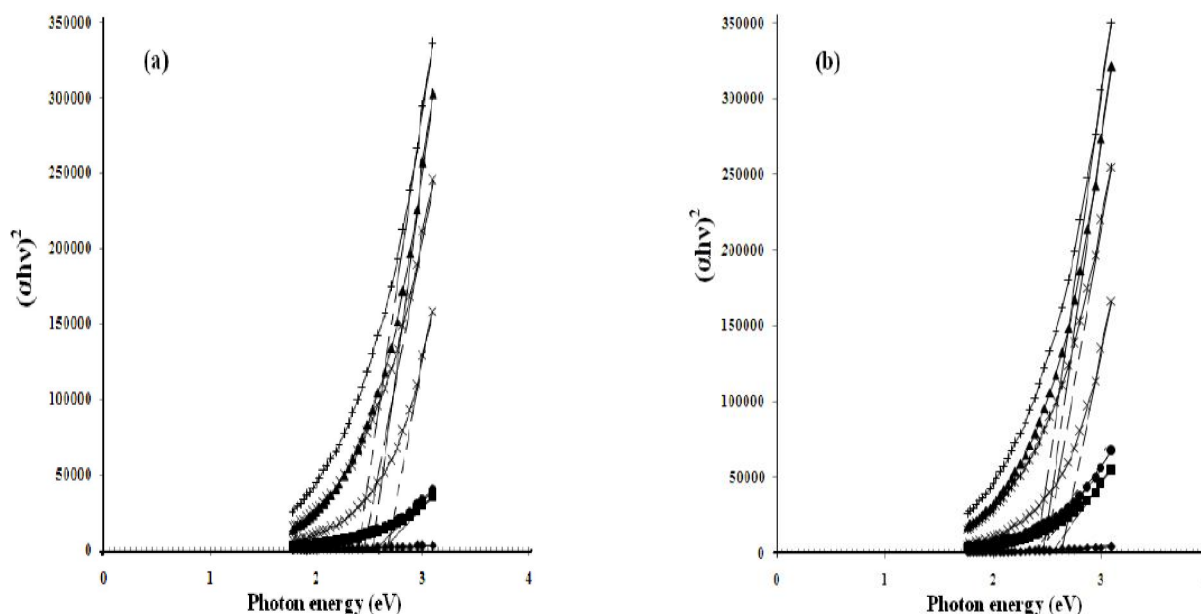

Figure 6 : The variation of ($\alpha h\upsilon$)² of PVA/BSA blends as a function of photon energy (hυ) in the visible range before (a) and after (b) irradiation with fast neutrons fluence 1 x 10⁷ n/cm²: (♦) 100/0, (■) 97.5/2.5, () 95/5, (x) 92.5/7.5, (*) 90/10, (▲) 87.5/12.5 and (+) 85/15 (wt/wt%)

Figure 7 shows the variation of ($\alpha h\upsilon$)$^{1/2}$ as a function of hυ for PVA/BSA blended samples before (a) and after (b) irradiation with fast neutrons fluence 1 x 10⁷ n/cm², respectively. From the figure, the allowed indirect energy gap (E_{ind}) is determined by extrapolating the linear parts of the curves to zero absorption and the values of E_{ind} are represented in TABLE 2. It is clear that the values of E_{ind} for the blend samples are

TABLE 2 : Values of absorption edge (E_e), band tail energy (E_b), direct energy gap (E_d), and indirect energy gap (E_{ind}) for PVA/BSA blend samples before and after irradiation with fast neutrons fluence 1 x 10⁷ n/cm² and their percentage changes

PVA/BSA blend (wt/wt%)	E_e (eV)	$\Delta E_e\%*$	E_b (eV)	$\Delta E_b\%*$	E_d (eV)	$\Delta E_d\%*$	E_{ind} (eV)	$\Delta E_{ind}\%*$
Before irradiation								
100/0	0.067	-	0.195	-	2.066	-	0.068	-
97.5/2.5	1.442	2052.24	0.563	188.72	2.486	20.32	0.932	1270.59
95/5	1.557	2223.88	0.668	242.56	2.508	21.39	1.015	1392.65
92.5/7.5	1.812	2604.48	0.803	311.79	2.574	24.59	1.286	1791.18
90/10	1.110	1556.72	0.658	237.44	2.100	1.65	0.598	559.41
87.5/12.5	1.427	2029.85	0.778	289.97	2.475	19.79	0.931	1269.91
85/15	0.755	1026.87	0.584	199.49	2.351	13.79	0.468	588.24
After irradiation								
100/0	0.071	-	0.320	-	2.241	-	0.183	-
97.5/2.5	1.514	2032.39	0.709	121.56	2.497	11.42	1.017	455.74
95/5	1.506	2021.13	0.590	84.38	2.506	11.83	1.020	457.38
92.5/7.5	1.836	2485.92	0.828	158.75	2.617	16.78	1.347	636.07
90/10	1.102	1452.11	0.641	100.31	2.430	8.43	0.683	273.22
87.5/12.5	1.268	1685.92	0.692	116.25	2.450	9.33	0.816	345.90
85/15	0.851	1098.59	0.590	84.38	2.359	5.27	0.464	153.55

* $\Delta E\%$ means $\Delta E_e\%$, $\Delta E_b\%$, $\Delta E_d\%$, or $\Delta E_{ind}\%$

increases nearly gradually with increasing BSA concentration up to 7.5 wt% as well as by irradiation with fast neutron and then decrease and show fluctuation values up to 15 wt% BSA but still higher than the values of the pure PVA. The obtained values for E_{ind} show the dependence on the composition of the sample. It may be presumed that the variation of them may be due to the difference in the change in molecular configuration induced by dopant concentration and/or by irradiation with fast neutron.

It was noticed that the variations in the values of E_e, E_b, E_d and E_{ind} with increasing the concentration of BSA and fast neutron irradiation may be due to induced structural changes in the system. In another meaning, this change may arise from the random fluctuations of the internal fields associated with the structure disorder in the amorphous region of polymer material. Furthermore, it was recognized that dopant plays a dominant role in morphological and microstructure changes occurring in the polymer matrix[14,27].
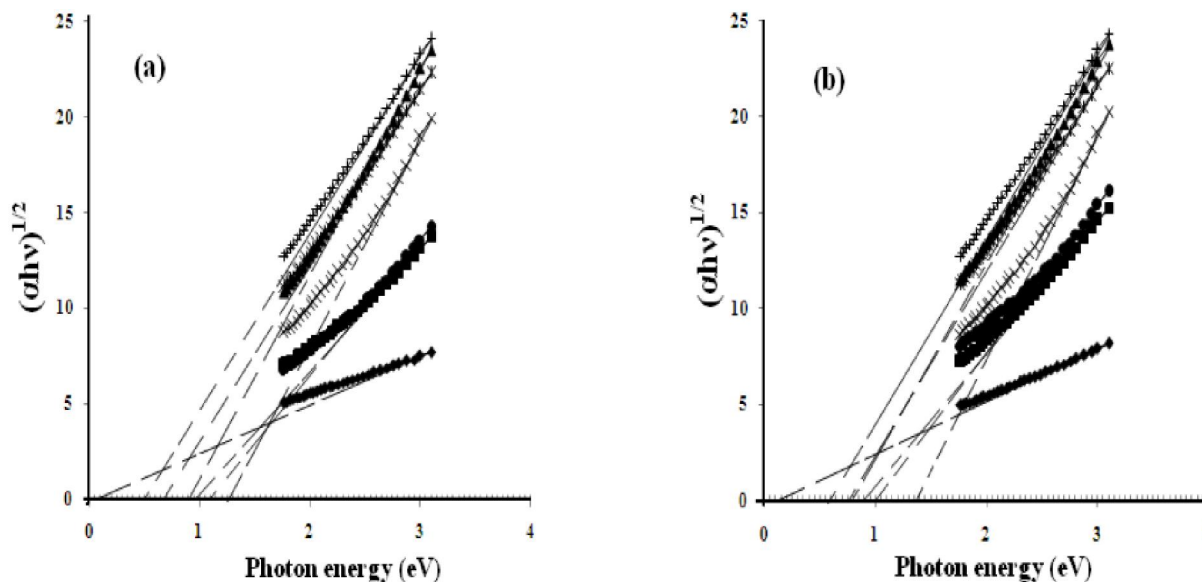

Figure 7 : The variation of $(\alpha h\upsilon)^{1/2}$ of PVA/BSA blends as a function of photon energy (hυ) in the visible range before (a) and after (b) irradiation with fast neutrons fluence 1 x 10^7 n/cm^2: ($\blacklozenge$) 100/0, ($\blacksquare$) 97.5/2.5, ($\bullet$) 95/5, (x) 92.5/7.5, (*) 90/10, ($\blacktriangle$) 87.5/12.5 and (+) 85/15 (wt/wt%)

Extinction coefficient

The extinction coefficient (K) describes the properties of the material to light of a given wavelength and indicates the amount of absorption loss when the electromagnetic wave propagates through the material, i.e. represents the damping of an EM wave inside the material. Figure 8 shows the variation in the extinction coefficient (K) with wavelength for PVA/BSA blended samples before (a) and after (b) irradiation with fast neutrons fluence 1 x 10^7 n/cm^2, respectively. It is clear from the figure that similar behavior for all samples are observed and the values of K are found to be small in the order 10^{-4} throughout the studied wavelength range which indicate that the samples under investigation are considered to be insulating materials at room temperature[29]. Furthermore, it is also clear that, the blend sample 85/15 wt/wt% for PVA/BSA indicates the high-

est value of K through the whole range of wavelength (400-700 nm). Moreover, the values of K for PVA/BSA blend samples are higher than that of the pure PVA value in the whole range of wavelength. The values of K for the irradiated PVA/BSA blend samples are higher than that for the unirradiated ones.

Optical transmittance and color difference calculations of PVA/BSA blends

From the values of transmittance (Figure 1), the tristimulus transmittance values (x_t, y_t and z_t) are calculated and plotted as a function of wavelength (400-700 nm) and shown in Figures 9-11, respectively, for PVA/BSA blended samples before (a) and after (b) irradiation with fast neutrons fluence 1 x 10^7 n/cm^2, respectively. TABLE 3 illustrates the values of x_r, y_r and z_r at the peak positions for PVA/BSA unirradiated and irradiated blended samples. It is observed from the figures
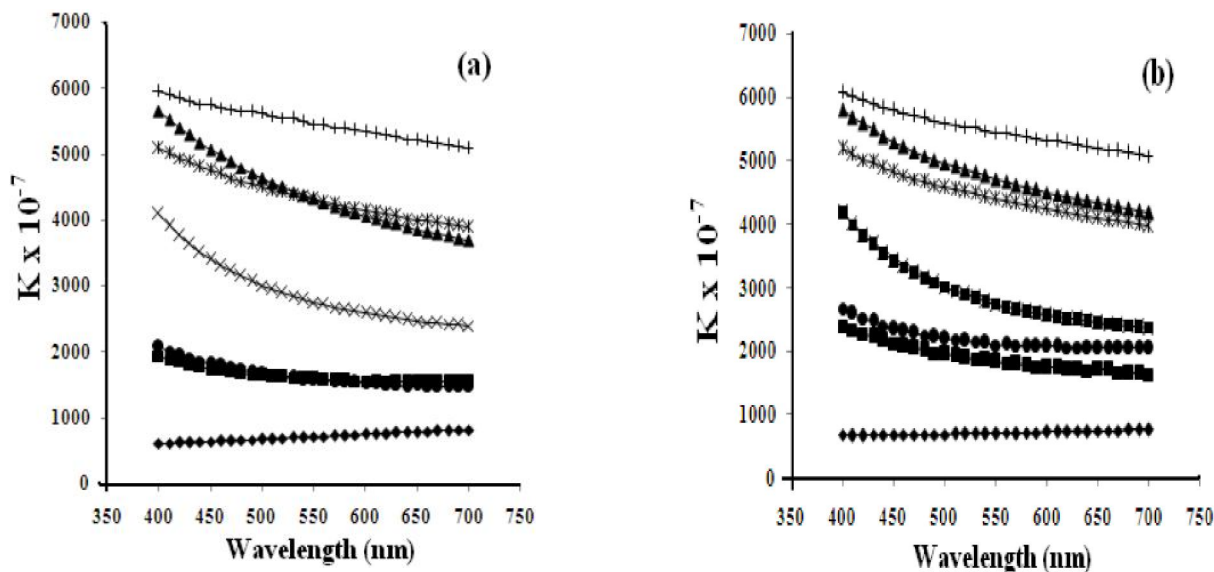
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Figure 8 : Variation in the extinction coefficient (K) as a function of wavelength (λ) of PVA/BSA blends before (a) and after (b) irradiation with fast neutrons fluence 1 x 10^7 n/cm²: ($\blacklozenge$) 100/0, ($\blacksquare$) 97.5/2.5, ($\bullet$) 95/5, (x) 92.5/7.5, (*) 90/10, ($\blacktriangle$) 87.5/12.5 and (+) 85/15 (wt/wt%)

TABLE 3 : Represents the x_r, y_r and z_r tristimulus transmittance values of PVA/BSA blends before and after irradiation with fast neutrons fluence 1 x 10^7 n/cm² calculated from transmittance data

PVA/BSA Blend (wt/wt%)	x_r		y_r	z_r
	$\lambda = 445$ nm	$\lambda = 595$ nm	$\lambda = 560$ nm	$\lambda = 455$ nm
Before irradiation:				
100/0	331.91	767.86	838.26	1727.40
97.5/2.5	241.24	646.48	691.72	1271.71
95/5	235.49	650.06	692.12	1241.38
92.5/7.5	151.71	520.83	535.25	799.72
90/10	104.14	376.04	377.59	548.97
87.5/12.5	95.29	383.02	378.98	502.33
85/15	331.91	767.86	838.26	1727.40
After irradiation:				
100/0	323.18	767.91	837.37	1703.67
97.5/2.5	216.38	619.99	654.23	1140.66
95/5	202.68	578.73	613.39	1068.43
92.5/7.5	150.41	521.91	536.24	792.91
90/10	101.71	367.89	369.04	536.18
87.5/12.5	89.11	349.03	344.93	469.72
85/15	77.6	292.90	290.80	409.05

and the table that, the behaviors of the tristimulus transmittance values for the samples are similar and almost no changes in peak positions are detected either with increasing the concentration of BSA or irradiated with fast neutron fluence of 1 x 10^7 n/cm². It is also ob-

served that the values of x_t, y_t and z_t decreases remarkably with increasing the concentration of BSA up to 15 wt% for both the unirradiated and irradiated blended. On other hand, slightly variations in the values x_t, y_t and z_t are detected of the irradiated PVA/BSA blended samples in comparison with the unirradiated samples. Figure 12 shows the percentage changes in the tristimulus transmittance values (x_t, y_t and z_t) with the increasing of concentration of BSA before and after irradiation with fast neutrons of fluence 1 x 10^7 n/cm².

TABLE 4 represents the variations of color parameters calculated from the transmittance curves for PVA/BSA blends before and after irradiation with fast neutrons fluence and their percentage changes. From the table it is observed that:

- **The brightness (L)**
  The brightness (L) shows remarkable decrease of about 41% for unirradiated samples and about 42% for irradiated samples are detected with increasing the concentration of BSA up to 15.
- **The color constants A and B**
  For PVA/BSA unirradiated and irradiated blended samples, the values of color constant A decreases with increasing BSA concentration up to 7.5 wt% which means that there is an increase in green component instead of red one and then highly increases with BSA concentration up to 15 wt% which means that there is an increase in red component instead of green one.
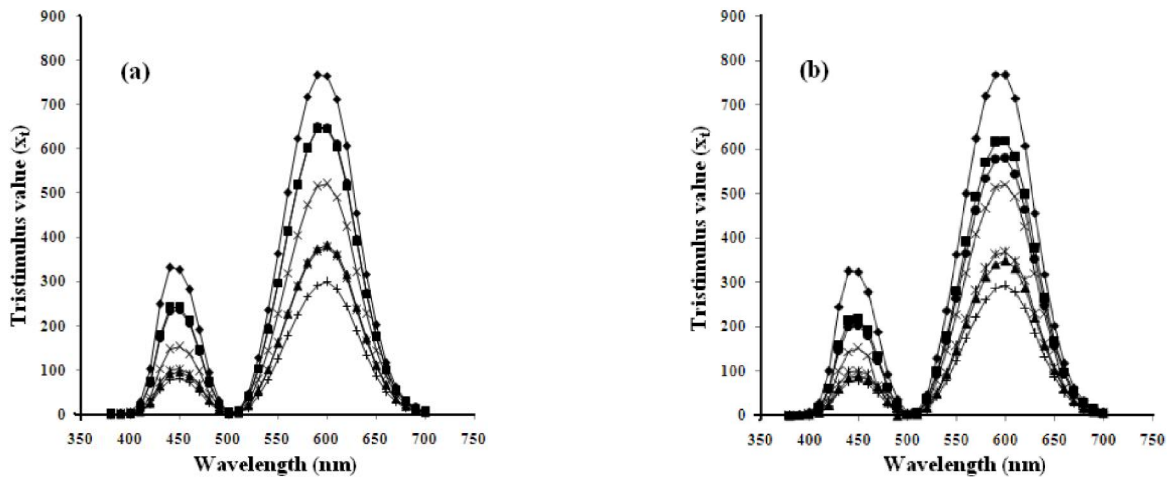
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Figure 9 : Variation of the tristimulus value (x_t) with wavelength for PVA/BSA blends before (a) and after (b) irradiation with fast neutrons fluence 1 x 10^7 n/cm^2: (♦) 100/0, (■) 97.5/2.5, (●) 95/5, (x) 92.5/7.5, (*) 90/10, (▲) 87.5/12.5 and (+) 85/15 (wt/wt%)

Figure 10 : Variation of the tristimulus value (y_t) with wavelength for PVA/BSA blends before (a) and after (b) irradiation with fast neutrons fluence 1 x 10^7 n/cm^2: (♦) 100/0, (■) 97.5/2.5, (●) 95/5, (x) 92.5/7.5, (*) 90/10, (▲) 87.5/12.5 and (+) 85/15 (wt/wt%)
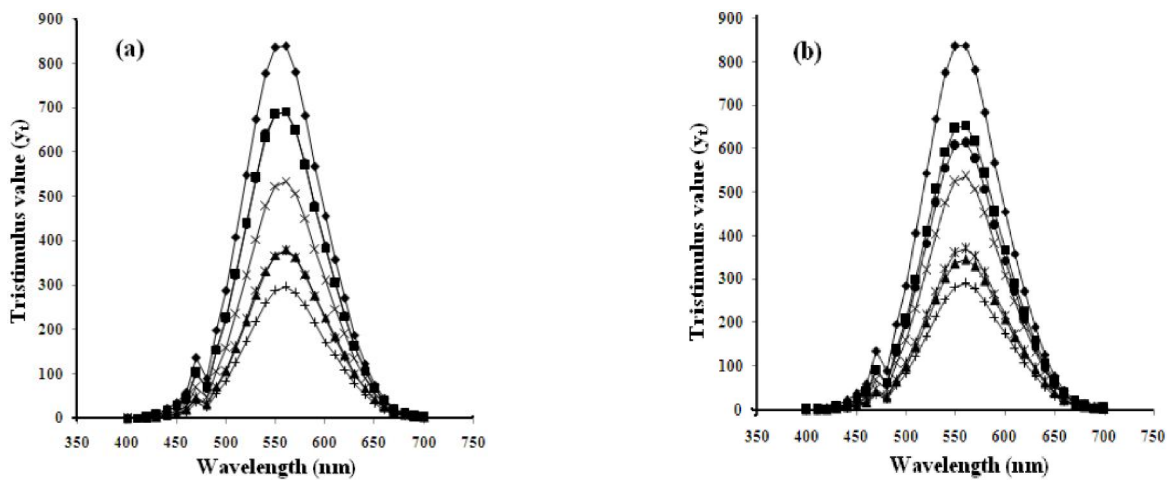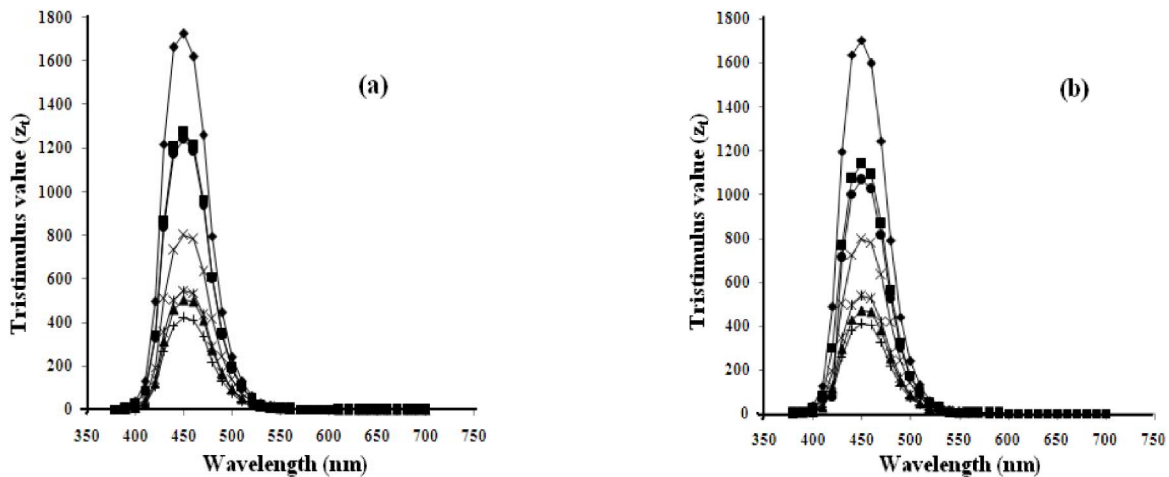
Figure 11 : Variation of the tristimulus value (z_t) with wavelength for PVA/BSA blends before (a) and after (b) irradiation with fast neutrons fluence 1 x 10^7 n/cm^2: (♦) 100/0, (■) 97.5/2.5, (●) 95/5, (x) 92.5/7.5, (*) 90/10, (▲) 87.5/12.5 and (+) 85/15 (wt/wt%)
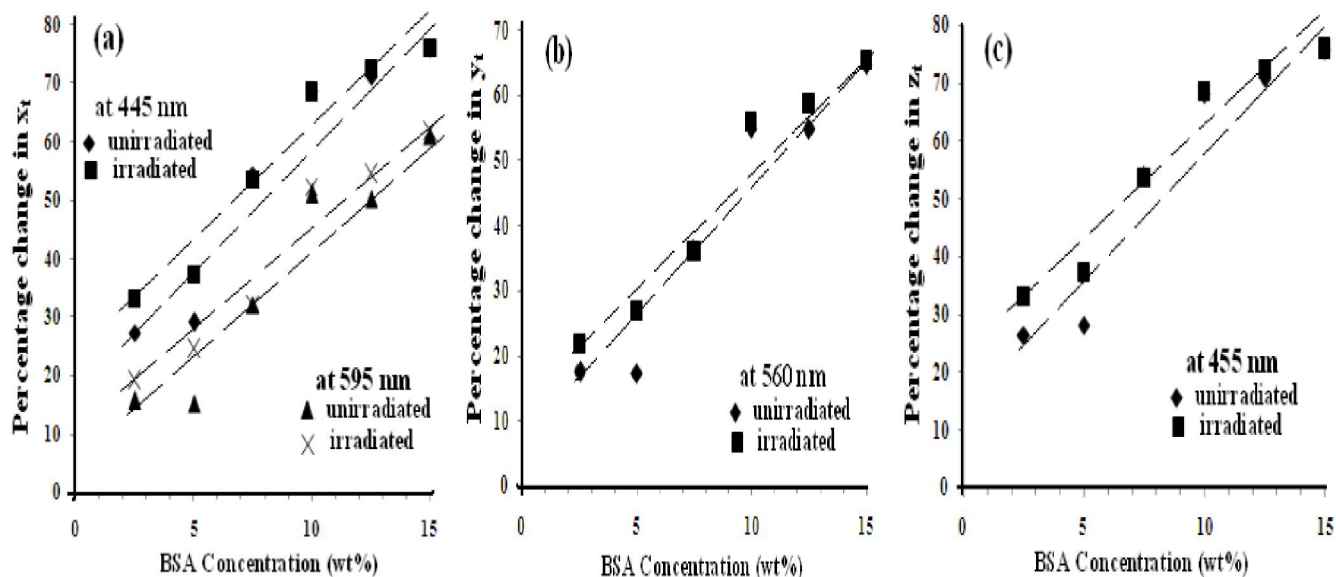
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Figure 12 : Variations in the percentage changes of the tristimulus values: (a) $\Delta x_t\%$, (b) $\Delta y_t\%$ and (c) $\Delta z_t\%$ with the concentration of BSA (wt%) before and after irradiation with fast neutrons fluence 1 x 10^7 n/cm²

TABLE 4 : The variations of color parameters for PVA/BSA blends before and after irradiation with fast neutrons fluence 1 x 10^7 n/cm² and their percentage changes

Color parameters	PVA/BSA blends (wt/wt%)						
	100/0	97.5/2.5	95/5	92.5/7.5	90/10	87.5/12.5	85/15
Before irradiation:							
L	92.249	83.553	83.600	73.209	61.638	61.592	54.476
$\Delta L\%$	-	-9.43	-9.38	-20.64	-33.18	-33.23	-40.95
A	-0.051	-0.228	-0.365	-0.004	1.140	1.459	1.400
$\Delta A\%$	-	-347.06	-615.69	+92.16	+2335.29	+2960.78	+2845.10
B	1.011	6.583	7.785	13.549	12.306	14.664	11.418
$\Delta B\%$	-	+551.37	+670.03	+1240.16	+1117.21	+1350.45	+1029.38
W	-686.112	-589.919	-596.302	-485.456	-347.289	-355.096	-272.953
$\Delta W\%$	-	+14.02	+13.09	+29.25	+49.38	+48.25	+60.02
Ye	1.917	13.873	16.318	33.045	36.971	44.204	39.264
$\Delta Ye\%$	-	+623.68	+751.23	+1623.79	+1828.59	+2205.89	+1948.20
ΔE	-	10.333	10.991	22.797	32.649	33.596	39.204
ΔC	-	5.575	6.781	12.538	11.358	13.736	10.508
ΔH	-	0.016	0.000	0.000	0.000	0.000	0.000
After irradiation:							
L	92.134	80.878	78.273	72.713	60.391	58.275	53.572
$\Delta L\%$	-	-12.22	-15.04	-21.08	-33.45	-36.75	-41.85
A	-1.412	-3.705	-3.829	-2.748	-0.848	-0.460	-0.279
$\Delta A\%$	-	-162.39	-171.18	-94.62	+39.94	+67.42	+80.24
B	7.505	13.078	12.682	17.169	14.722	15.704	13.748
$\Delta B\%$	-	+74.26	+68.98	+128.77	+96.16	+109.25	+83.18
W	-718.603	-583.736	-546.857	-494.317	-342.573	-323.971	-271.684
$\Delta W\%$	-	+18.77	+23.90	+31.21	+52.33	+54.92	+62.19
Ye	10.597	25.603	25.439	39.470	42.530	47.559	45.456
$\Delta Ye\%$	-	+141.61	+140.06	+272.46	+301.34	+348.80	+328.95
ΔE	-	12.768	14.992	21.734	32.558	34.851	39.081
ΔC	-	6.026	5.713	9.756	7.239	8.254	6.345
ΔH	-	11.256	13.861	19.421	31.743	33.859	38.562

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The values of the color constant B for PVA/BSA unirradiated and irradiated blended samples increases by increasing the concentration of BSA, which indicates that there in an increase in yellow component instead of blue one.

From the table, it is clear that, the variations of the color constant A and B with fast neutron irradiation is smaller than that of the unirradiated ones by a ratio of about 1:10.

- **The whiteness index (W)**
  Whiteness is an attribute by which an object is judged to approach the preferred white. The whiteness index (W) shows measurable decrease with increasing the concentration of BSA for unirradiated and irradiated PVA/BSA blended samples.

- **The yellowness index (Y_e)**
  Yellowness index can be used when measuring clear, non-colorless liquids or solids in transmission. The yellowness index (Y_e) values for PVA/BSA unirradiated and irradiated blended samples increase with increasing BSA concentration up to 15 wt% and/or by irradiation with fast neutrons. Moreover, the increase in yellowness index with fast neutron irradiation is smaller than that of the unirradiated ones by a ratio of about 1:6.

- The obtained results illustrated in TABLE 4 indicate that increases in color difference between samples are occurred by the presence of BSA by different concentrations with PVA as well as irradiation with fast neutron.

The observed changes in the color parameters with the increase in the concentration of BSA and irradiation with fast neutron fluence of 1×10^7 n/cm^2 may be due to the change in the physical bonds and then changes in the molecular configuration of PVA as well as may be attributed to the radiation induced changes in the color centers of the irradiated samples which may lead to formation of new dopant centers of the polymeric material. In addition, the obtained results of the color parameters are of great importance for the improvement of the optical properties of the PVA.

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