

# CHAPTER - VI

STUDIES ON GLYCERINE - WATER  
AND DIOXAN - WATER  
WITH PARAMAGNETIC IONS

## INTRODUCTION:

The presence of paramagnetic substances in a liquid reduces the relaxation times  $T_1$  and  $T_2$  of nuclei of the solvent. This effect was first demonstrated by Block, Hansen and Packard (1) for protons in aqueous solutions of  $Fe^{3+}$  ions. This effect was further studied by Bloembergen, Purcell and Pound (BPP) (2) in aqueous solutions of paramagnetic ions such as  $Cu^{++}$  and  $Fe^{+++}$ . An important mechanism towards decrease of  $T_1$  is the modulation of nuclear magnetic dipolar interaction resulting from both the rotation as well as translational motion of the different molecules. Bloembergen et al (2) attributed the reduction in the values of relaxation times is due to diffusional Brownian motion of the water molecules in the vicinity of paramagnetic ions. According to Bernheim et al (3) the primary contribution towards the reduction of relaxation times ( $T_1$ ) in the presence of paramagnetic ions comes from rotational terms. The decrease in the values of relaxation times can also be interpreted in terms of some models. The ions are surrounded by a coordination spheres of solvent molecules. The nuclei in this salvation shell interact strongly with the unpaired electrons of the ion, the interaction having both magnetic dipole-dipole and hyperfine terms. For most iron-group ions dissolved in water, a

rapid exchange of water molecules between 'free' solvent and hydration shell takes place, and only a single proton resonance line is observed, which is the result of an averaging of the resonance of the free and bound molecules.

Several workers have reported the effect of paramagnetic ions on proton relaxation times (4-6). Gutowsky and Ravikind (7,8) were the first to study the effect of free radicals on NMR relaxation times in certain non viscous solvents. Modak et al (9) carried out NMR relaxation time ( $T_1$ ) measurements in glycerine-water mixtures by continuous wave technique by measuring the NMR signal heights. In their study free radicals and paramagnetic ions were added to three different (glycerine rich) glycerine-water compositions. The results reveal that the free radicals increase the viscosity of these systems whereas there is no appreciable change in viscosity on the addition of paramagnetic ions (copper nitrate). Also the proton signal heights in these solutions showed an initial increase and a small decrease at higher concentration and also indicate that at a given concentration pair formation is more probable for free radicals than for paramagnetic ions. The initial increase in the signal height is attributed to the complex formation of the paramagnetic ions with water, glycerine and associated glycerine-water molecules. Since the relaxation times in the above study are not absolute measurements, it is considered worthwhile to repeat the

measurements of ( $T_1$ ) and ( $T_2$ ) using more sophisticated low resolution pulsed NMR spectrometer.

In the present investigation, the PMR relaxation times were measured in the solutions of glycerine-water mixtures of volume proportions 90% glycerine and 10% water (solution A), 80% glycerine and 20% water (solution B), 70% glycerine and 30% water (solution C) and 60% glycerine and 40% water (solution D). Solution (1.0 M) of copper and chromium nitrates are formed by dissolving it in double distilled water. This solutions were added in different amounts to glycerine and the proportion of glycerine to water is brought to the desired value by further addition of the required amount of water. The concentration is expressed as number of particles/cc and the range is from  $0.1 \times 10^{20}$  ions/cc to  $0.5 \times 10^{20}$  ions/cc.

The spin-lattice relaxation time ( $T_1$ ) and spin-spin relaxation time ( $T_2$ ) in these solutions in the above concentrations were measured at different temperatures of  $30^\circ$ ,  $40^\circ$ ,  $50^\circ$ ,  $60^\circ$  C using Bruker PC 120 NMR process analyser at a frequency of 20 MHz. Saturation recovery technique was used for the measurement of ( $T_1$ ) and CPMG pulse sequence was used for the measurement of ( $T_2$ ). Temperature variation was carried out circulating water from a thermostatically controlled water bath to an accuracy of  $\pm 1^\circ$ C. Viscosity and density measurements were done using Ostwald's viscometer and pyknometer at a temperature at

30°C.

## RESULT:

### COPPER IONS:

The variation of spin-lattice relaxation times ( $T_1$ ) and spin-spin relaxation times ( $T_2$ ) in glycerine water solution (A-D) with paramagnetic ions (PMI) ( $\text{Cu}^{++}$ ) at different (PMI) concentrations and at different temperatures are shown in figure 6.1-6.8 and the values are listed in Tables 6.1,6.2.

The relaxation times generally decrease with increase of PMI concentration. The initial decrease in the relaxation times is quite large upto PMI concentration of  $0.1 \times 10^{20}$  ions/cc for all the solutions studied. Further increase of PMI concentration decreases the relaxation times gradually. Similar behaviour is seen for all the solutions at higher temperature.

The variation of viscosity against concentrations of copper nitrate in glycerine-water mixtures at room temperature is shown in figure 6.9. From the figure, it can be seen that the viscosity remains fairly constant for all the PMIs studied.

### CHROMIUM IONS:

The variation of relaxation times ( $T_1$ ) and ( $T_2$ ) with

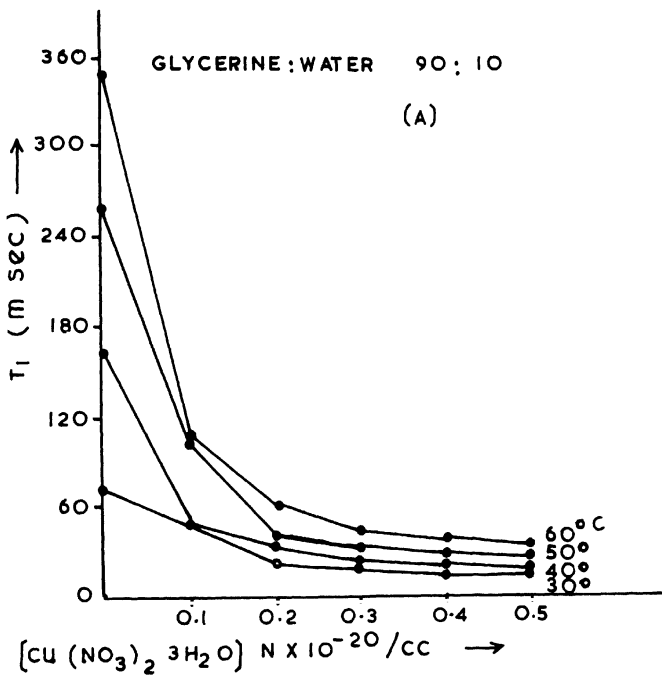


FIG. 6.1

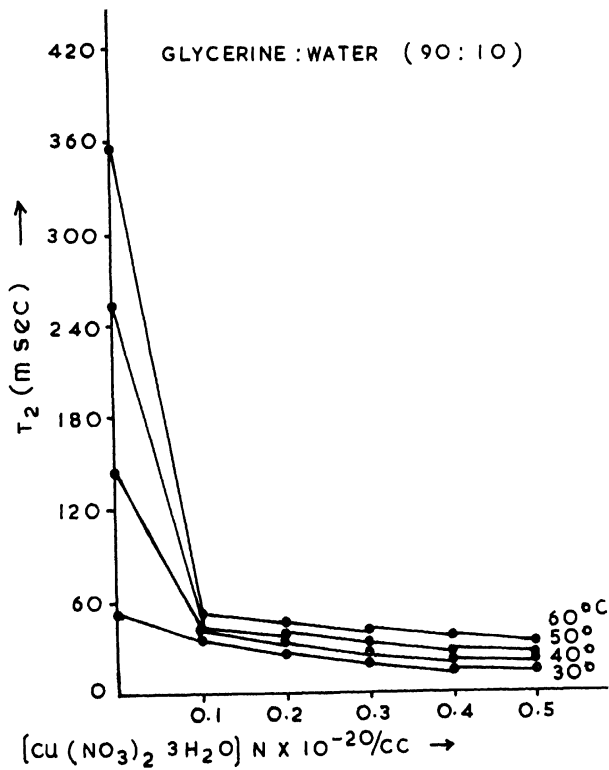


FIG. 6.2

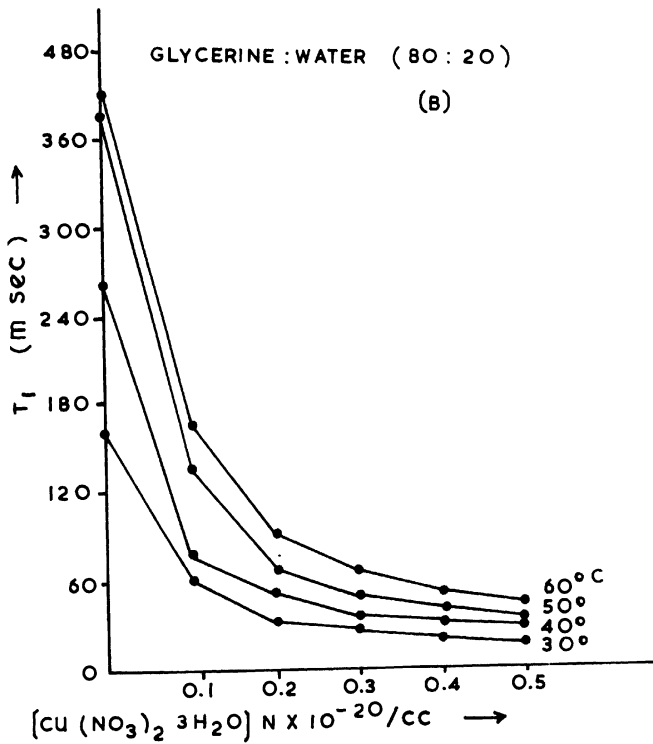


FIG. 6.3



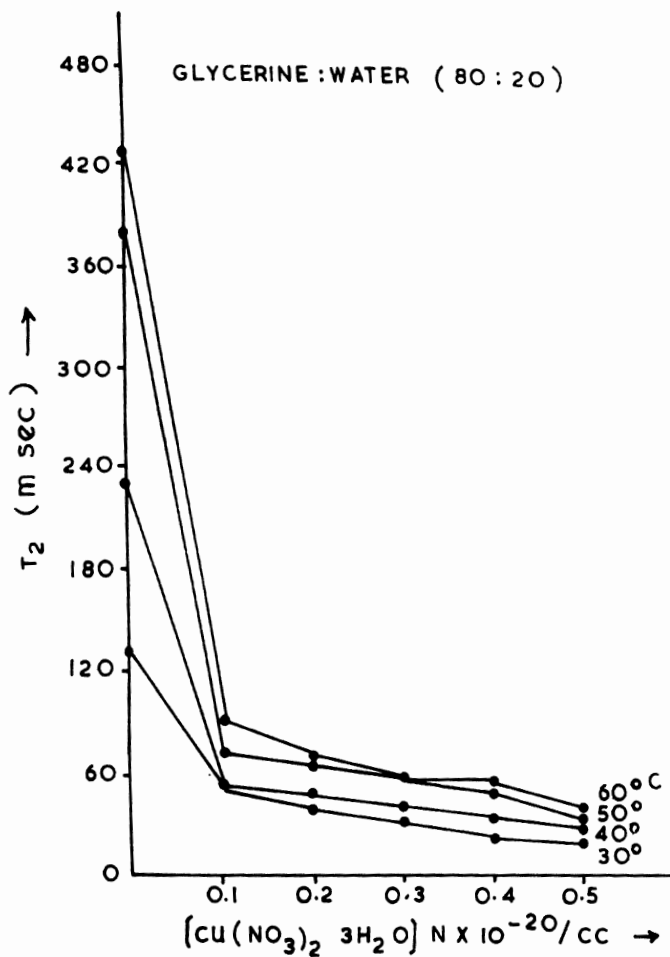


FIG. 6. 4

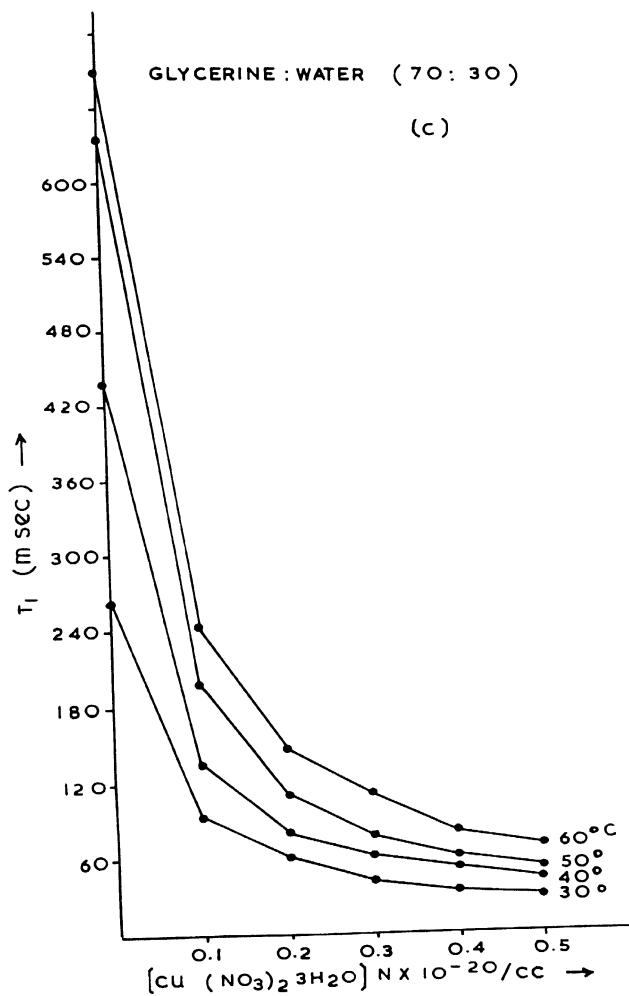


FIG. 6.5

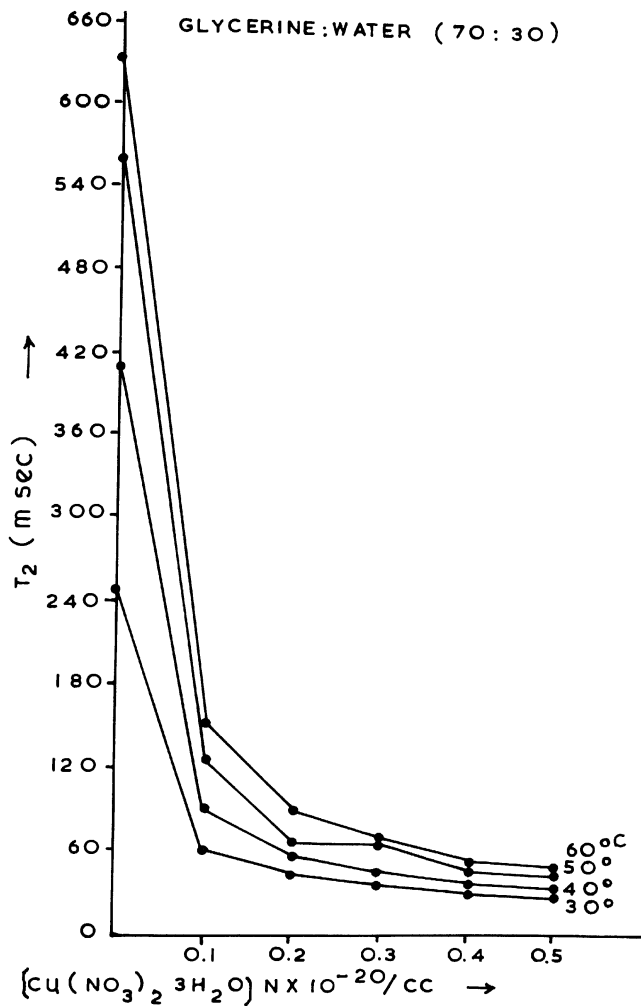


FIG. 6.6

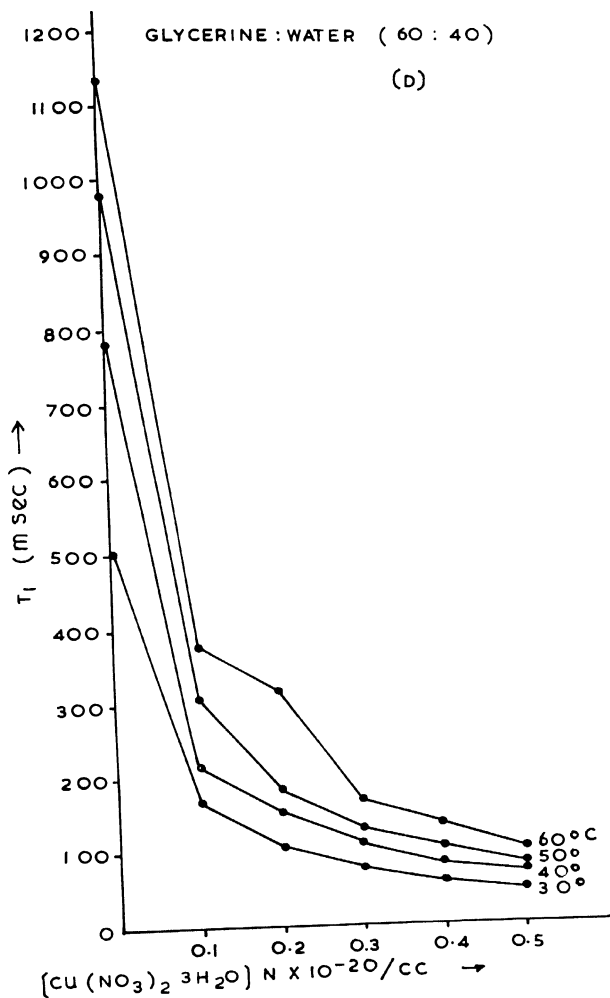


FIG. 6.7

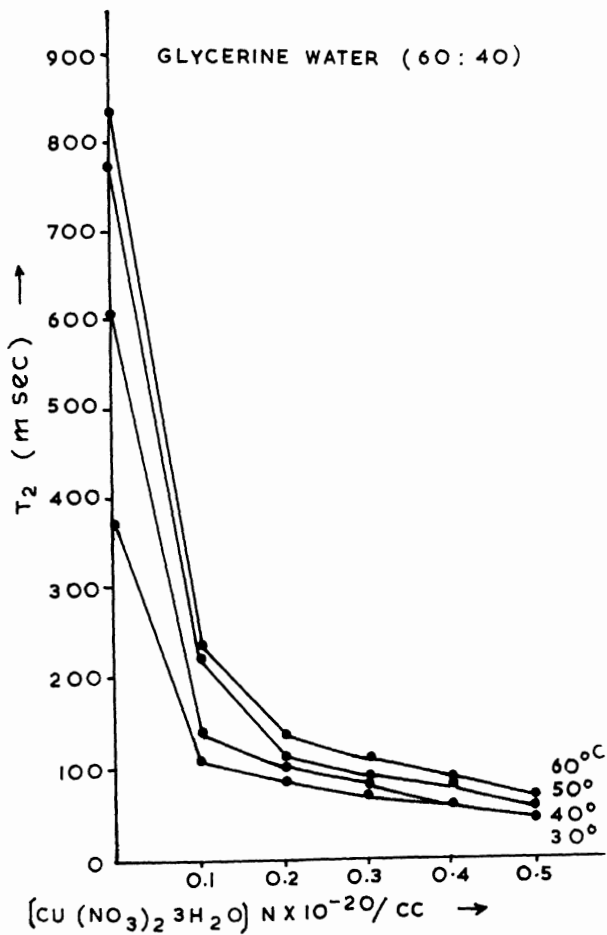
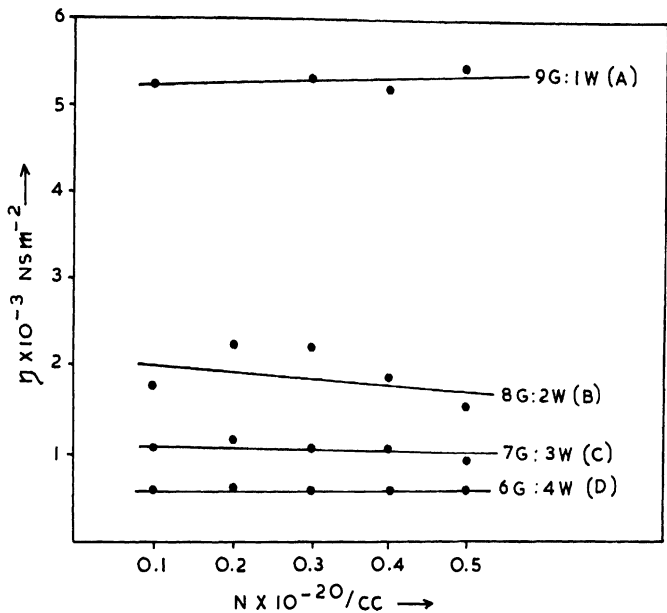


FIG. 6.8



VISCOSITY VERSUS CONCENTRATION OF  
COPPER NITRATE IN GLYCERINE WATER MIXTURE

FIG. 6.9

different compositions of glycerine-water mixtures with paramagnetic ions ( $\text{Cr}^{++}$ ) for solutions A-D at different temperature ( $30^\circ, 40^\circ, 50^\circ, 60^\circ$ ) are shown in figure 6.10-6.17 (Tables 6.3,6.4). The results obtained in solutions A-D for  $\text{Cr}^{++}$  solution is similar to the results obtained for copper. The relaxation times ( $T_1$ ) and ( $T_2$ ) are found to increase with increase of temperature. The variation of viscosity for glycerine water mixtures with the addition of PMI ( $\text{Cr}^{++}$ ) at  $303^\circ\text{K}$  are shown in figure 6.18. From the figure, it can be seen that the addition of PMI for all the solutions does not show any appreciable change. The decay of magnetisation with time intervals between  $90^\circ$  and  $90^\circ$  pulse are shown in the figure 6.19,6.20, it can be seen from the figure that the decay is found to be mono exponential.

#### DISCUSSION:

It will be appropriate to discuss the results obtained in glycerine-water mixture without paramagnetic ions first and then assess the influence of para magnetic ions on highly viscous systems. Since the relaxation times  $T_1$  and  $T_2$  are approximately equal in these mixtures, it can be concluded that dipole-dipole interaction is a dominant relaxation mechanisms.

Relaxation times ( $T_1$ ) and ( $T_2$ ) were measured for the volume proportions of glycerine-water solutions which cover

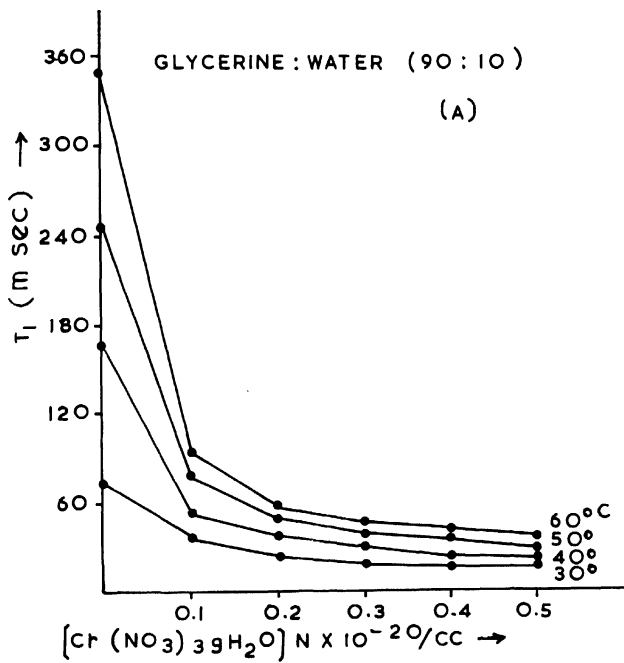


FIG. 6.10



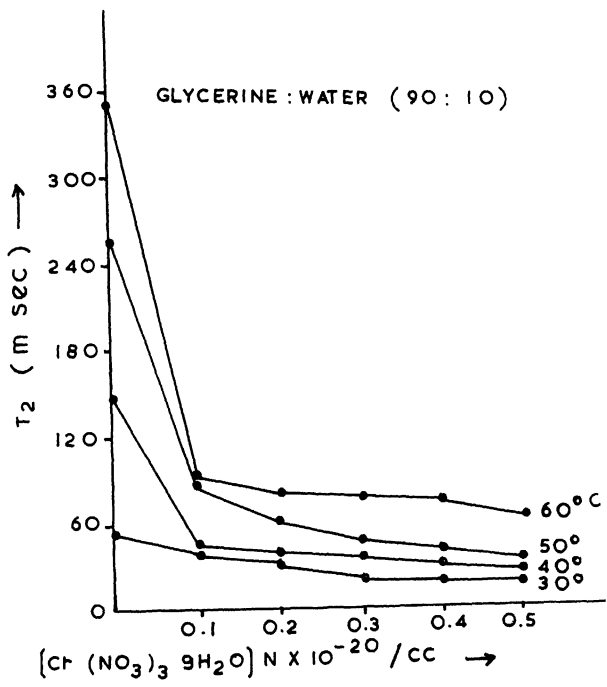


FIG. 6.11

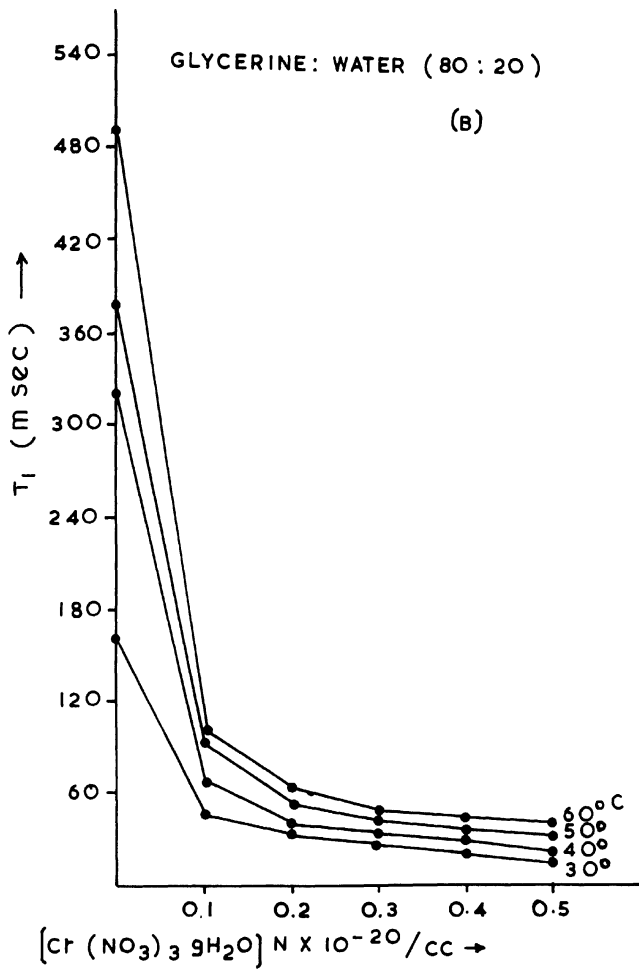
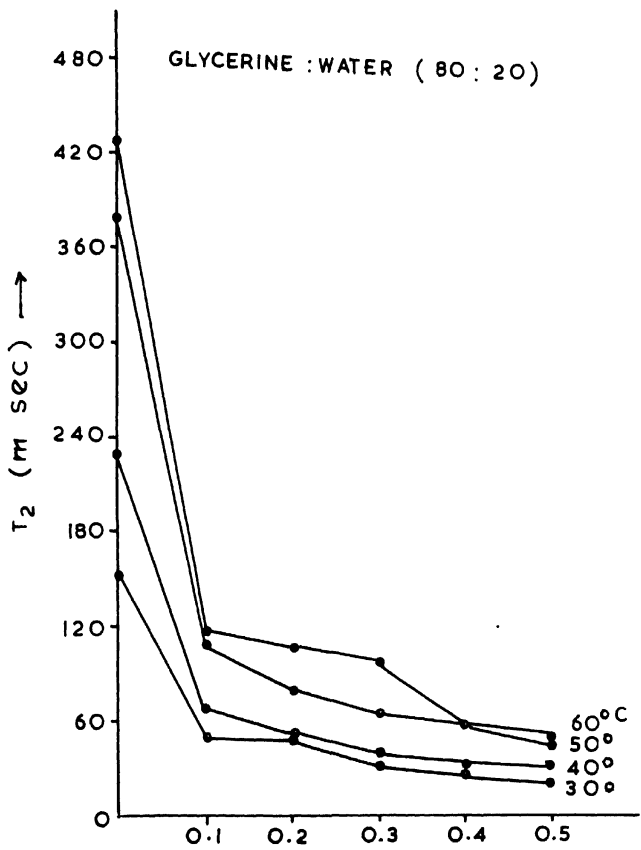


FIG. 6.12



$[Cr(NO_3)_3 \cdot 9H_2O] N \times 10^{-20} / CC \rightarrow$   
 FIG. 6.13

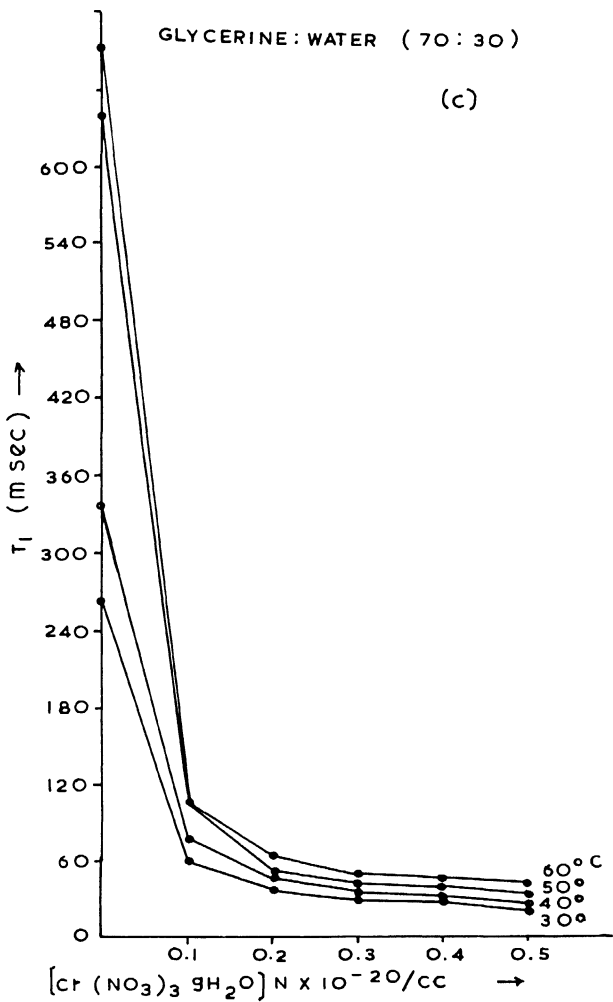


FIG. 6.14

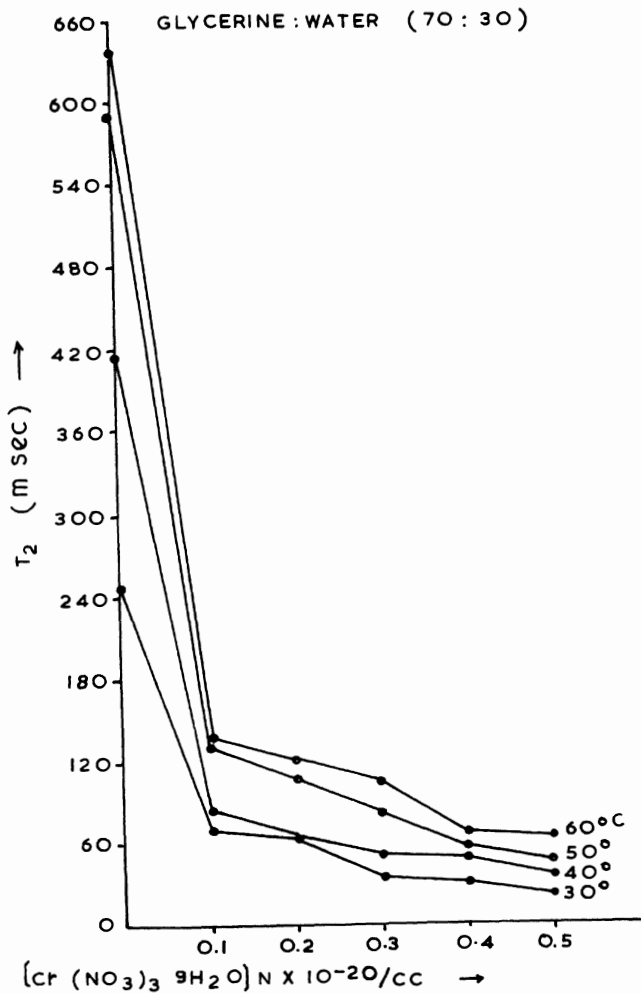


FIG. 6.15

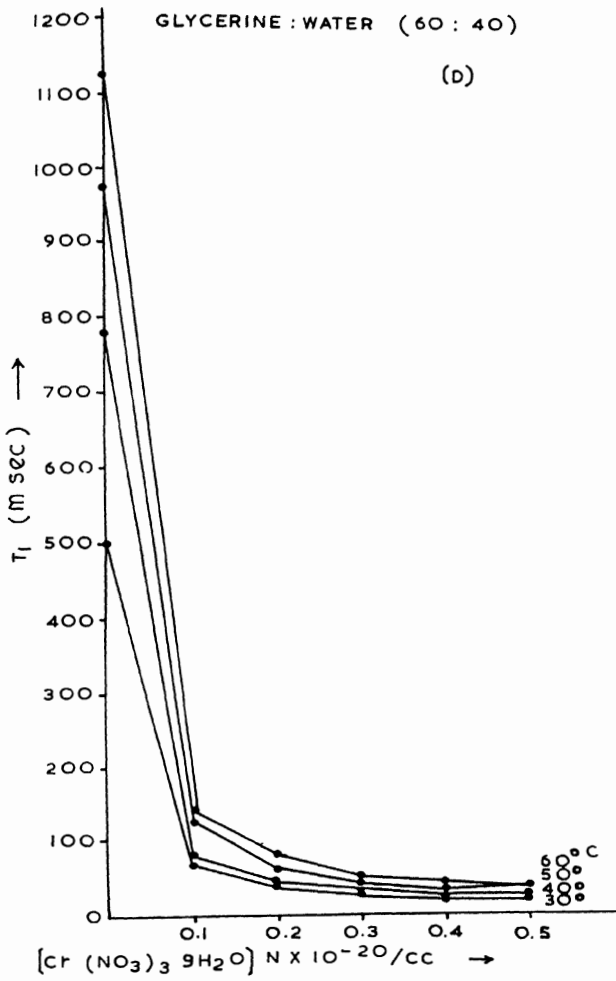


FIG. 6.16

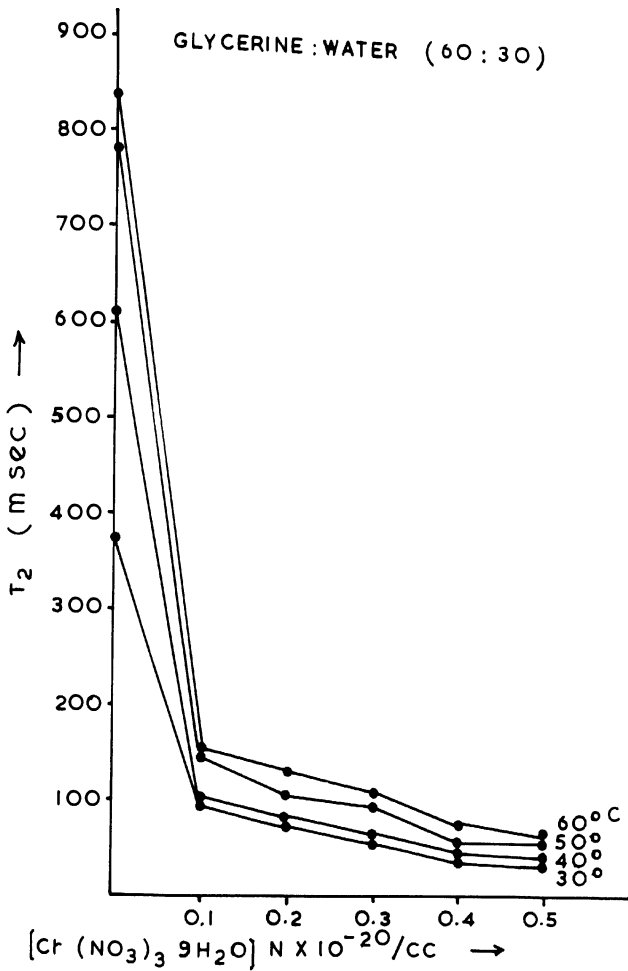
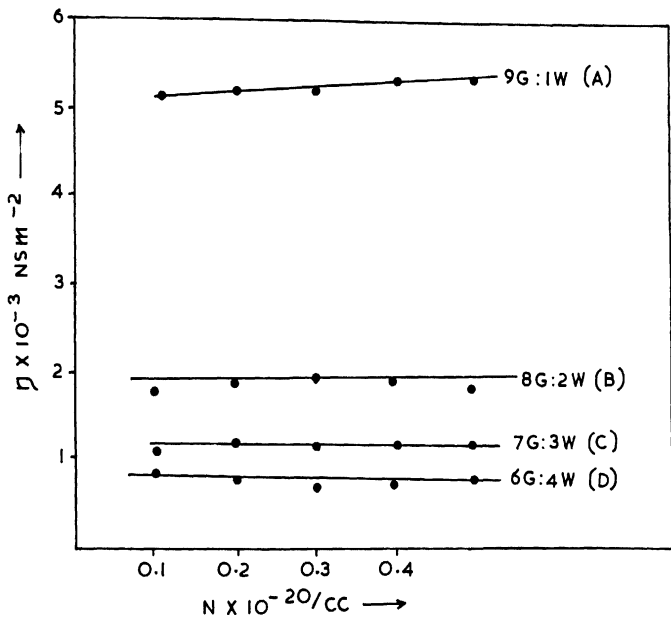


FIG. 6.17



VISCOSITY VERSUS CONCENTRATION OF  
CHROMIUM NITRATE IN GLYCERINE-WATER MIXTURE

FIG. 6.18



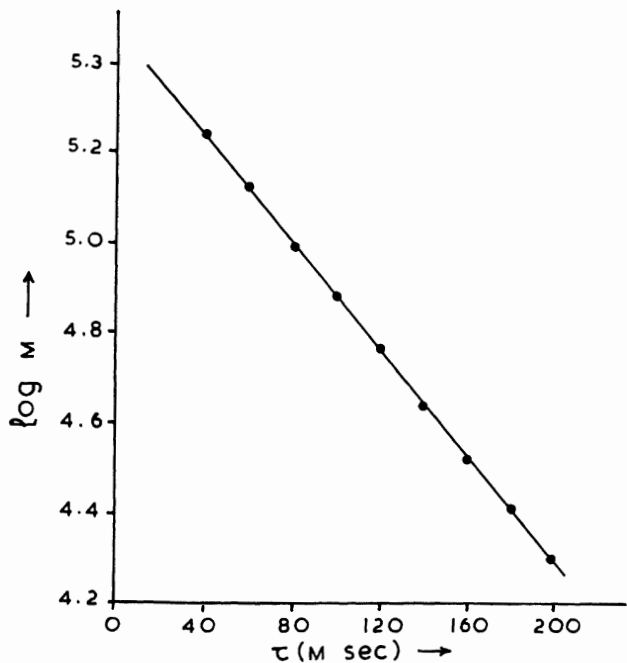


FIG. 6.19  $\log M$  VERSUS  $\tau$  OF SOLUTION D  
(80% GLYCERINE AND 20% WATER)

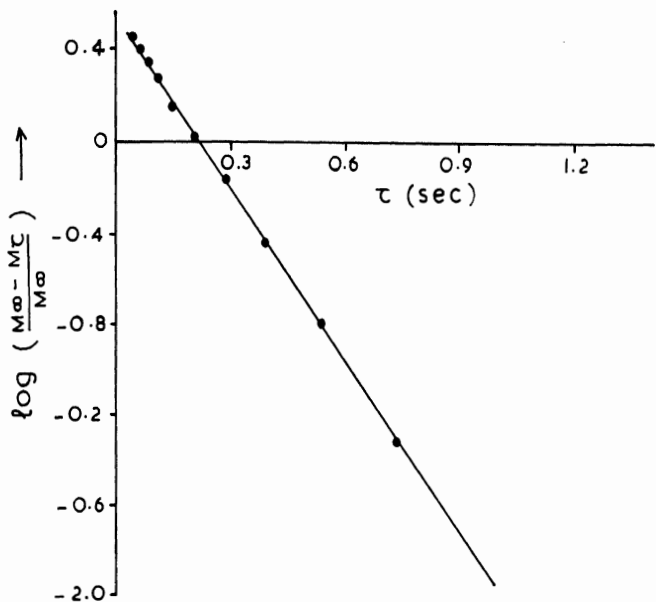


FIG. 6.20  $\log \left( \frac{M_{\infty} - M_{\tau}}{M_{\infty}} \right)$  VERSUS  $\tau$  OF SOLUTION C

a wide range of viscosity at a temperature of 303°K are shown in Table 6.5. From the table it can be seen that exact proportionality between  $1/T_1$  and  $\eta$  is not perhaps to be expected, since the progressive change of concentration must bring with it a change in the environment of each proton (10).

It may also be seen from figure 6.1 that the relaxation time ( $T_1$ ) changes from 74-349 msec as the temperature is increased from 30°-60° C for solution A with zero PMI concentration. This effect may be entirely due to the change in the viscosity ( $\eta$ ) as  $\eta$  in glycerol decreases from 612 cp to 81 cp (11) in this temperature range. Since  $(1/T_1)$  is inversely proportional to  $\eta/T$  (10), it can be inferred that the large change observed in the value of ( $T_1$ ) with increase of temperature may be due to the combined effect of change in viscosity and temperature. Similar effect is also observed in solutions B,C and D without paramagnetic ions. A similar effect observed for the variation of ( $T_2$ ) with temperature in the above solutions.

#### GLYCERINE- WATER WITH PARAMAGNETIC IONS:

According to Bernheim et al (3), the longitudinal relaxation time ( $T_1$ ) for the protons in the presence of paramagnetic ions is given by

$$\frac{1}{T_1} = \text{Constant } N \mu_{\text{eff}}^2 \tau_c \text{ ----- (6.1)}$$

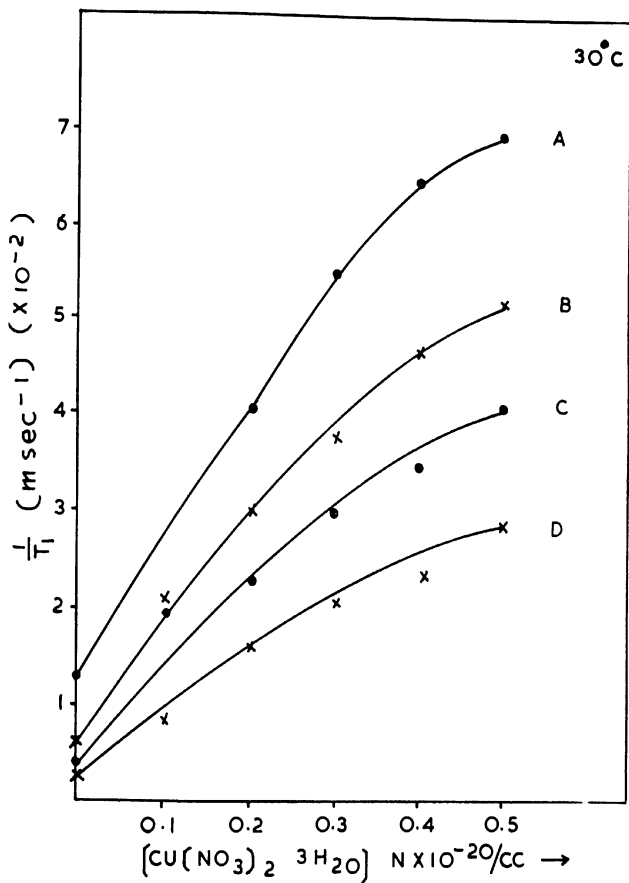
where  $N$  is the concentration of paramagnetic ions,  $\mu_{\text{eff}}^2$  is their effective magnetic moment and  $\tau_c$  is the correlation time for the rotation of the molecules containing protons as well as paramagnetic ions

$$\tau_c = \frac{4 \pi \eta a^3}{KT} \quad \text{-----} \quad (6.2)$$

where ' $k$ ' is the Boltzmanns constant, ' $T$ ' the absolute temperature, ' $a$ ' the molecular radius of the complex and ' $\eta$ ' is the co efficient of viscosity. combining equation 3 and 4 at constant temperature we get

$$\frac{1}{T_1} = \text{constant } N \mu_{\text{eff}}^2 \eta a^3 \quad \text{-----} \quad (6.3)$$

From the equation 6.3 and figure 6.21,6.22 that  $1/T_1$  increases linearly for the solutions of C and D containing  $\text{Cu}^{++}$  ions, whereas for solutions A and B that  $1/T_1$  increases linearly upto PMI concentration of  $0.3 \times 10^{20}$  ions/cc and for higher PMI concentration there is deviation from linearity. The linear increase of  $1/T_1$  observed with increase of PMI concentration indicate that the molecular radius ' $a$ ' does not change appreciably in these solutions thereby indicating that the complex formation in these solution is rather weak. Solutions A and B are highly viscous systems as compared to C and D and such systems, the mobility of the



VARIATION OF  $\frac{1}{T_1}$  VERSUS ION CONCENTRATION OF COPPER NITRATE

FIG. 6.21

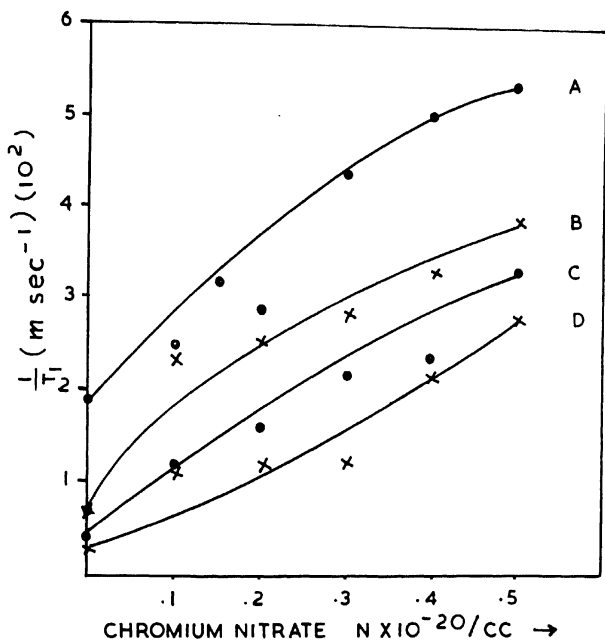


FIG. 6.22 ( $\frac{1}{T_1}$ ) VS ION CONCENTRATION AT SEVERAL TEMPERATURES

ions is restricted and this may increase the probability of anti parallel bonding of the paramagnetic ions. This anti parallel bonding reduces the value of  $\mu_{\text{eff}}$  and  $(1/T_1)$  decreases with increase of PMI concentration. It can be seen from figures that the variation of  $(T_2)$  with PMI concentration similar to that of the variation of  $(T_1)$  with PMI concentration and the explanation proposed above may also hold good for  $(T_2)$ .

#### DIOXAN - WATER MIXTURE WITH PARAMAGNETIC IONS:

In continuation of the above work, the present investigation is undertaken to study the effect of addition of paramagnetic ions in less viscous medium of dioxan rich, dioxan-water mixtures. The dioxan-water system is particularly appropriate since dioxan mixes freely in all proportions with water, has almost identical density and many studies of physical properties of the mixtures were already carried out (12,13). Further infrared and NMR studies (14-16) indicate that molecules of water and dioxan interact strongly. Hence it is considered worthwhile to study the relaxation studies in these mixtures with and without paramagnetic ions. The paramagnetic ions are likely to be more mobile in these mixtures (as compared to highly viscous glycerine-water mixtures) and this should reveal some interesting information on the nature of molecular interactions.

The present relaxation study was carried out in dioxan-water mixtures of volume ratio 9:1 (solution I), 8:2 (solution J) , 7:3 (solution K). The paramagnetic ions used are copper nitrate and chromium nitrate. In these paramagnetic ions, copper ions are weakly paramagnetic whereas chromium ions are strongly paramagnetic.

One molar solutions of copper nitrate, chromium nitrate were prepared by dissolving it in double distilled water. This solution was added in different amounts to dioxan and the desired concentration value is obtained by further addition of the required amount to water. The concentration is expressed as number of ions per  $m^3$  and the range is from  $0.1 \times 10^{20}$  ions/cc to  $0.5 \times 10^{20}$  ions/cc.

The relaxation measurements in these solutions in the above concentrations were measured at room temperature ( $30^\circ C$ ) using Bruker PC 120 NMR processes analyser. 180- $\tau$ -90 pulse sequences was used for the measurement of  $T_1$  and CPMG pulse sequence was used for the measurement of  $T_2$ . The accuracy in the measured values of  $T_1$  and  $T_2$  is of the order of  $\pm 0.1\%$ . The viscosities and densities in these solutions were measured at the same temperature using Ostwald's viscometer and Pyknometer at a temperature Of  $30^\circ C$ .

#### RESULTS:

The variation of spin-lattice relaxation times ( $T_1$ ) and spin-spin relaxation times ( $T_2$ ) in dioxan-water solutions



(I-K) with PMI concentrations of copper and chromium nitrates are shown in figure 6.23-6.28, and the values are listed in Tables 6.6, 6.7.

The relaxation times generally decreases with increase of PMI concentration. The initial decrease in the relaxation times is quite large upto PMI concentration of  $0.1 \times 10^{20}$  ions/cc for all the solutions studied. Further increase of PMI concentration decreases the relaxation times gradually. Similar behaviour is seen for all the solutions.

The values of viscosity and density for all the three solutions is shown in Tables 6.6, 6.7. The variation of viscosity and density is not highly significant in all the solutions. The comparison of variation of  $(1/T_1)$  against PMI concentrations are shown in figure 6.29-6.31. The decay of magnetisation were checked for all the solutions and the decay is found to be mono exponential.

#### DISCUSSION:

It can be seen from the table 6.6,6.7 that in all the three solutions I, J and K of dioxan-water mixtures (without paramagnetic ions) the relaxation times ( $T_1$ ) and ( $T_2$ ) is found to decrease with increase of concentration of water. The observed decrease in the relaxation time ( $T_1$ ) and ( $T_2$ ) may be attributed due to the strong hydrogen bond formation between dioxan with water molecules. Such strong hydrogen bond formation results in a decrease in the value of

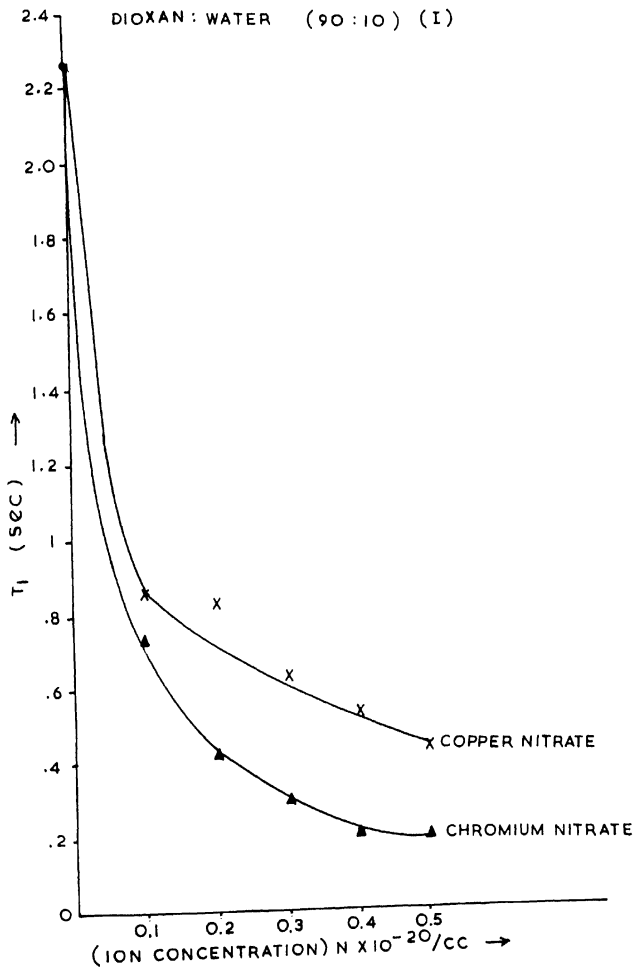


FIG. 6.23

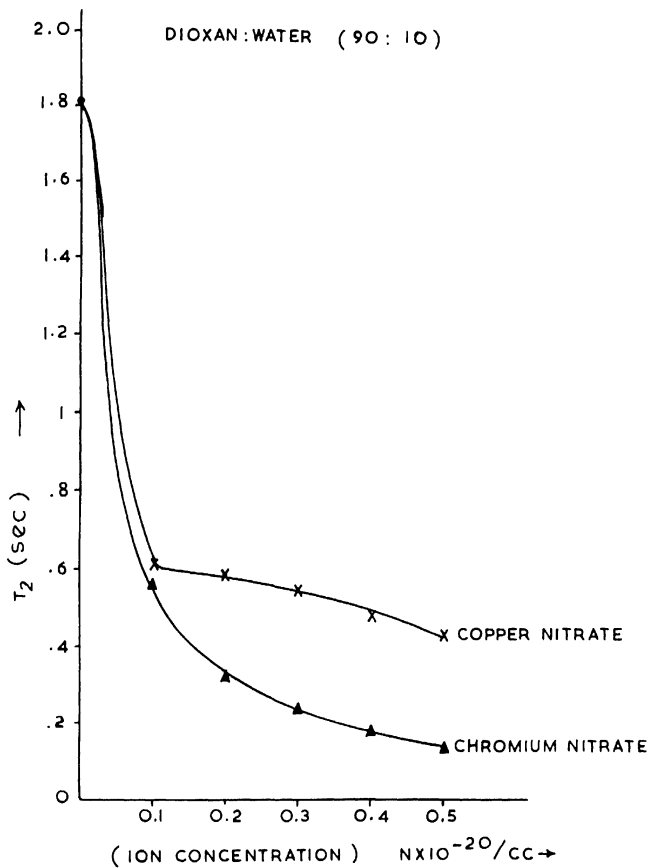


FIG. 6.24

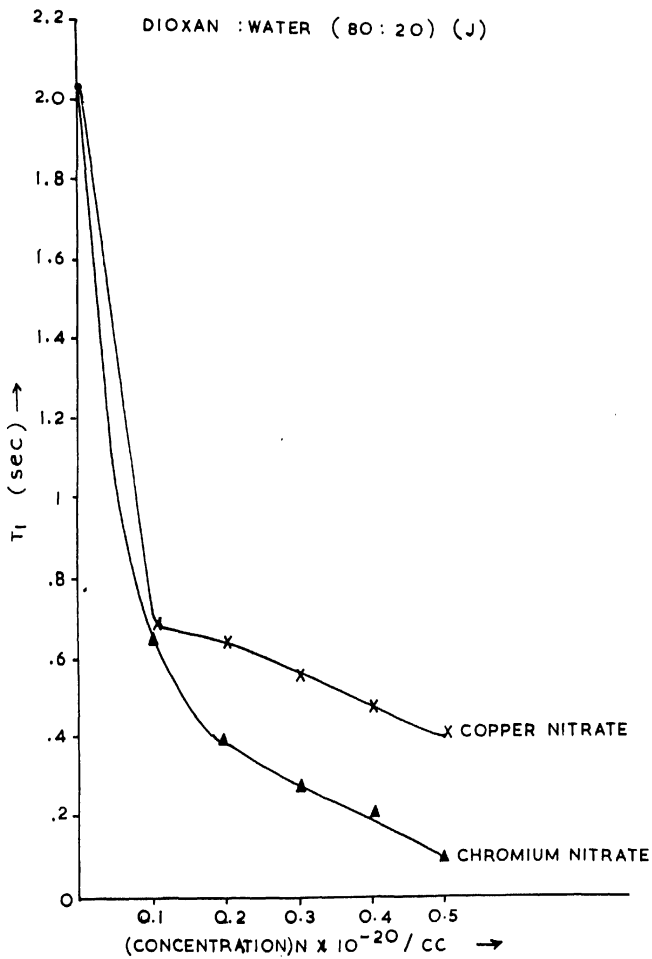


FIG. 6.25

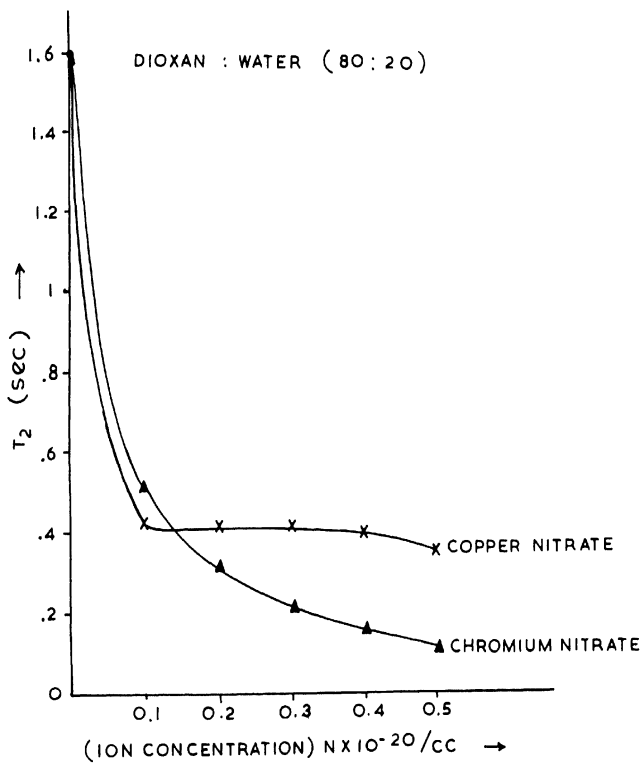


FIG 6-26

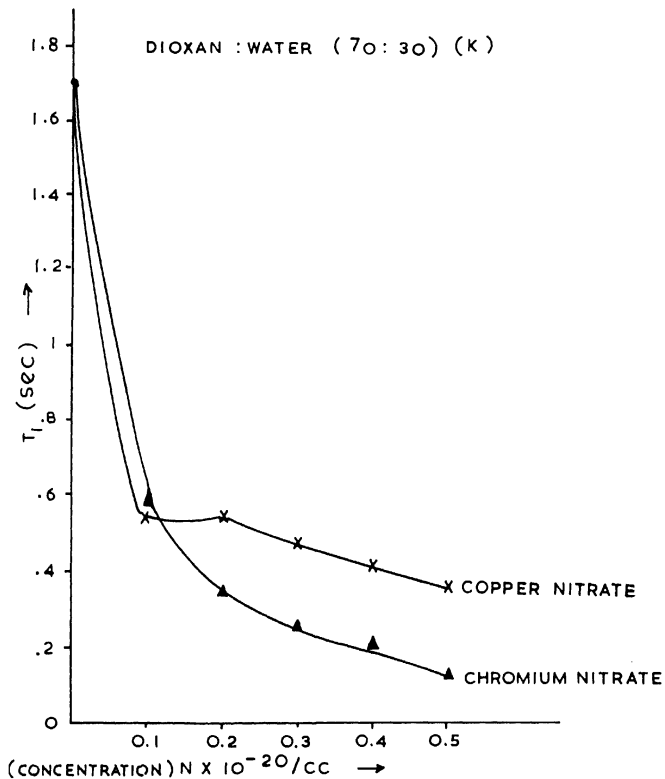


FIG. 6.27

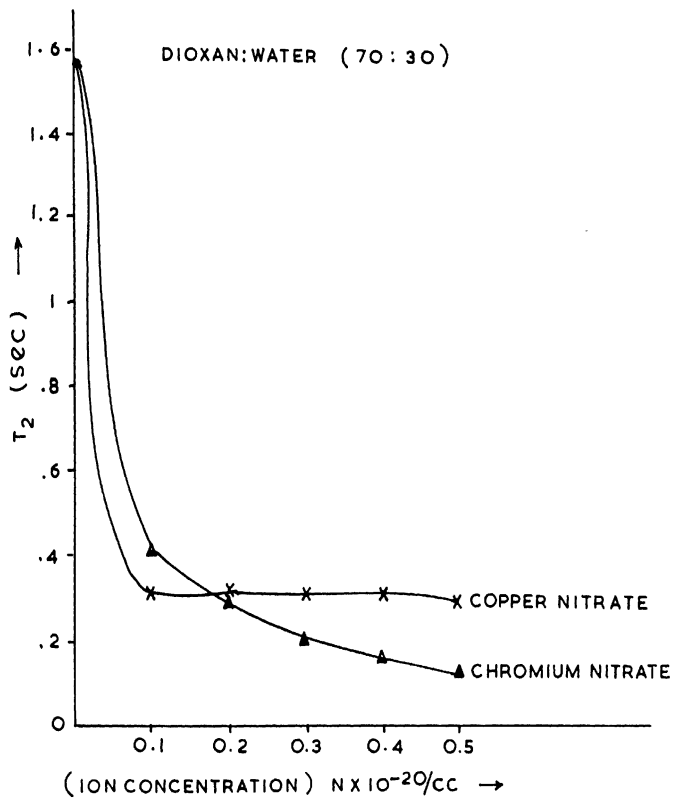


FIG. 6.28

relaxation times ( $T_1$ ) and ( $T_2$ ) as it is known that ( $T_1$ ) decreases with increase in hydrogen bond energy (17).

As discussed earlier, the addition of paramagnetic ions should decrease the relaxation times (figure 6.23-6.28). The variation of ( $1/T_1$ ) against PMI concentrations were shown in figure 6.29- 6.31. From the figure, it can be seen that ( $1/T_1$ ) increases linearly for both copper and chromium nitrate for all the three solutions. It may be noticed that the plots of ( $1/T_1$ ) against PMI concentrations (N) has a larger slope for  $Cr^{++}$  ion as compared to  $Cu^{++}$  ion in these solutions. This increase in the value of the slope may be attributed to the larger value of ' $\mu$ ' for  $Cr^{++}$  ion (18). The linearity of the plot ( $1/T_1$ ) versus PMI concentrations indicates the absence of anti parallel bonding of the paramagnetic ions in these low viscous system. This is to be expected because of the free mobility of the ions. The linear relationship between  $1/T_1$  and PMI concentration also indicates that the molecular radius 'a' (equation 6.3) is not significantly altered by the presence of paramagnetic ions.

In conclusion it may be mentioned that the present study indicates the possibility of anti parallel bonding of the paramagnetic ions in highly viscous solutions as compared to the low viscosity system. These results support the earlier ultrasonic studies in these solutions (19,20).



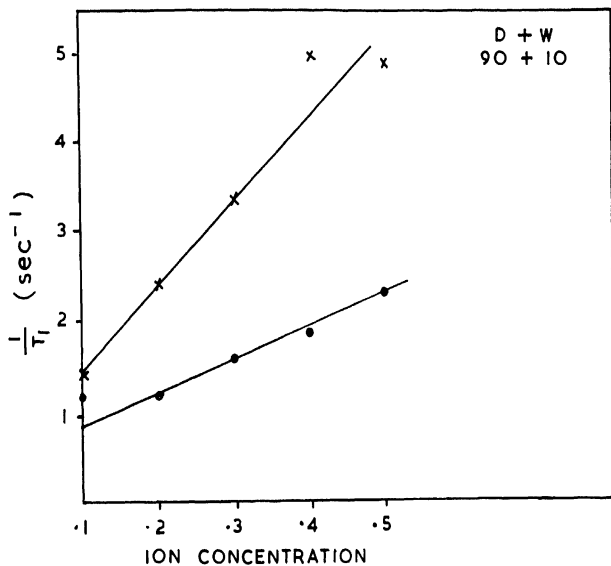


FIG. 6.29 ( $\frac{1}{T_1}$ ) VERSUS ION CONCENTRATION (x) CHROMIUM AND (•) COPPER NITRATE

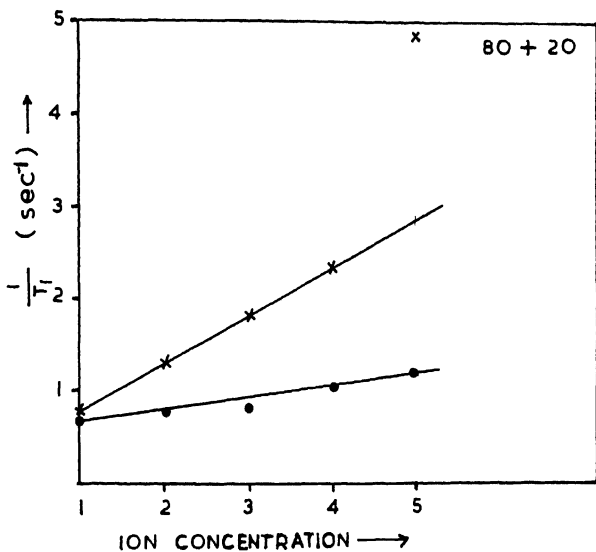


FIG. 6.30 ( $\frac{1}{T_1}$ ) VS ION CONCENTRATION (x) CHROMIUM AND (•) COPPER NITRATE

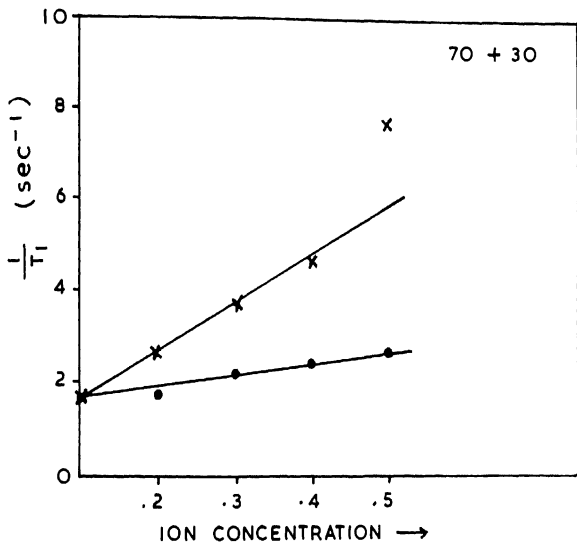


FIG. 6.31 ( $\frac{1}{T_1}$ ) VERSUS ION CONCENTRATION (x) CHROMIUM AND (•) COPPER NITRATE

TABLE 6.1

Variation of spin-lattice relaxation time T1 (msec) in glycerine-water mixture with para magnetic ions  
(Copper nitrate) with different temperatures.

Concentration	Solution.A 90% Glycerine + 10% Water				Solution.B 80% Glycerine + 20% Water			
	30°	40°	50°	60°	30°	40°	50°	60°
110 <sup>-2</sup>								
0.00	73.97	164.66	260.35	349.24	162.60	263.04	377.01	491.40
0.10	49.45	47.83	105.57	106.34	61.72	77.74	134.77	148.64
0.20	24.71	33.33	44.41	62.24	35.23	54.45	69.03	93.72
0.30	18.14	26.22	33.54	46.87	26.93	39.96	51.55	69.29
0.40	15.45	21.21	28.78	36.77	21.38	32.98	42.58	54.54
0.50	14.36	19.07	24.58	34.35	19.21	29.61	34.94	46.45

Concentration	Solution.C 70% Glycerine + 30% Water				Solution.D 60% Glycerine + 40% Water			
	30°	40°	50°	60°	30°	40°	50°	60°
110 <sup>-2</sup>								
0.00	265.67	438.38	638.59	720.72	502.00	785.79	977.95	1138.5
0.10	100.09	138.27	202.22	242.76	170.22	219.56	310.19	382.51
0.20	61.94	86.07	115.31	149.32	107.18	155.40	183.03	222.36
0.30	43.88	63.93	79.81	114.11	74.16	110.83	127.26	172.63
0.40	35.04	53.08	64.07	84.67	57.15	85.78	104.02	136.11
0.50	29.95	44.69	54.75	73.46	45.57	69.63	80.91	100.39

TABLE 6.2

Variation of spin-spin relaxation time T<sub>2</sub> (msec) in glycerine-water mixture with para magnetic ions  
(Copper nitrate) with different temperatures.

Concentration	Solution.A 90% Glycerine + 10% Water				Solution.B 80% Glycerine + 20% Water			
	30°	40°	50°	60°	30°	40°	50°	60°
0.00	54.020	148.54	256.29	358.29	132.60	227.84	378.89	431.04
0.10	45.121	43.615	44.149	51.812	50.653	51.010	71.718	89.776
0.20	30.156	35.162	38.681	46.516	40.152	45.125	65.156	68.596
0.30	25.312	32.172	35.162	40.612	30.162	40.715	56.765	58.125
0.40	20.127	25.621	27.156	35.616	22.152	30.167	50.126	52.394
0.50	17.616	19.156	23.626	30.721	20.652	28.617	35.215	38.676

Concentration	Solution.C 70% Glycerine + 30% Water				Solution.D 60% Glycerine + 40% Water			
	30°	40°	50°	60°	30°	40°	50°	60°
0.00	248.84	410.96	560.57	638.01	375.07	613.18	779.83	839.00
0.10	60.678	95.469	130.75	154.94	113.42	146.83	225.24	247.75
0.20	45.382	58.927	70.193	91.420	88.239	102.84	111.39	148.49
0.30	40.562	47.115	67.712	70.978	70.176	78.615	87.390	108.62
0.40	32.115	40.135	48.739	49.855	60.312	53.366	83.781	80.842
0.50	30.117	38.111	45.115	48.121	42.615	48.854	59.520	64.710

TABLE 6.3

Variation of spin-lattice relaxation time  $T_{1\rho}$  in glycerine-water mixture with para magnetic ions  
(Chromium nitrate) with different temperatures.

Concentration	Solution.A 90% Glycerine + 10% Water				Solution.B 80% Glycerine + 20% Water			
	30°	40°	50°	60°	30°	40°	50°	60°
0.00	73.97	164.66	260.35	349.24	162.60	263.04	377.01	491.40
0.10	37.47	54.81	77.08	91.57	48.36	68.23	93.05	102.57
0.20	24.29	37.64	51.18	58.32	34.86	43.98	56.35	61.72
0.30	20.05	30.20	41.08	47.22	27.10	36.81	43.83	49.96
0.40	16.38	25.09	35.70	41.00	22.58	31.29	40.03	43.70
0.50	16.07	21.77	29.45	36.85	20.64	25.91	34.02	39.90

Concentration	Solution.c 70% Glycerine + 30% Water				Solution.D 60% Glycerine + 40% Water			
	30°	40°	50°	60°	30°	40°	50°	60°
0.00	265.67	438.38	638.59	720.72	502.00	785.79	977.95	1138.50
0.10	61.37	76.41	116.76	117.09	69.72	86.08	132.85	140.58
0.20	39.41	47.73	58.34	65.42	42.86	48.98	66.99	85.35
0.30	33.10	39.38	44.40	49.73	35.58	36.71	43.18	49.39
0.40	30.10	34.96	39.02	41.74	31.46	33.21	37.30	40.82
0.50	25.10	29.36	35.28	38.84	26.24	33.77	33.82	35.49

TABLE 6.4

Variation of spin-spin relaxation time T<sub>2</sub>( $\mu$ sec) in glycerine-water mixture with para magnetic ions  
(Chromium nitrate) with different temperatures.

Concentration	Solution.A 90% Glycerine + 10% Water				Solution.B 80% Glycerine + 20% Water			
	30°	40°	50°	60°	30°	40°	50°	60°
110 <sup>-4</sup>								
0.00	54.019	148.54	246.29	358.04	132.60	227.81	378.89	431.04
0.10	40.313	44.411	86.720	94.483	49.427	65.813	112.83	119.31
0.20	34.459	40.561	61.691	82.893	48.640	48.174	82.794	107.80
0.30	22.718	35.617	45.424	80.283	30.018	39.175	64.088	100.82
0.40	20.615	30.165	42.121	45.427	28.156	33.512	57.263	58.737
0.50	18.767	25.123	30.151	35.152	25.107	32.111	43.683	53.431

Concentration	Solution.c 70% Glycerine + 30% Water				Solution.D 60% Glycerine + 40% Water			
	30°	40°	50°	60°	30°	40°	50°	60°
110 <sup>-4</sup>								
0.00	248.84	410.96	560.57	638.01	375.07	613.18	779.83	839.01
0.10	73.615	89.148	133.85	140.04	99.276	100.79	144.56	154.20
0.20	64.728	65.210	108.58	123.17	76.310	77.582	105.39	130.90
0.30	38.151	54.095	82.618	109.45	53.513	67.458	95.512	112.66
0.40	30.215	49.165	59.262	69.138	41.483	45.160	59.263	73.645
0.50	25.165	38.515	50.701	67.312	37.841	42.590	55.162	70.315

TABLE 6.5

Relaxation Times ( $T_1$  &  $T_2$ ) and related parameters in  
Glycerine-Water Mixtures at 303 K

X	$T_1$ (msec)	$T_2$ (msec)	$\rho^{3-3}$ 10 Kg $m^{-3}$	$\eta^{-3-2}$ 10 NS $m^{-2}$
G : W				
6 : 4	502.00	375.07	1.1688	0.8260
7 : 3	265.67	248.84	1.1849	0.9706
8 : 2	162.60	132.60	1.2002	3.0722
9 : 1	73.97	54.02	1.2001	4.1226
10 : 1	20.20	15.60	1.2600	8.0000

X - Volume ratio of glycerine and water

$T_1$  - spin-lattice relaxation time

$T_2$  - spin-spin relaxation time

$\rho$  - Density       $\eta$  - Viscosity



TABLE 6.6

PMR RELAXATION TIMES (T<sub>1</sub> & T<sub>2</sub>) AND OTHER RELATED PARAMETERS OF  
DIOXAN-WATER MIXTURE WITH PARA MAGNETIC IONS (CHROMIUM NITRATE)  
(90%D + 10%W)

Concentration	T <sub>1</sub> (sec)	T <sub>2</sub> (sec)	$\eta \times 10^{-3}$ NSm <sup>-2</sup>	$\rho \times 10^{+3}$ Kgm <sup>-3</sup>
0.0	2.2686	1.8127	1.3169	1.0286
0.1	0.7402	0.5692	1.3033	1.0293
0.2	0.4243	0.3272	1.3108	1.0296
0.3	0.3026	0.2465	1.3404	1.0313
0.4	0.2035	0.1838	1.3191	1.0315
0.5	0.1900	0.1435	1.3407	1.0325

(80%D + 20%W)

Concentration	T <sub>1</sub> (sec)	T <sub>2</sub> (sec)	$\eta \times 10^{-3}$ NSm <sup>-2</sup>	$\rho \times 10^{+3}$ Kgm <sup>-3</sup>
0.0	2.0350	1.6013	1.5006	1.0320
0.1	0.6638	0.5120	1.4860	1.0310
0.2	0.4030	0.3159	1.4968	1.0320
0.3	0.2855	0.2216	1.4994	1.0344
0.4	0.2169	0.1721	1.5232	1.0330
0.5	0.1033	0.1304	1.6561	1.0363

Contd.

(70%D + 30%W)

Concentration	$T_1$ (sec)	$T_2$ (sec)	$\eta \times 10^{-3}$ NSm <sup>-2</sup>	$\rho \times 10^{+3}$ Kgm <sup>-3</sup>
0.0	1.6976	1.5938	1.6020	1.0327
0.1	0.5763	0.4214	1.6102	1.0339
0.2	0.3546	0.2887	1.6512	1.0337
0.3	0.2612	0.1971	1.6592	1.0358
0.4	0.2147	0.1588	1.6542	1.0351
0.5	0.1286	0.1319	1.6561	1.0363

TABLE 6.7

PMR RELAXATION TIMES ( $T_1$  &  $T_2$ ) AND OTHER RELATED PARAMETERS OF  
DIOXAN-WATER MIXTURE WITH PARA MAGNETIC IONS (COPPER NITRATE)  
(90%D + 10%W)

Concentration	$T_1$ (sec)	$T_2$ (sec)	$\eta \times 10^{-3}$ $\text{NSm}^{-2}$	$\rho \times 10^{+3}$ $\text{Kgm}^{-3}$
0.0	2.2686	1.8127	1.3169	1.0286
0.1	0.8474	0.6075	1.3690	1.0296
0.2	0.8268	0.5502	1.4522	1.0308
0.3	0.6332	0.5478	1.4486	1.0296
0.4	0.5281	0.4888	1.5054	1.0284
0.5	0.4395	0.4395	1.5095	1.0286

(80%D + 20%W)

Concentration	$T_1$ (sec)	$T_2$ (sec)	$\eta \times 10^{-3}$ $\text{NSm}^{-2}$	$\rho \times 10^{+3}$ $\text{Kgm}^{-3}$
0.0	2.0350	1.6013	1.5006	1.0320
0.1	0.6905	0.4224	1.5826	1.0320
0.2	0.6561	0.4189	1.5858	1.0306
0.3	0.5686	0.4243	1.6062	1.0318
0.4	0.4885	0.4032	1.6061	1.0293
0.5	0.4240	0.3537	1.6099	1.0296

(70%D + 30%W)

Concentration	$T_1$ (sec)	$T_2$ (sec)	$\eta \times 10^{-3}$ $\text{Nsm}^{-2}$	$\rho \times 10^{+3}$ $\text{Kgm}^{-3}$
0.0	1.6976	1.5938	1.6020	1.0327
0.1	0.5423	0.3139	1.6787	1.0337
0.2	0.5480	0.3198	1.7486	1.0337
0.3	0.4670	0.3153	1.7636	1.0325
0.4	0.4092	0.2979	1.7426	1.0310
0.5	0.3644	0.2857	1.7465	1.0313

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