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Preparation of Ultra Dispersive Glasses for Designing Novel Coatings

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ABSTRACT

In order to attain glasses with ultra dispersions properties, different heavy metal oxides were used. The desired glasses were obtained from the addition of high amounts of PbO and Bi_2O_3 to B_2O_3 based glasses. Refractive index measurements were carried out accurately at different wavelengths by 'the minimum angle of deviation in prisms' method employing a spectrometer. Results indicated that, as the amount of Bi_2O_3 increased in the glass system, the measured dispersions deviated from the commercial glass trend to the higher levels, due to the presence of higher number of non-bridging oxygen bonds. Since the research is genuine, and along with it, many families of glasses have been tried elsewhere, it may require more studies to be done, till better and higher optical quality glasses are conquered. These glasses can be employed in designing and constructing novel coatings or glazes, in which the incident white light entering, the coating layer, refracts out broadly in different colors. Therefore, these glazes will appear in different colors, when are observed at different angles. Prog. Color Colorants Coat. 2(2009), 7-21. © Institute for Color Science and Technology.

1. Introduction

Glazes, from optical and color appearances points of view, are characterized by their light transmission, refraction, reflection, absorption, dispersion, scattering and luminous properties. These properties are ascribed to: the electronic configurations, the atomic or ionic cloud status and the structural relations of constituted atoms or ions in the glass [1].

The attempt is to propose and design optically induced color coating or glazes which generate colors by dispersing white light rays [2]. Therefore, tailoring glasses of high light dispersive property, which correlate with designs of the above glazes, are most desired. In fact, the colors transmitted from these glazes, varies with the change of incident rays or observers' angle. In the other words, the constructed glaze layer depending on the proper choice of components and the design could cause widely spread of the rainbow color spectra [3]. Therefore, in this respect, the refractive index and dispersion properties of the glasses used, in these glazes, are of the most consideration. The former represents generally the relative speeds of light as electromagnetic waves in two different media, where the latter indicates the differences in the speeds of monochromatic light

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beams upon the wavelength in a medium [4].

The relative refractive index, n_r, is defined; as a ratio of speeds of light spectrum traveling through the media i.e.

$$n_r = \frac{\text{Speed of light in medium1}}{\text{Speed of light in medium2}} \quad (1)$$

The refractive index, n, of a dense medium, e.g., liquids, glasses and etc. is presented as:

$$n = \frac{\text{Speed of light in vacuum or air}}{\text{Speed of light in a dense medium}} \quad (2)$$

The value of the ratio is always greater than unity, since the speed of light in vacuum and air is considered approximately similar, i.e. $300x10^6$ m/s, and greater than denser media. It is dependent on the wavelength and increases when the wavelength decreases [5]:

$$n^2(\lambda) - 1 = \sum_{j=1}^{l} \frac{a_j \lambda^2}{\lambda^2 - \lambda_j^2} \ [4] \quad (3)$$

$n^2 \approx A + B/\lambda^2$ (Cauchy equation) [6-8]

λ is the incident beam wavelength, a_j, A, and B are coefficients.

Dispersion, as an optical property, refers to the variation characteristics of refractive index, 'n', with wavelength in denser media, e.g. glasses. It generally correlates and increases with the refractive index property of the media [2,9] (Figure 1). Other optical properties, which are affected by wavelength of light rays, are the absorption and reflection. These phenomena are expected to rise with refractive index. Here, with respect to the transmission of optical colors emerge from glazes, the absorption is mostly undesirable and the reflection enhances the gloss property and the light scattering [5].

The refractive index of inorganic glazes is dependent on the two factors; the molecular polarization and the structural volume of the inorganic components constituted in the glassy phases. These phenomena are normally presented in the molar refractivity, R_M, and the molar volume, V_M, of the corresponding glasses, respectively. Both R_M and V_M have been related to the refractive index, 'n', by the "Lorentz-Lorenz" équation [9]:

$$(n^2-1)/(n^2+2) = \alpha_M(4\pi N/3) = (R_M/V_M) \quad (4)$$

Where, α_M, is the molar electronic polarisibility, and N is the Avogadro's number. In tailoring optical glazes, α_M or R_M and V_M of glasses constructed in the glaze layer, can be calculated from the individual constituted chemical components related to ions refractivities or basicities [10, 11]. Finally, 'n' can be predicted and compared with measured values [12].

Qi, *et. al.* [13] experimentally, presented a linear relationship between molar polarisibility per molar volume and the density for some binary glasses. Their results can assist tailoring optical glasses based on heavy metal borates, such as: Bi and Pb. These large heavy ions are easily polarisible under electromagnetic waves and contribute higher densities to glasses.

For direct measurements of high refractive index values with high accuracies, "minimum angle of deviation" of light beam in a prism technique is used, in which a prism is prepared from the glass sample and a spectrometer is employed [12].

Therefore, by tailoring glasses composed of high polarisable and heavy ions, such as; Tl^+, Pb^{2+}, Bi^{3+} and etc., ultra refractive index glasses even greater than 2.5, are possible to be achieved [12]. Another group of heavy ions which enhance polarisability, are alkali and alkali earth cations, such as; K^+, Cs^+, Ba^{2+}, La^{3+} and etc. These ions, because of their large atomic radii and unsaturated *d*-shells, can be easily deformed and increase the polarisation, especially in unsymmetrical and highly co-ordinated structures. In addition, anions, such as; oxygen and fluorine facilitates polarization, in particular, when oxygen atoms are in the form of non-bridging [9, 11]. For investigating and predicting the polarisibility in oxide glasses and their relation to the composition from the acid-base properties aspects, Duffy and Ingram, reported by [14, 15], proposed the optical basicity of an oxide medium (glass) based on the oxygen bond nature and the electron donor power of oxide species. They also followed limited studies on the above heavy atoms.

Commonly, measured refractive index, 'n_d', refers to a particular spectrum, i.e. yellow Helium line of wavelength, 587.56 nm. (Table 1), [9]

Optical dispersive property of a glass is presented as "Mean Dispersion" or "Principal Dispersion". It is defined by the difference between the refractive indices of blue (486.13nm) and red (656.27nm), i.e. "n_F-n_C".

Relatively, the dispersive index or "Abbe Number" υ_d [1] as a measure of dispersion is introduced by:

$$\upsilon_d = (n_d-1)/(n_F-n_C) \quad (5)$$

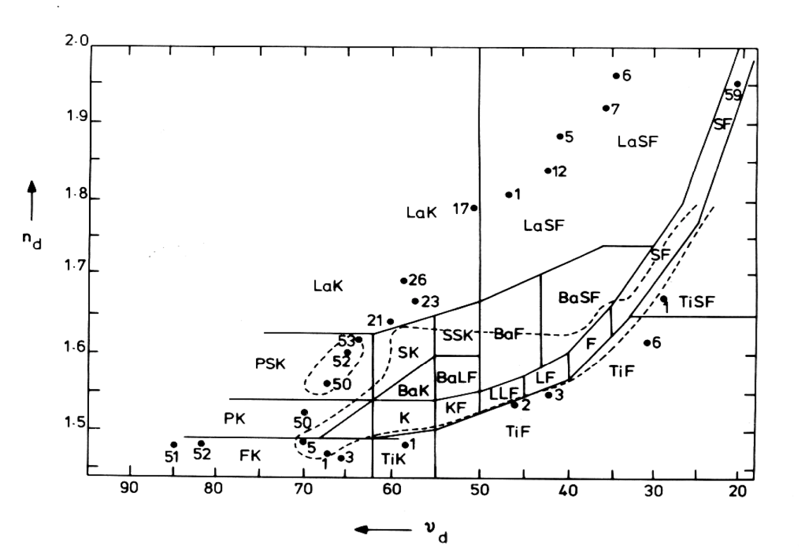


Figure 1a: variation of refractive index versus Abbe No. as dispersion quality.

The curved lines represent the generalized trend for most commercial glasses (Flint Schott glasses, SF) [9].

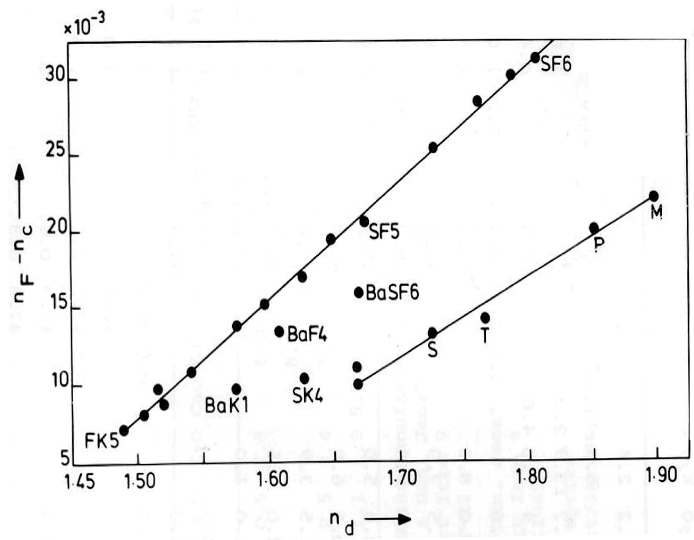


Figure 1b: Linear Relationship between mean dispersion and refractive index for commercial glasses (Flint Schott glasses, SF) [9].

For commercial glasses, a generalized trend obtained from plotting $n_{d \text{ or } D \text{ (yellow Na line=589.3nm)}}$ versus Abbe No. $\upsilon_{d \text{ or } D}$. In fact, it characterizes the dispersion in relation to the refractive index. (Figure 2)

Here, we are concerned with the proposition of a designed novel glaze, in which the observed colors vary widely with the angle of viewing, i.e., the glaze in white light looks red from one side and may be blue from the other side. These glazes can be constructed from ultra light dispersive glasses which have been prepared and tested in this research. The following compositions, from their high ionic polarisability, have been predicted for the high refractive index and ultra dispersion properties achievement.

BPB1: x Bi_2O_3-(93.71-x) PbO -6. 29 B_2O_3

BPB2: x Bi_2O_3-(92.86-x) PbO -7.14 B_2O_3

BPB3: x Bi_2O_3-(90.65-x) PbO -9.35 B_2O_3 wt%

Where, 'x', was from 5 to 55, in which the proportion of Bi_2O_3 increases in the glass systems with x, while substituting PbO. B_2O_3 is constant and acts as a strong glass former.

In the present study, more than 30 batches were prepared, melted and shaped (cut, ground and polished) into prisms of different sizes and angles. Because these glasses exhibited steep melt viscosity/temperature variation and high thermal expansion coefficient characteristics, researcher melted compounded glass batches and shaped molded glasses properly, and suitable for implementing the mentioned optical property measurements and other tests, See Table 2.

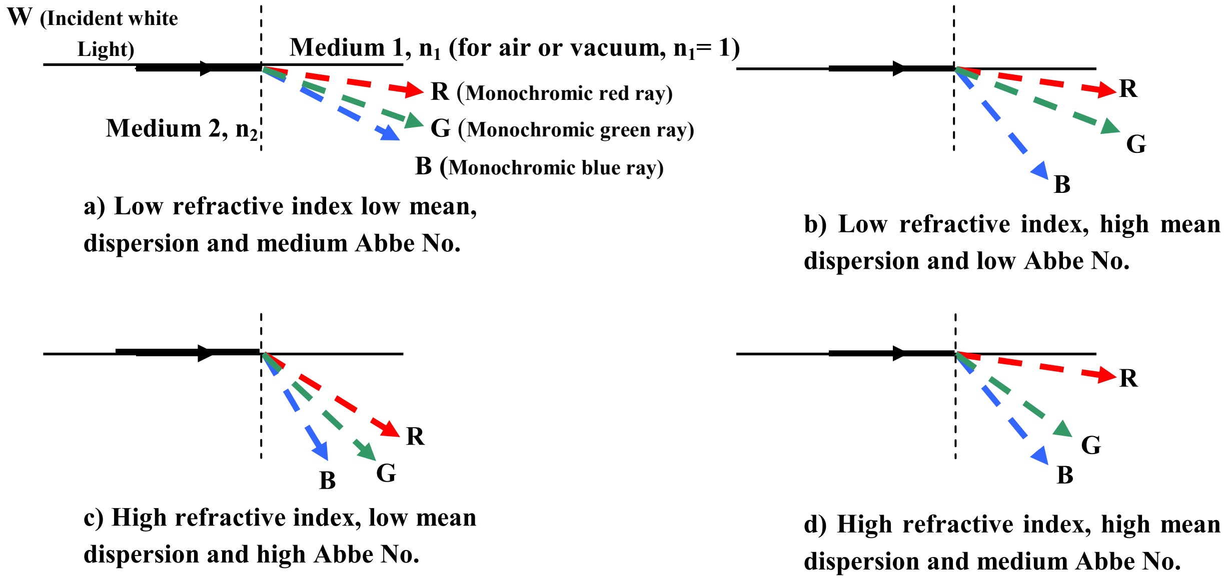


Figure 2: Analogy of the refractive index, mean dispersion and Abbe No. relations in different optical property media.

Table 1: The spectral of different atoms utilized for dispersion measurements. Table includes Cd/Hg and Na lamps spectral lines (denoted by * and **).

No.	Atoms spectral line	Colour	Wavelength (nm)	Symbol
1	He	Red	706.52	C
2	*Cd	Red	643.8	C'
3	**Na	Yellow	589.3	D
4	He	Yellow	587.52	d
5	*Hg	Yellow	579.1	d'
6	*Hg	Green I	546.1	e
7	*Cd	Green II	508.5	e'
8	*Cd	Blue I	480.0	F'
9	*Cd	Blue II	467.8	F"
10	*Hg	Blue III	435.8	G
11	*Hg	Violet	404.66	h

Table 2: Compounds formulations were used for the ultra dispersive glass preparation.

No.	Glass code	Glass compounds compositions wt% (mole.%)		
		$x=Bi_2O_3$	PbO	B_2O_3
xBPB1				
1	5BPB1	5.21 (2.24)	88.50 (79.41)	6.29 (18.15)
2	10BPB1	10.41 (4.60)	83.30 (76.80)	6.29 (18.60)
3	15BPB1	15.62 (7.07)	78.09 (73.85)	6.29 (19.08)
4	17.5BPB1	18.22 (8.36)	75.49 (72.32)	6.29 (19.32)
5	20BPB1	20.82 (9.68)	72.88 (70.74)	6.29 (19.58)
6	22.5BPB1	23.43(11.04)	70.28 (69.12)	6.29 (19.84)
7	25BPB1	26.03 (12.43)	67.68 (67.46)	6.29 (20.11)
8	30BPB1	31.24 (15.33)	62.47 (64.00)	6.29 (20.67)
9	40BPB1	41.64 (21.64)	52.06 (56.48)	6.29 (21.88)
10	50BPB1	52.06 (28.74)	41.65 (48.01)	6.29 (23.15)
xBPB2				
11	5BPB2	5.16 (2.19)	87.70 (77.57)	7.14 (20.24)
12	10BPB2	10.32 (4.48)	82.54 (74.78)	7.14 (20.74)
13	15BPB2	15.48 (6.88)	77.38 (71.86)	7.14 (21.26)
14	40BPB2	41.87 (20.97)	51.59 (54.74)	7.14 (24.29)
15	50BPB2	51.59 (27.80)	41.27 (46.44)	7.14 (25.76)
xBPB3				
16	5BPB3	5.04 (2.04)	85.61 (72.55)	9.35 (25.41)
17	10BPB3	10.07 (4.18)	80.57 (69.83)	9.35 (25.99)
18	15BPB3	15.11 (6.42)	75.34 (66.99)	9.35 (26.60)
19	25BPB3	25.18 (11.22)	65.47 (60.89)	9.35 (27.89)
20	30BPB3	30.22 (13.80)	60.41 (57.61)	9.35 (28.59)
21	40BPB3	40.29 (19.37)	50.16 (50.56)	9.35 (30.10)
22	50BPB3	50.36 (25.55)	40.29 (42.68)	9.35 (31.77)

2. Experimental

2.1. Raw materials and compounding

B_2O_3, Pb_3O_4 and Bi_2O_3 powders as raw materials of 99.99% purity were obtained from Aldrich Company. All powders were dried and crushed in an oven at 220 ^oC for 1 hour, before compounding is done. Due to the hygroscopic nature of the B-O bond, B_2O_3 powder normally contents great deal of absorbed water (from the surrounding moisture, about 30 wt %). To determine the absorbed water, 10 g of B_2O_3 powder was placed in a Platinum crucible and dried in an oven at 220 ^oC for 24 hours. Then it was transferred to a digital balance and continuously noted the weight increase, during cooling proceeded to the room temperature. The amount of water absorption was calculated and deduced from B_2O_3 in the glass composition formula. For different compositions of B_2O_3-PbO-Bi_2O_3 (BPB) glass system, batches of 20 g were prepared. Every batch before melting was tumble mixed for a few minutes. Over mixing was avoided to prevent the mixed powders segregation.

2.2. Melting and sample preparation

Melting was performed in covered alumina crucibles at about 800 ^oC for one hour or less in an electrical furnace. While melting was in progressed, difficulties arose from the evaporation of B_2O_3 and the volatilization of PbO and Bi_2O_3 [16, 17], which could upset the glass formulations. In addition the dissolution of Al_2O_3 from the crucibles might influence the melt. It was assessed to be less than 1 wt%, by screening crucibles after melting and it was considered to be minimal. Table: 2 presents the attempted glass compositions for melting. The existence of wide differences in both the melting temperatures, and also, the densities of the constituents in the glass composition, believed to be the source of the observed high non-homogeneity in these glasses [18]. In order to improve homogeneity, melts were stirred at 60 rpm for about half an hour after the melting was completed. But this was believed to enhanced volatilization. Therefore, the consistency in the melting procedure for each batch was practiced. The glass melts were poured in assembled rectangular iron molds, to solidify in thickness of almost 1 cm. Then the obtained glass block annealed in an annealing furnace at above 400^oC for one hour, and it let cool at a rate of 60^oC per hour to room temperature. Figure 3 shows the regions of 3D glass formation diagram obtained in this study. White circles indicate complete glass formation and the confined region represents the predicted glass formation region. Those melts which fully or partially had devitrified, were not included.

The large enough glass pieces were cut and shaped into prisms of different suitable angles. With increasing the relevant refractive indices of glass samples, the prisms angles decreased, in order to make the measurements of the minimum deviation of the light ray, in the prism, possible. Then, successive grinding with SiC powders of meshes 300 to 800 in paraffin was applied. To make sure the prism faces are flat enough for higher accuracies, large guide prisms made from hard glass were employed. Finally, prisms were polished with 1μm diamond paste on flat discs. The flatness was examined by the light reflection. Generally, Prisms were examined by optical microscopes for any defects.

Measurements

The glasses densities were measured in paraffin using density flasks and a temperature controlled water bath at fixed temperatures of about 5^oC above room temperature to avoid over flowing.

Thermal characteristics and stabilities of glasses were studied by the Deferential Thermal Analysis (DTA) experiments with heating rate of 10^oC/min. and the maximum temperature of 600^oC.

Refractive index and dispersion properties were measured by employing a spectrometer and an Hg/Cd cord lamp as a source of white light with the distinguished non-continuous spectra. (Table 1). The method was by the 'Minimum angle of Deviation 'D_m' in a prism of angle 'A' using the following equation [1, 12].

$$n = \mathrm{Sin}\,[(D_m + A)/2]/\mathrm{Sin}(A/2) \qquad (6)$$

The accuracy of the measurements was up to four digits and even more, when the largest possible prism angles were made and utilized in the measurements.

3. Results and discussion

High lead/bismuth content glasses, especially those with borate bases, exhibited water-like melt viscosity; 10^{-3} Pa s at 20^oC [5]. This caused cords and stream lines to be popular in the prepared samples. Therefore, melt pouring was done at the lowest viscosity in hot molds. Shattering and cracking occurred also easily, when: 1- molds were not at suitable temperature or not properly being heated, 2- the solidified glass was too thick or 3- molded samples were not quickly transferred to the annealing furnaces. The reasons for these observations were due to: steep viscosity-temperature relationship, high thermal expansion and low mechanical strength behaviors in high lead/bismuth glasses [19]. The former properties were the causes of the appreciable depressions in large casts, and voids and cracks in long molded glasses. The color of lead/bismuth borate glasses was yellow. As Bi_2O_3 increased and replaced PbO, the color changed to brown. The brownish color intensified on prolonged stirring of the melts. Due to relatively greater evaporation of B_2O_3 than PbO and/or Bi_2O_3, below 800 ^oC, the glass composition existed the glass-forming region in the 3-D glass formation diagram in Figure 3, and the glasses molded from these melts devitrified in the bulk. Also, in Figure 3, substitution of Bi_2O_3 for PbO in the unstable 83PbO-17 B_2O_3 (mole %) glass [11] resulted stable glasses, i.e.; BPB1. This could be ascribed to the introduction of more oxygen, as a polarizable component into the glass structure when adding Bi_2O_3 [20, 21]. On the contrary, introducing Bi^{3+} cations, as a glass modifier, would cause structural complexity which could facilitate ease of verification [22].

Results obtained from the DTA and the thermal expansion experiments, (Table 3), showed the regions of the most stable or workable glasses containing Bi_2O_3 about 5 to 12 mole %, i.e.; 17.5-22.5BPB1, 15BPB2 and 15BPB3 samples (Figure 4). The three glass groups (BPBP1, 2 and 3) followed almost similar trends. In these glasses, 'T_C-T_g' values were comparatively large enough, or 'T_C' peaks would not exist, where their compositions tended towards the eutectic regions in the B_2O_3-PbO, B_2O_3-Bi_2O_3 and Pb-Bi_2O_3 phase diagrams [16, 23, 24]. These results, to some extent, might suggest that the reduction in the amount of B_2O_3, could aid the glass stability, when comparing xBPB1, xBPB2 and xBPB3 glasses.

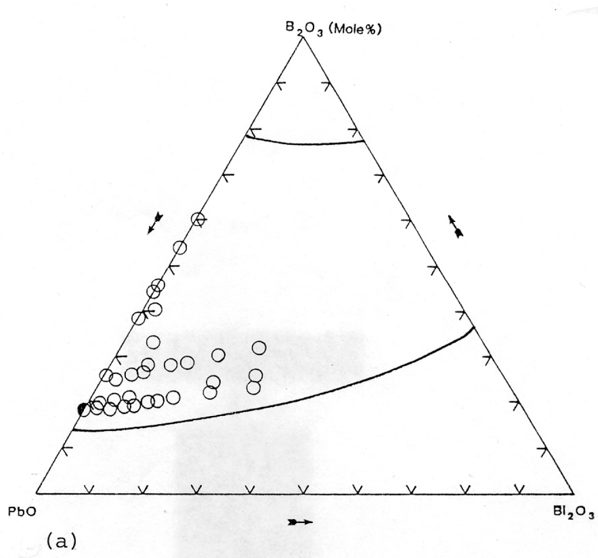


Figure 3: 3-phase glass forming diagram for "Bi_2O_3-PbO-B_2O_3" system.

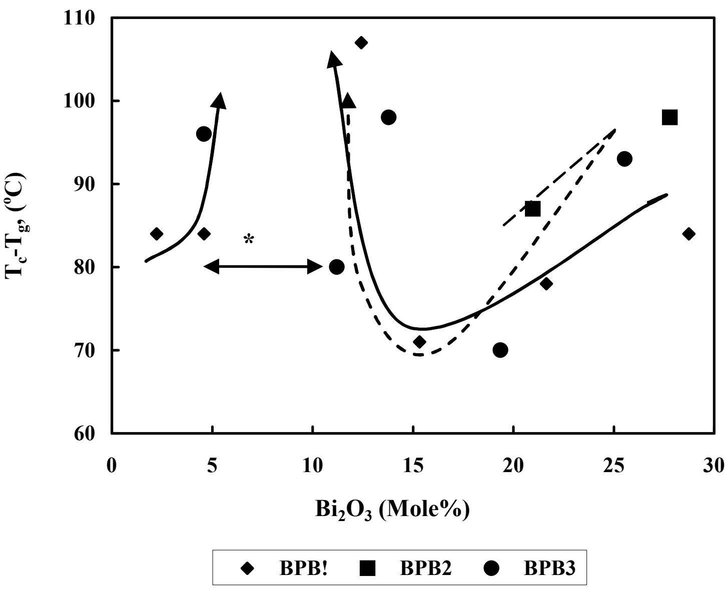


Figure 4: Indicating regions of relative stability and workability in BPB glasses, when substituting PbO for Bi_2O_3. The stability and workability is shown by the differences between the glass crystallization temperature, T_C, and glass transition temperature, T_g, i.e.: T_C-T_g.

*- Regions of glasses which no crystallization peaks were observed in their DTA traces.

Table 3: Dependent of thermal property and glass stability limits on Bi^{3+} contents in xBPB1, 2, and 3 glasses

No.	Glass code	Bi_2O_3 content wt% (mole.%)	T_g (ºC)	T_c (ºC)	T_c-T_g (ºC)
xBPB1					
1	5BPB1	5.21 (2.24)	281	365	84
2	10BPB1	10.41 (4.60)	258	342	84
3	17.5BPB1	18.22 (8.36)	281	-----	----
4	20BPB1	20.82 (9.68)	290	-----	----
5	22.5BPB1	23.43(11.04)	281	-----	----
6	25BPB1	26.03 (12.43)	287	394	107
7	30BPB1	31.24 (15.33)	290	361	71
8	40BPB1	41.64 (21.64)	291	360	78
9	50BPB1	52.06 (28.74)	285	369	84
xBPB2					
10	5BPB2	5.16 (2.19)	296	----	----
11	10BPB2	10.32 (4.48)	301	----	----
12	15BPB2	15.48 (6.88)	282	----	----
13	40BPB2	41.87 (20.97)	315	402	87
14	50BPB2	51.59 (27.80)	315	413	98
xBPB3					
15	5BPB3	5.04 (2.04)	302	400*	98
16	10BPB3	10.07 (4.18)	301	397	96
17	15BPB3	15.11 (6.42)	309	----	----
18	25BPB3	25.18 (11.22)	313	393**	80
19	30BPB3	30.22 (13.80)	314	412	98
20	40BPB3	40.29 (19.37)	323	393	70
21	50BPB3	50.36 (25.55)	325	418	93

*- Uncertain, very shallow peak

**- Peaks not observed

Table 4: Calculated oxygen and heavy ions contents from the molar volume in xBPB1 glasses.

Sample	Density, d, (g/cm^3)	Molar volume, V_M, (cm^3/g.mole)	No. of (O^{2-})/V_M (x10^{-3} g. atom/cm^3)	No. of (Pb^{2+} +Bi^{3+})/V_M (x10^{-3} g. atom/cm^3)
5BPB1	7.24	27.73	50.76	3.03
10BPB1	7.43*	27.70	52.85	3.11
17.5BPB1	7.31	29.25	53.11	3.04
20BPB1	7.37	29.39	53.94	3.07
22.5BPB1	7.32	29.99	53.94	3.04
25BPB1	7.29	30.52	54.08	3.03
30BPB1	7.36	31.07	55.37	3.05
40BPB1	7.37	32.87	56.92	3.04
50BPB1	7.49	34.35	59.38	3.07

*- Anomalous result

The most experimental glasses BPB system presented higher refractive index values than commercial glasses and followed the trend of generalized 'refractive index versus dispersion properties presented as "Abbe Number" curve' [19, 25] (Figures 1, 2, 5). The exceptionally high dispersion properties observed, in BPB glasses system, were associated with those compositions of least B_2O_3 and high Bi_2O_3.content, i.e. 40, 50BPB1, and also 4.5 hour stirred 20BPB(4h) glasses (Figure. 6). Although, these glasses might content relatively less number of oxygen atoms (as the amount of B_2O_3 reduces in the glass melt by evaporation), but it is believed statistically to have more non-bridging oxygens, due to the increase of weaker bonds in heavy metal oxides, such as; Bi-O and Pb-O. In addition, the existence of the popular structural distortion, e.g.; in Pb-O cells, could raise the polarisability as a whole. These two issues may dominate over the oxygen population effects on increasing the BPB glasses refractivity properties. Generally, the above phenomena counts for higher refractivity, and hence, the higher refractive index glasses are expected [19, 26, 27]. (Figures 7, 8, 9) The results depict the almost linear curves for especially, BPB3 glasses. But, in the cases of 40BPB1 and 2 glasses, if they were considered to be genuine results, it might suggest that the increase of non-bridging oxygen, structural distortion or other phenomena could influence the dispersion more than the refractive index. This is observed in the results for dispersion dependent on Bi_2O_3 (or PbO) content in Figures 8 and 9, which exhibit a pronounced maxima around 40BPB1 and 2 glasses. Hence, Abbe number, as an inversion of dispersion power (or dispersion index) tends towards the right hand side of the trend of the general refractive index versus Abbe number curve (Figure. 5) [21, 26, 27].

The other factor, which might affect refractive index, could be the phenomenon of 'Boron anomaly'. It is related to the boron ion co-ordination number changes from 3 to 4, when a glass structure modifier component, such as: PbO or Bi_2O_3, is added to the composition [19, 21, 28].

But, on the other hand, the measured molar volumes, for BPB1 glasses, increase with replacing PbO by Bi_2O_3, (Figure 10). This could have contrary effects on the increase of refractive index [11]. While as, it might not have significant influences on decreasing dispersion properties though, because oxygen concentration and then non-bridging oxygens, in the system, would rise (refer to the introduction and Figures 5 and 6). Table 3 shows the increase of the oxygen concentration in BPB1 glasses as Bi_2O_3 replaces PbO, where the heavy metal concentration does not change appreciably. Therefore, these could be the reasons for the deviation from the trend of generalized 'refractive index versus dispersion curve towards the lower values of Abbe Number, i.e. ultra dispersion properties. (Figure 5) The decline of curves in Figures 6, 7 and 9 may be attributed to the effect of some appreciable increase in B_2O_3 mole% (Table 2), and its influences on lowering values in the above properties generally.

On the bases of dispersion of white light by a glass prism with a suitable angle, (Figure 11), novel glazes may be proposed and designed. These glazes can be constructed from ultra dispersive glasses, in combination with low refractive index glasses. (Figure 12), in which a beam of white light can be dispersed widely and transmitted in spectrum of colors.

There are two different propositions for introducing new glazes: 1- a crown or low refractive glass containing sharp edged, possibly diamond shaped [1, 3], particles of high dispersive glasses, 2- applying ultra dispersive glass on a sharp grooved surface of a low refractive index glass, considered as a based glaze. (Figure 12)

In the second constructed glaze long spectra of incident white light refract and pass through, whereas the shorter wavelength colors are absorbed, reflected or refracted back. Hence, the glaze appears, for instance: red, orange, yellow or other relatively low wavelength colors in the opposite side of the incident white light and green, blue or violet on the other side of glazes. In addition, the appearance of colors of the above glaze varies with the change of the angles of the either viewer or incident light. The transmitted colors and their extent, in the above designed glazes, may be governed by: 1- the proper choice of properties for the comprised glasses in the glaze and 2- the suitable optical geometry in the glaze, i.e. appropriate angles in the triangle shaped grooves (Figures. 12). Here, we are not going to involve with calculating the mentioned angles of the grooves, i.e. A. Hopefully, it may be presented in near future papers. Never the less, the angles of the groove, A's must correlate with the critical angles of the particular spectrum which would not be going to be refracted out at particular directions.

In the end, it should be bore in mind that factors such as: the glaze thickness, the shapes of grooves, the relative optical properties of composed glasses, e.g.: the differences in their refractive indices (n_2-n_3), and the substrate optical properties, play important roles in the appearances of the designed glaze.

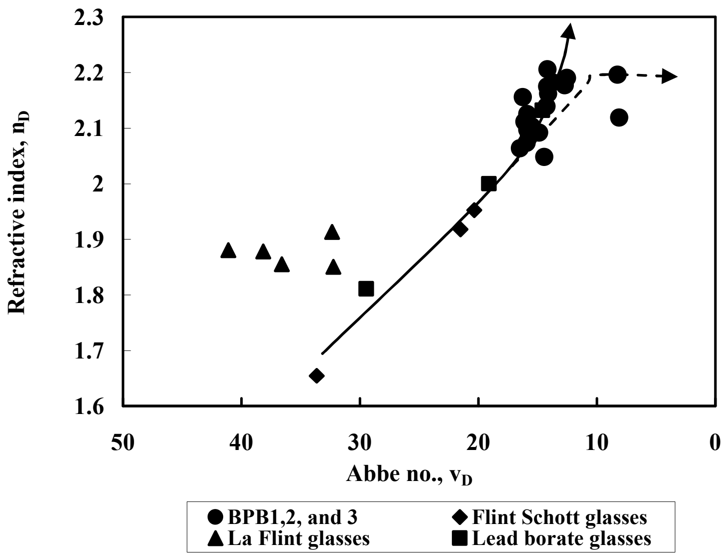


Figure 5: Presenting deviation of BPB glasses from the generalized trend of commercial glasses towards ultra dispersion qualities in comparison with Figure 1.

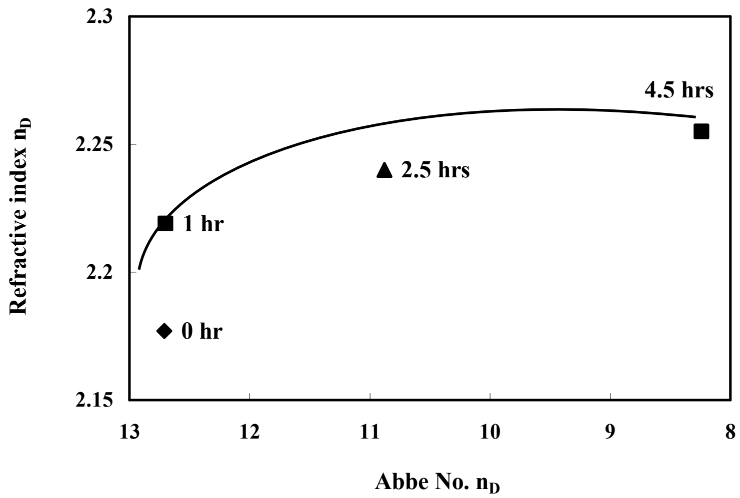


Figure 6: Display of the effect of stirring 20BPB1 glass melt at 60 rpm on dispersion quality in comparison with refractive index, as a result of evaporations of the melt constitutes, in which B_2O_3 dominates.

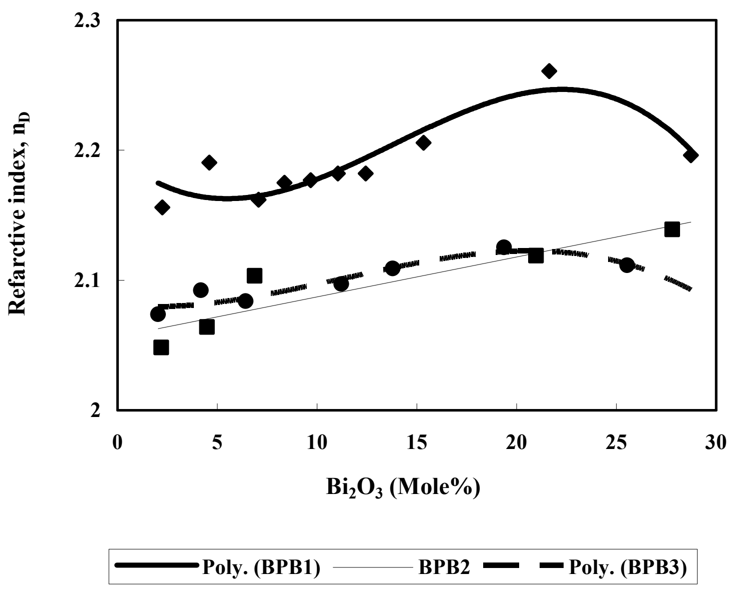


Figure 7: Increase of refractive index, n_D, with the substituting PbO for Bi_2O_3 and decreasing B_2O_3 in BPB glasses.

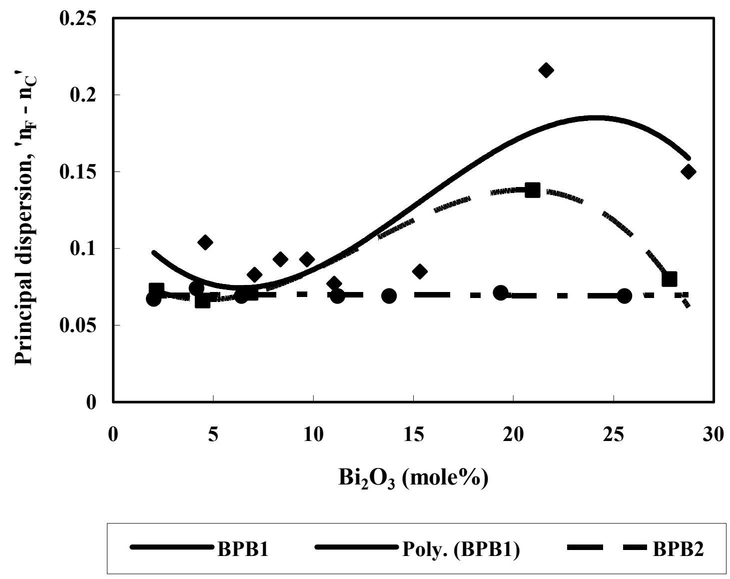


Figure 8: Variation of light principal or mean dispersion with increase of Bi_2O_3 in BPB glasses. The most pronounced effects are observed with the lower B_2O_3 content glass systems, i.e. BPB1.

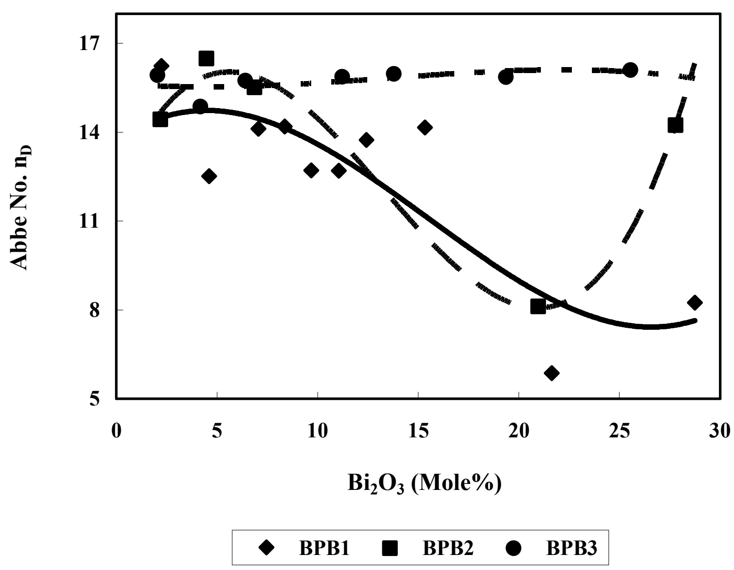


Figure 9: Variation of Abbe Number as dispersion quality of BPB glasses with replacing PbO by Bi_2O_3, in which non-bridging oxygen population and polarisibility increases, especially when B_2O_3 concentration is lower.

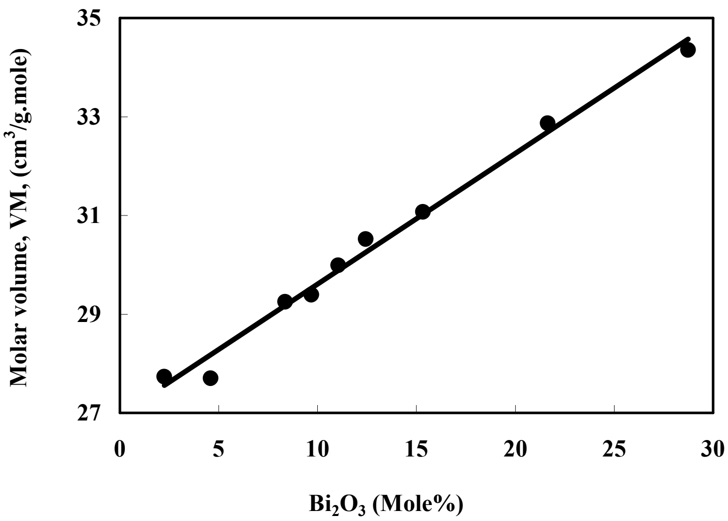


Figure 10: Linear increase of measured molar volume with Bi_2O_3 replacing PbO in BPB1 glasses.

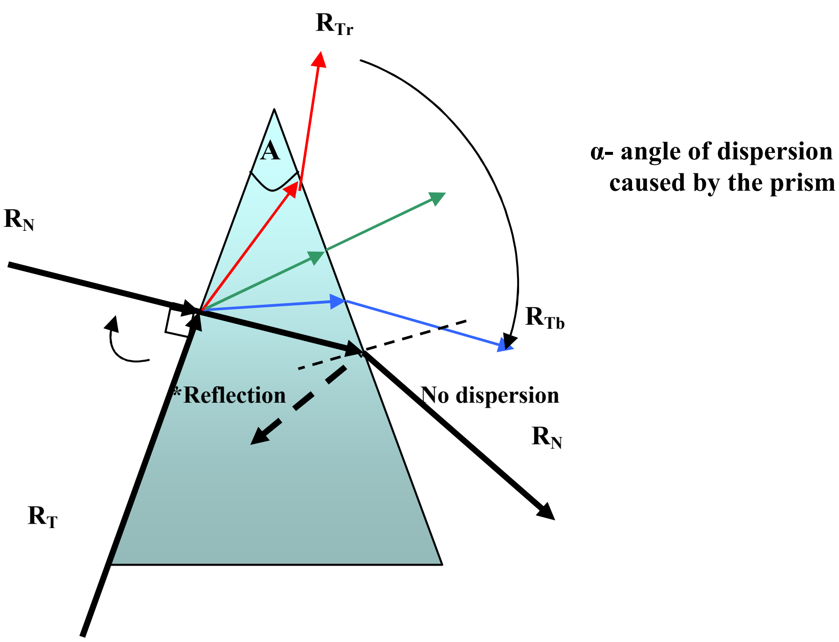
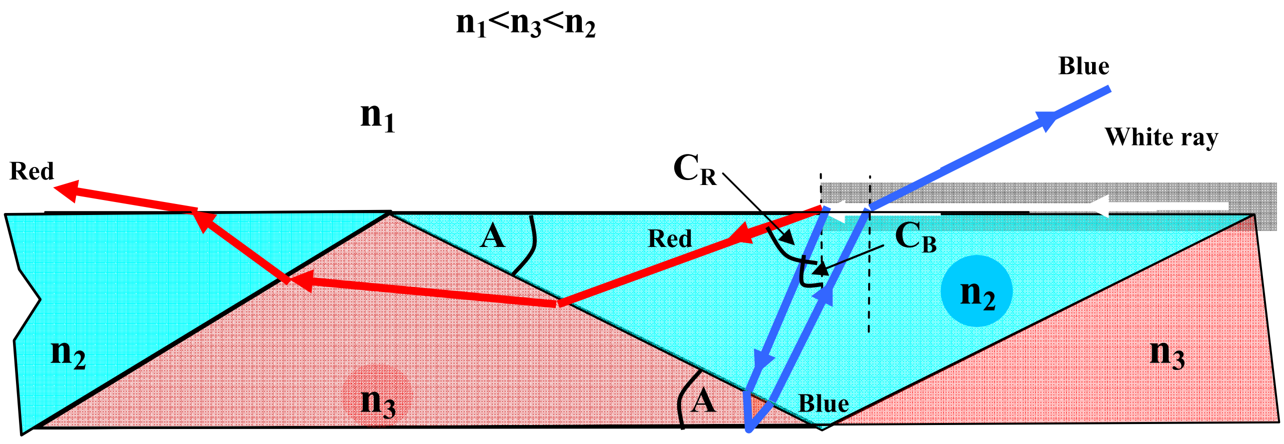
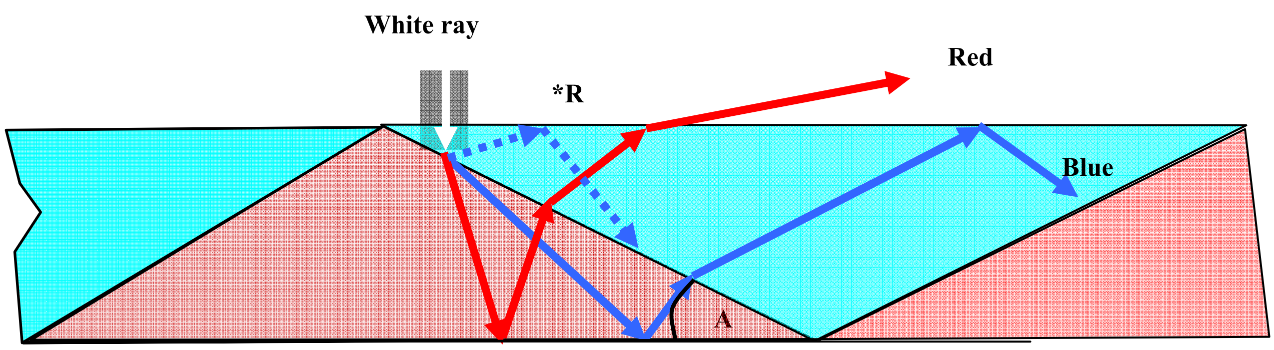


Figure 11: Dispersion of white light by a prism. The maximum dispersion is attained by suitable choices of the prism angle, A, in correlation with the refractive index, n, of the prism glass and the proper adjustment of the prism with incident ray.

* If higher than the critical angle.



(a)



(b)

Figure 12: Spectral refraction of incident white light is caused by a designed glaze made from an ultra light dispersive glass, n_2 and a low refractive index glass, n_3.

*R- Reflection may occur if n_2-n_3 is large enough.

(a) and (b) display two extreme situations for incident of a white ray.

4. Conclusions

Substituting PbO for Bi_2O_3 in the borate glasses increases refractive index and dispersion. This is related to the increase of oxygen concentration in the glasses and probably non-bridging oxygen.

Ultra dispersion properties have been observed in 40BPB1 and 2 glasses when they deviated from the generalized trend of refractive index versus dispersion curve towards higher dispersion properties.

In general, as the dispersion property of glass in a glaze increases, the refraction of the incident white light will be widened, and the colors spectrum will differentiate more. Therefore, changes of colors coming from transparent items will be more distinguishable. Hence, designing glazes (or coating layers), from these materials, can give different perceptions of tinned colors, in different viewed angles.

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