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Solvent – Dependent Molecular Interaction of Copper (II) Nitrate Trihydrate Probed by Ultrasonic (5MHz) and UV-Visible Spectroscopy at 293.15 – 313.15 K

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Abstract: *Ultrasonic and UV–Visible absorption spectroscopic studies were carried out to investigate molecular interactions in electrolytic solutions of copper(II) nitrate trihydrate in aqueous and 5% ethanol–water media. Measurements were performed over the temperature range 293.15–313.15 K at an ultrasonic frequency of 5 MHz under atmospheric pressure. Density and ultrasonic velocity data were utilized to calculate key acoustic and thermodynamic parameters, including adiabatic compressibility, acoustic impedance, apparent molar volume, apparent molar compressibility, and relative adiabatic compressibility, as functions of concentration, temperature, and solvent composition. UV–Visible absorption spectra were recorded to examine electronic transitions and to verify adherence to Beer–Lambert's law. The evaluated parameters enable systematic assessment of solute–solvent and ion–solvent interactions in both solvent systems, while spectral variations reflect changes in solvation environment and ligand field characteristics associated with solvent polarity and temperature.*

Keywords: Ultrasonic velocity; Acoustic parameters; UV–Visible absorption spectroscopy; Copper(II) nitrate trihydrate; Ion–solvent interactions; Mixed solvent system; Adiabatic compressibility; Apparent molar volume; Structure-making behavior

I. INTRODUCTION

The investigation of solute–solvent and ion–solvent interactions in electrolyte solutions is fundamental for understanding the physicochemical characteristics of transition metal salts. Among several analytical techniques, ultrasonic velocity measurements have emerged as a reliable, sensitive, and non-destructive method for exploring molecular interactions, liquid structure, and compressibility in solutions. Such measurements provide detailed insight into intermolecular forces, solvation behavior, and structural variations in both pure and mixed solvent systems [1–3].

Copper nitrate, a divalent transition metal salt, exhibits a pronounced ionic nature and a strong tendency to form coordination complexes in aqueous media. The physicochemical behavior of this electrolyte is highly dependent on the solvent environment and solute concentration. Studying the ultrasonic velocity of copper nitrate in solvents of differing polarities—such as pure water and alcohol–water mixtures—helps in understanding ion–ion and ion–solvent interactions, which are critical for interpreting the acoustic and thermodynamic properties of the system [4–6].The inclusion of a small proportion of alcohol (5%) in water changes the dielectric constant, polarity, and hydrogen-bonding characteristics of the medium, thereby altering the solvation and molecular association patterns. Alcohol molecules interfere with the extensive hydrogen-bonded network of water, which affects the compressibility and cohesive nature of the solution. Therefore, comparing the acoustic behavior of copper nitrate in pure aqueous and mixed solvent environments provides valuable information on how solvent composition influences electrostatic forces and molecular structuring [7–9].In the present work, the ultrasonic velocity, density, and viscosity of copper nitrate solutions have been measured in the concentration range 0.01 M to 0.1 M and at different temperatures—20°C, 25°C, 30°C, 35°C, and 40°C—using a constant frequency

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of 5 MHz. Based on the experimental data, several thermodynamic and acoustic parameters, including as adiabatic compressibility (β),Relative adiabatic compressibility, the apperent molal compressibility, acoustic impedance (Z), and apparent molar volume (Φv),. The dependence of these parameters on temperature and concentration has been analyzed to elucidate the nature, intensity, and temperature sensitivity of ion–solvent interactions in the systems studied.This investigation provides meaningful insights into the molecular interactions and structural alterations occurring in copper nitrate solutions under varying solvent compositions and thermal conditions, thereby enhancing the understanding of transition metal electrolyte behavior in mixed solvent environments [10–12].

II. MATERIALS AND METHODS

Analytical-grade copper nitrate trihydrate was obtained from Merck (India) Ltd., and used without further purification. The solvent systems employed were double-distilled water and a 5% (v/v) aqueous ethanol mixture, both freshly prepared to minimize contamination and ionic impurities during measurements. All glassware was thoroughly cleaned and rinsed with distilled water before use to ensure accuracy and reproducibility. Density measurements were performed using a Mettler Toledo portable digital densitometer, known for its high precision and suitability for solution studies in chemical and physical research [13–15]. Temperature control during all experiments was maintained using a thermostatically regulated water bath with an accuracy of ±0.1°C. The bath was equipped with a continuous circulation system and a digital temperature controller, ensuring uniform temperature distribution throughout the measurement process [16–17].
Ultrasonic velocity was determined using a single-crystal ultrasonic interferometer (Mittal type, Model F-83), operating at a fixed frequency of 5 MHz and providing a velocity accuracy of ±0.1 $m \cdot s^{-1}$. This instrument is widely recognized for its reliability and sensitivity in investigating molecular interactions and thermodynamic behavior of liquids [18–21].
The UV–Visible absorption spectra of $Cu(NO_3)_2 \cdot 3H_2O$ were recorded using a single beam UV–Visible spectrophotometer in the wavelength range of 350–1100 nm at room temperature (28 ± 2 °C). A 1 cm quartz cuvette was used for all measurements. The instrument was calibrated with the respective blank solvent before each scan. The absorption maxima (λmax) were recorded to study d–d transitions of Cu^{2+} ions and to understand the effect of solvent composition and concentration on solute–solvent interactions. Each reading was repeated three times to ensure precision, and the average value was considered for data analysis[22-25]
Measurements of density and ultrasonic velocity were carried out for both aqueous and 5% alcoholic solutions of copper nitrate over a concentration range of 0.01 M to 0.1 M.
Observations were made at five distinct temperatures — 20°C, 25°C, 30°C, 35°C, and 40°C — under constant frequency conditions. Each experimental reading was repeated at least three times, and the average value was taken to ensure precision and consistency in the data.[26-28]

III. RESULT AND DISCUSSION

In the present study, experimental measurements of absorption spectroscopy, density (ρ), viscosity (η), and ultrasonic velocity (u) were performed for copper nitrate solutions in both aqueous and 5% alcoholic media at varying concentrations and temperatures. These basic parameters serve as the foundation for evaluating a series of derived acoustic and thermodynamic quantities, which provide valuable insights into solute–solvent interactions, ion–ion associations, and the structural characteristics of the medium.

1. Adiabatic Compressibility (β_a)

Adiabatic compressibility (β_a) represents the ease with which a liquid medium can be compressed under adiabatic conditions. It provides an indirect measure of the strength of molecular interactions within the system. The parameter was computed using the standard relation:
The adiabatic compressibility of the solution is a key parameter reflecting the ease with which a medium can be compressed under adiabatic conditions. It is calculated using the following relation:

$$\beta a = 1/ u^2 \rho$$

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where u = ultrasonic velocity ρ = density of the solution

2. Change in Adiabatic Compressibility (Δβ):To assess the influence of solute addition on the compressibility of the solvent, the change in adiabatic compressibility was determined using:

$$\Delta\beta = \beta a - \beta''$$

where β0 is the compressibility of pure solvent (water)

3. Apparent Molar Volume (Φ_v):The apparent molal volume (Φ_v) provides information about solute–solvent interactions and solvation effects, and was calculated as:

$$\Phi v = 1000 \frac{\dot{\rho}0-\dot{\rho}}{m\dot{\rho}0\dot{\rho}} + \frac{m}{\dot{\rho}}$$

Where ρ0 = density of pure solvent
M = molar mass of copper nitrate trihydrate m = molality

4. Specific Acoustic Impedance (Z):Specific acoustic impedance (Z) signifies the resistance offered by the medium to the propagation of sound waves and was calculated by:

$$Z = u \cdot \rho$$

5) Apparent Molar Compressibility (Φ□):Apparent molar compressibility is the contribution of one mole of solute to the compressibility of a solution and was calculated as:

$$\Phi\square = 1000\frac{(\beta a - \beta 0)}{m\ \square 0} + \beta a\Phi v$$

6) Relative Adiabatic Compressibility (RAC):Relative adiabatic compressibility is the ratio of the adiabatic compressibility of a solution to that of the pure solvent and was calculated as

$$RAC = \frac{\Delta\beta}{\beta o}$$

Table 1: Acoustic parameters of aqueous solution of Cu(NO3)2.3H2O at 20°C.

Conc.	Ultrasonic velocity	Viscosity	Density	Adiabatic Compressibility βa dyn-1.cm2	Acoustic Impedance Z dyn-1.cm2	App. Molar Volume Φv cm3.mol-1	App.Mol.Compr. Φk cm5. dyn-1mol-1	Relative Adiabatic Compressibility (RAC):
0.01	1490.2	1.0251	1.0003	4.50444E-07	1490.6471	31.6569826	-0.000389844	-0.008894
0.02	1492.4	1.0353	1.0017	4.49746E-07	1494.9371	66.7200962	-0.000523435	-0.010431
0.03	1496.4	1.045	1.0031	4.4797E-07	1501.0388	78.4078007	-0.000764776	-0.014339
0.04	1500.6	1.0602	1.005	4.4631E-07	1508.103	71.7291124	-0.001017319	-0.017992
0.05	1505.2	1.0753	1.0067	4.44336E-07	1515.2848	71.7291124	-0.001292061	-0.022334
0.06	1507.4	1.0904	1.008	4.43612E-07	1519.4592	78.4078007	-0.001423643	-0.023927
0.07	1510.4	1.1057	1.0101	4.42655E-07	1525.8571	71.7291124	-0.001614977	-0.026033
0.08	1512.2	1.1161	1.0115	4.42331E-07	1529.5903	75.4858746	-0.001711119	-0.026746
0.09	1514.6	1.1246	1.0131	4.41628E-07	1534.4413	76.1815713	-0.001854292	-0.028293
0.1	1516.2	1.1357	1.0141	4.41131E-07	1537.5784	82.7489481	-0.00194948	-0.029386

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Table 2: Acoustic parameters of aqueous solution of Cu(NO3)2.3H2O at 25°C.

Conc.	Ultrasonic velocity	viscosity	Density	Adiabatic Compressibility βa dyn-1.cm2	Acoustic Impedance Z dyn-1.cm2	App. Molar Volume Φv. cm3.mol-1	App.Mol.Compr. Φk cm5. dyn-1mol-1	Relative Adiabatic Compressibility (RAC):
0.01	1500	0.9196	0.9987	4.43867E-07	1498.05	96.890672	-0.000434651	-0.009297
0.02	1507.2	0.9101	0.9999	4.40164E-07	1507.0493	88.5322635	-0.000691883	-0.013382
0.03	1511.6	0.9253	1.0016	4.3835E-07	1514.0186	79.338014	-0.000901844	-0.016202
0.04	1515.2	0.9354	1.0035	4.37097E-07	1520.5032	89.8696088	-0.001075712	-0.019012
0.05	1518.2	0.9506	1.0046	4.35848E-07	1525.1837	100.234035	-0.00131714	-0.023543
0.06	1522.4	0.9608	1.0055	4.33835E-07	1530.7732	99.0399771	-0.001512684	-0.02644
0.07	1525.8	0.9709	1.007	4.32548E-07	1536.4806	100.651956	-0.001616783	-0.027479
0.08	1527.6	0.9821	1.0083	4.32086E-07	1540.2791	102.60768	-0.001709314	-0.028358
0.09	1529.2	0.9902	1.0095	4.31696E-07	1543.7274	101.905717	-0.001892389	-0.030974
0.1	1532.4	1.0031	1.011	4.30533E-07	1549.2564	96.890672	-0.000434651	-0.009297

Table 3: Acoustic parameters of aqueous solution of Cu(NO3)2.3H2O at 30°C.

Conc.	Ultrasonic velocity	Viscosity	Density	Adiabatic Compressibility βa dyn-1.cm2	Acoustic Impedance Z dyn-1.cm2	App. Molar Volume Φv. cm3.mol-1	App.Mol.Compr. Φk cm5. dyn-1mol-1	Relative Adiabatic Compressibility (RAC):
0.01	1512	0.8056	0.9965	4.35887E-07	1506.708	162.330487	-6.73864E-05	-0.002964
0.02	1515.6	0.8152	0.9982	4.34559E-07	1512.8719	117.127072	-0.000274861	-0.006002
0.03	1521.2	0.8353	0.9996	4.3197E-07	1520.5915	112.10447	-0.000595203	-0.011923
0.04	1525.4	0.8454	1.0012	4.30282E-07	1527.2305	104.570568	-0.000834254	-0.015784
0.05	1528.8	0.8605	1.0026	4.28969E-07	1532.7749	104.068307	-0.00102701	-0.018786
0.06	1532.6	0.8708	1.0036	4.27271E-07	1538.1174	110.43027	-0.001240809	-0.022672
0.07	1535.4	0.8802	1.0046	4.26138E-07	1542.4628	114.974528	-0.001398001	-0.025263
0.08	1537.2	0.8931	1.006	4.25733E-07	1546.4232	113.360121	-0.001499976	-0.02619
0.09	1539.6	0.9002	1.0074	4.24997E-07	1550.993	112.10447	-0.001635023	-0.027872
0.1	1543.2	0.9145	1.0088	4.23605E-07	1556.7802	111.09995	-0.001835774	-0.031058

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Table 4: Acoustic parameters of aqueous solution of Cu(NO3)2.3H2O at 35°C.

Conc.	Ultrasonic velocity	Viscosity	Density	Adiabatic Compressibility βa dyn-1.cm2	Acoustic Impedance Z dyn-1.cm2	App. Molar Volume Φv. cm3.mol-1	App.Mol.Compr. Φk cm5. dyn-1mol-1	Relative Adiabatic Compressibility (RAC):
0.01	1522	0.8056	0.9942	4.29185E-07	1513.1724	222.937626	-6.49857E-05	-0.003738
0.02	1525.4	0.8152	0.9956	4.27875E-07	1518.6882	162.575453	-0.000256605	-0.006777
0.03	1529.6	0.8353	0.997	4.26127E-07	1525.0112	142.454728	-0.000492093	-0.010835
0.04	1533.2	0.8454	0.9985	4.24767E-07	1530.9002	129.879276	-0.000693169	-0.013994
0.05	1536.4	0.8605	0.9999	4.23592E-07	1536.2464	124.346076	-0.000871291	-0.01672
0.06	1540.2	0.8708	1.0013	4.22095E-07	1542.2023	120.657277	-0.001081711	-0.020196
0.07	1543.6	0.8802	1.0028	4.20867E-07	1547.9221	116.585226	-0.001269506	-0.023046
0.08	1545.8	0.8931	1.0042	4.20256E-07	1552.2924	114.788732	-0.001391303	-0.024465
0.09	1547.2	0.9002	1.0056	4.2008E-07	1555.8643	113.39146	-0.001469515	-0.024872
0.1	1548.2	0.9145	1.007	4.20122E-07	1559.0374	112.273642	-0.001526032	-0.024776

Table 5: Acoustic parameters of aqueous solution of Cu(NO3)2.3H2O at 40°C.

Conc.	Ultrasonic velocity	viscosity	Density	Adiabatic Compressibility βa dyn-1.cm2	Acoustic Impedance Z dyn-1.cm2	App. Molar Volume Φv. cm3.mol-1	App.Mol.Compr. Φk cm5. dyn-1mol-1	Relative Adiabatic Compressibility (RAC):
0.01	1528	0.6722	0.9925	4.25093E-07	1516.54	212.871425	-6.35281E-05	-0.003622
0.02	1532.8	0.6755	0.9937	4.22945E-07	1523.1434	167.517666	-0.000329873	-0.008655
0.03	1536.4	0.6906	0.995	4.21516E-07	1528.718	149.040209	-0.000528671	-0.012005
0.04	1540.6	0.7004	0.9963	4.19769E-07	1534.8998	139.80148	-0.000759313	-0.0161
0.05	1543.2	0.7102	0.9976	4.18902E-07	1539.4963	134.258243	-0.00090195	-0.018133
0.06	1547.4	0.7206	0.999	4.17215E-07	1545.8526	128.882982	-0.001130771	-0.022086
0.07	1550.6	0.7304	1.0004	4.16077E-07	1551.2202	116.054275	-0.001304768	-0.024753
0.08	1552.2	0.7426	1.0018	4.15801E-07	1554.994	122.163907	-0.001392593	-0.025401
0.09	1554.4	0.7502	1.0032	4.15204E-07	1559.3741	119.924215	-0.001512465	-0.026799
0.1	1558.8	0.7596	1.0046	4.1344E-07	1565.9705	118.132462	-0.001749115	-0.030935

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Table 1: Acoustic parameters of 5%alcoholic solution of Cu(NO3)2.3H2O at 20°C.

Conc.	Ultrasonic velocity	viscosity	Density	Adiabatic Compressibility βa dyn-1.cm2	Acoustic Impedance Z dyn-1.cm2	App. Molar Volume Φv. cm3.mol-1	App.Mol.Compr Φk cm5. dyn-1mol-1	Relative Adiabatic Compressibility (RAC):
0.01	1488	1.0747	0.9925	4.48254E-07	1476.84	-618.29268	-0.000132267	0.0032227
0.02	1496	1.0795	0.9944	4.44322E-07	1487.6224	-282.92683	-0.00061178	-0.005578
0.03	1510	1.0969	0.9952	4.36472E-07	1502.752	-133.87534	-0.001433109	-0.023147
0.04	1525	1.1068	0.9976	4.2896E-07	1521.34	-100	-0.002293301	-0.03996
0.05	1535	1.1203	0.9996	4.24238E-07	1534.386	-71.544715	-0.00285632	-0.050528
0.06	1542	1.1309	1.0016	4.21236E-07	1544.4672	-52.574526	-0.00324732	-0.057246
0.07	1552	1.1441	1.0047	4.17112E-07	1559.2944	-54.994193	-0.003800466	-0.066476
0.08	1570	1.1582	1.0064	4.08292E-07	1580.048	-39.02439	-0.004759644	-0.086215
0.09	1582	1.1621	1.0091	4.03201E-07	1596.3962	-37.895212	-0.005391421	-0.097611
0.1	1592	1.1704	1.0096	3.98349E-07	1607.2832	-14.634146	-0.00589934	-0.10847

Table 2: Acoustic parameters of 5%alcoholic solution of Cu(NO3)2.3H2O at 25°C.

Conc.	Ultrasonic velocity	viscosity	Density	Adiabatic Compressibility βa dyn-1.cm2	Acoustic Impedance Z dyn-1.cm2	App. Molar Volume Φv. cm3.mol-1	App.Mol.Compr Φk cm5. dyn-1mol-1	Relative Adiabatic Compressibility (RAC):
0.01	1505	1.0021	9913	4.37655E-07	1491.9065	-496.34146	-0.000361209	-0.003263
0.02	1520	1.0231	9934	4.29969E-07	1509.968	-232.11382	-0.001223555	-0.020768
0.03	1532	1.0531	9942	4.236E-07	1523.1144	-100	-0.001896109	-0.035272
0.04	1545	1.0625	9964	4.17423E-07	1539.438	-69.512195	-0.00261197	-0.04934
0.05	1556	1.0909	9984	4.12368E-07	1553.5104	-47.154472	-0.003206711	-0.060852
0.06	1565	1.0932	1000.5	4.08497E-07	1565.7825	-33.943089	-0.003687603	-0.06967
0.07	1572	1.1114	1000.5	4.06081E-07	1577.502	-37.57259	-0.004063063	-0.075172
0.08	1585	1.118	1005.2	4.00123E-07	1593.242	-23.780488	-0.004734647	-0.08874
0.09	1590	1.127	1007.8	3.98639E-07	1602.402	-23.215899	-0.004999076	-0.09212
0.1	1605	1.1335	1008.3	3.91417E-07	1618.3215	-1.4227642	-0.005743616	-0.108568

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Table 3: Acoustic parameters of 5%alcoholic solution of Cu(NO3)2.3H2O at 30°C.

Conc.	Ultrasonic velocity	viscosity	Density	Adiabatic Compressibility βa dyn-1.cm2	Acoustic Impedance Z dyn-1.cm2	App. Molar Volume Φv. cm3.mol-1	App.Mol.Compr. Φk cm5. dyn-1mol-1	Relative Adiabatic Compressibility (RAC):
0.01	1520	0.9208	0.9903	4.28627E-07	1505.256	-394.71545	-0.00063631	-0.008724
0.02	1530	0.9373	0.9922	4.23854E-07	1518.066	-171.13821	-0.001197272	-0.019762
0.03	1545	0.9444	0.9928	4.15915E-07	1533.876	-52.574526	-0.002017578	-0.038122
0.04	1555	0.9602	0.9949	4.11451E-07	1547.0695	-31.402439	-0.002556418	-0.048446
0.05	1566	0.969	0.9969	4.06507E-07	1561.1454	-16.666667	-0.003138927	-0.05988
0.06	1575	0.9839	0.999	4.02721E-07	1573.425	-8.5365854	-0.003609991	-0.068636
0.07	1580	0.9918	1.0022	4.01458E-07	1583.476	-18.699187	-0.003877194	-0.071557
0.08	1590	1.0137	1.004	3.97136E-07	1596.36	-8.5365854	-0.004388644	-0.081552
0.09	1598	1.0162	1.0063	3.9407E-07	1608.0674	-6.2782294	-0.004796488	-0.088642
0.1	1620	1.0492	1.0068	3.83631E-07	1631.016	13.8211382	-0.0058625	-0.112786

Table 4: Acoustic parameters of 5%alcoholic solution of Cu(NO3)2.3H2O at 35°C.

Conc.	Ultrasonic velocity	Viscosity	Density	Adiabatic Compressibility βa dyn-1.cm2	Acoustic Impedance Z dyn-1.cm2	App. Molar Volume Φv. cm3.mol-1	App.Mol.Compr. Φk cm5. dyn-1mol-1	Relative Adiabatic Compressibility (RAC):
0.01	1533	0.8402	0.9884	4.2058E-07	1515.2172	-508.05301	-0.000617919	-0.009472
0.02	1540	0.8574	0.9905	4.17651E-07	1525.37	-237.92049	-0.001001741	-0.016371
0.03	1558	0.8659	0.9912	4.08344E-07	1544.2896	-100.30581	-0.001962672	-0.038289
0.04	1565	0.8694	0.9933	4.05557E-07	1554.5145	-67.176351	-0.002332299	-0.044854
0.05	1575	0.8755	0.9951	4.01149E-07	1567.2825	-41.182467	-0.002851003	-0.055235
0.06	1580	0.8913	0.9974	3.99535E-07	1575.892	-32.347944	-0.00311191	-0.059035
0.07	1585	0.9263	1.0007	3.98332E-07	1586.1095	-40.599971	-0.00337506	-0.061869
0.08	1595	0.9312	1.0024	3.94021E-07	1598.828	-26.401631	-0.003879727	-0.072022
0.09	1604	0.9332	1.0043	3.9035E-07	1610.8972	-17.62374	-0.004329043	-0.080667
0.1	1628	0.9426	1.0052	3.79266E-07	1636.4656	-0.4077472	-0.005476467	-0.106773

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Table 5: Acoustic parameters of 5%alcoholic solution of Cu(NO3)2.3H2O at 40°C.

Conc.	Ultrasonic velocity	viscosity	Density	Adiabatic Compressibility βa dyn-1.cm2	Acoustic Impedance Z dyn-1.cm2	App. Molar Volume Φv cm3.mol-1	App.Mol.Compr. Φk cm5. dyn-1mol-1	Relative Adiabatic Compressibility (RAC):
0.01	1540	0.7706	0.9867	4.16048E-07	1519.518	-539.73442	-0.000552566	-0.007781
0.02	1555	0.7815	0.9883	4.08722E-07	1536.8065	-228.19203	-0.00135372	-0.025253
0.03	1565	0.7911	0.9895	4.04005E-07	1548.5675	-110.72523	-0.001876781	-0.036501
0.04	1570	0.8019	0.9915	4.02248E-07	1556.655	-72.420838	-0.002138221	-0.040693
0.05	1580	0.8083	0.9935	3.97973E-07	1569.73	-49.438202	-0.00265133	-0.050887
0.06	1585	0.8301	0.9955	3.96262E-07	1577.8675	-34.116445	-0.002908071	-0.054967
0.07	1590	0.8392	0.9991	3.95198E-07	1588.569	-46.519772	-0.003168691	-0.057506
0.08	1600	0.8454	1.0008	3.90938E-07	1601.28	-31.562819	-0.00366755	-0.067666
0.09	1610	0.8717	1.0028	3.86868E-07	1614.508	-23.334468	-0.004160182	-0.077372
0.1	1635	0.8915	1.0039	3.75539E-07	1641.3765	-7.5587334	-0.005340184	-0.10439

Aq.solution of Cu(NO3)2. 3H2O

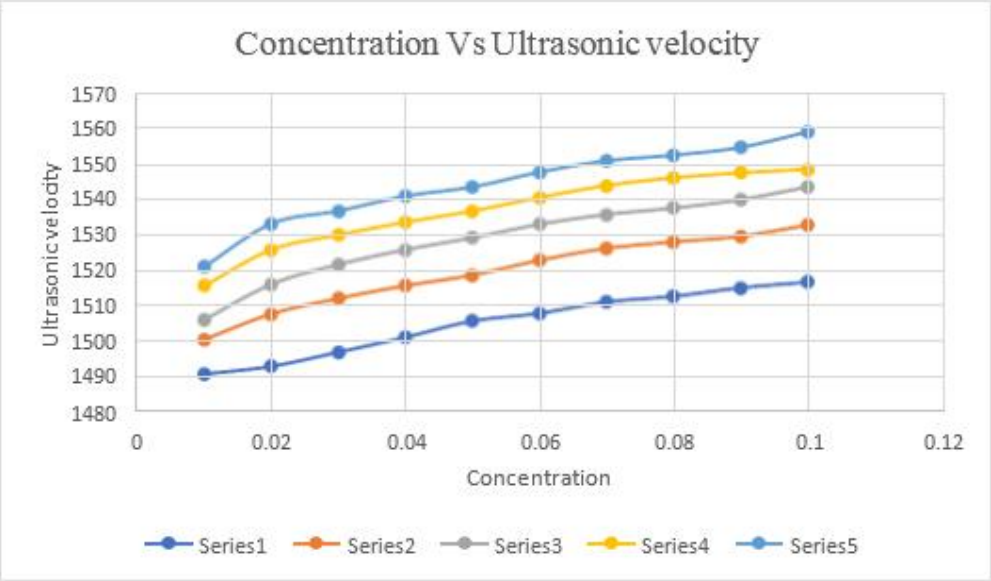

Fig No. 1 Concentration vs Ultrasonic velocity

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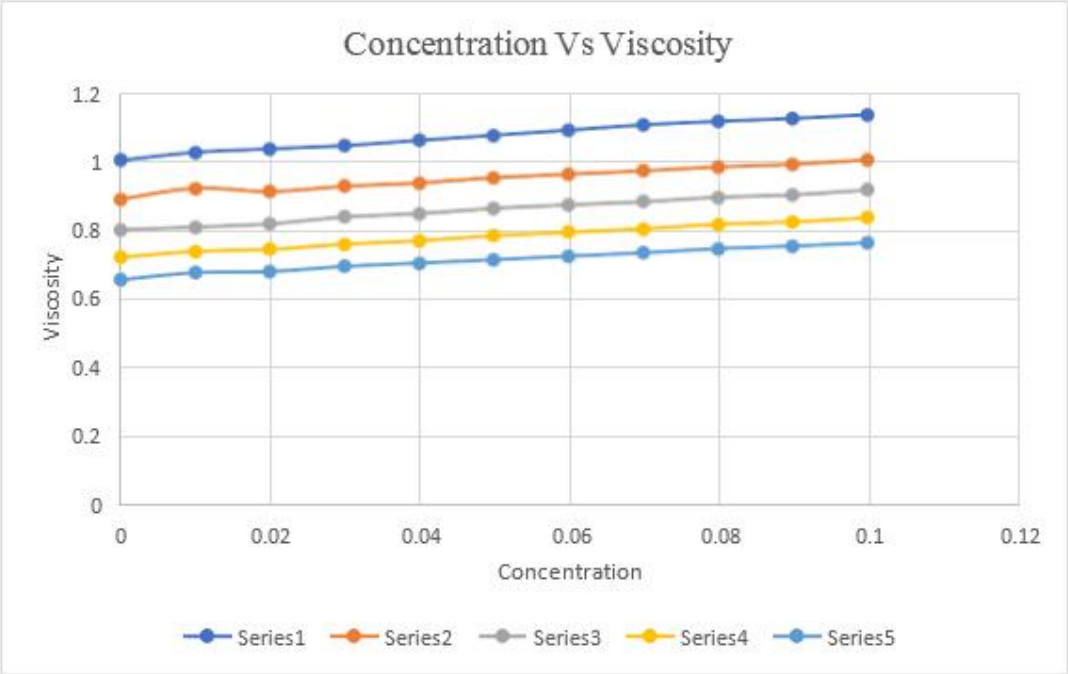

Fig No. 2 Concentration Vs Viscosity

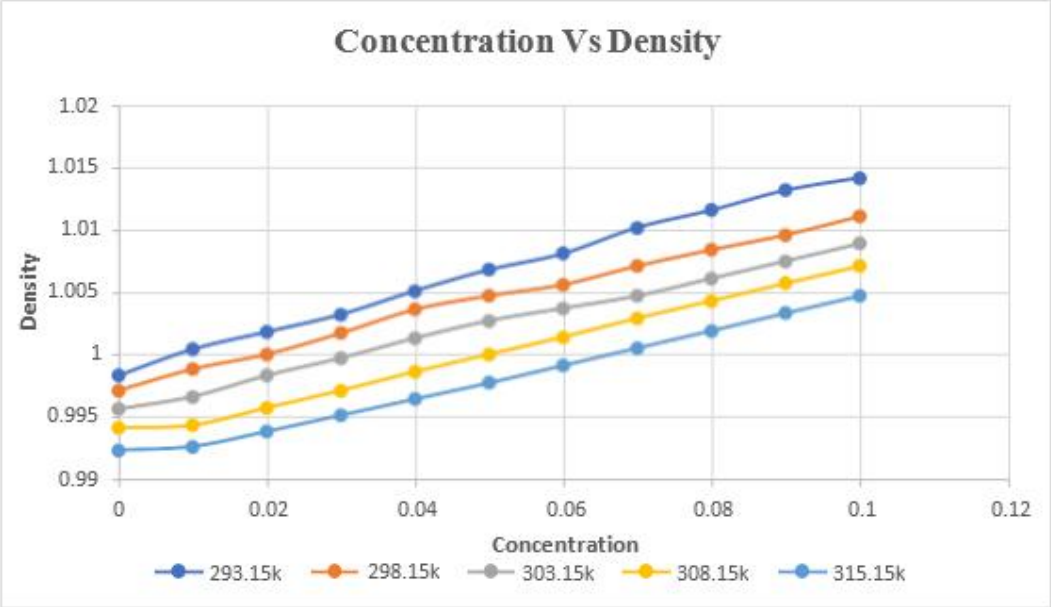

Fig No. 3 Concentration Vs Density

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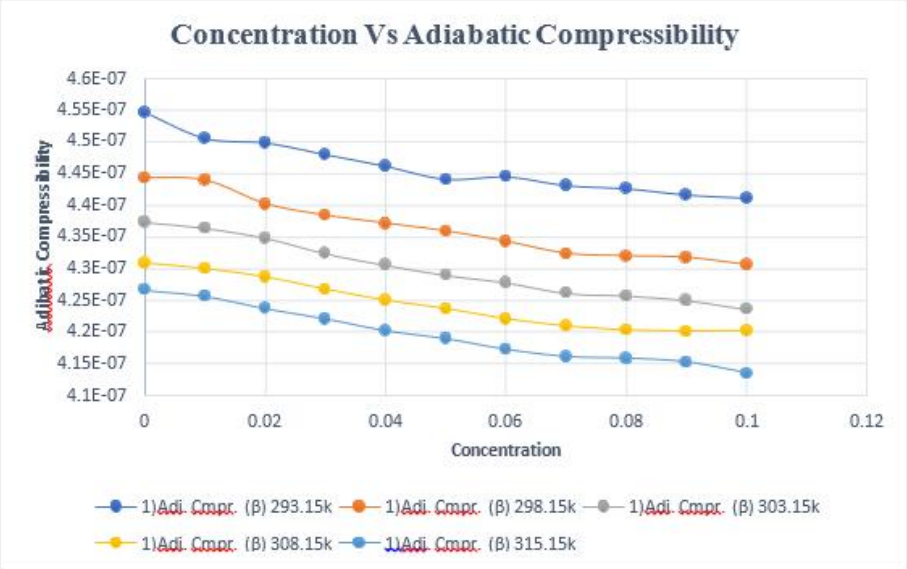

Fig No. 4 Concentration Vs Adiabatic Compressibility

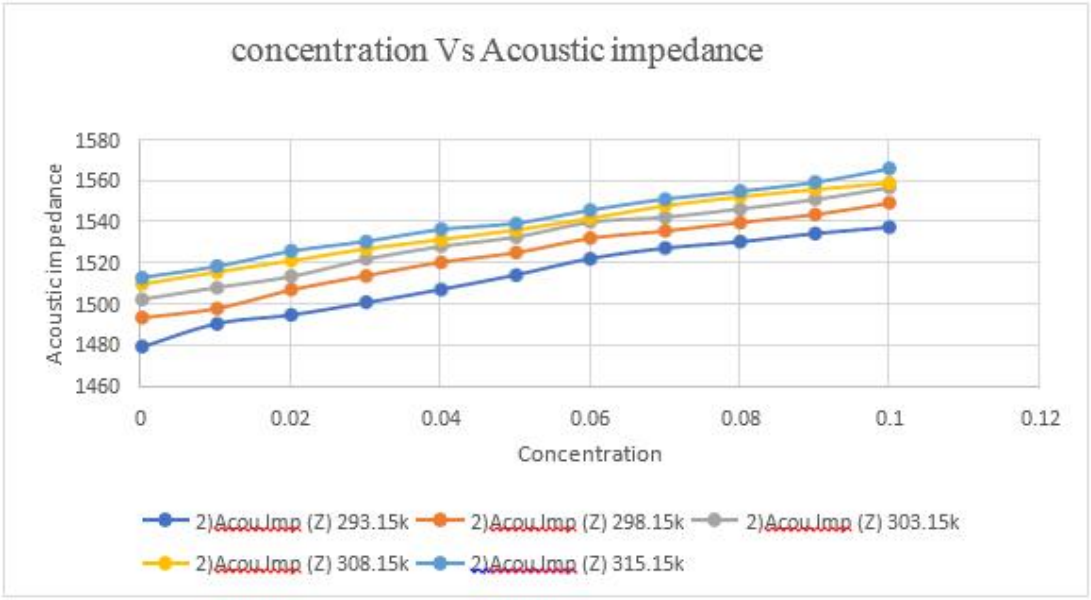

Fig No. 5 Concentration Vs Acoustic impedance

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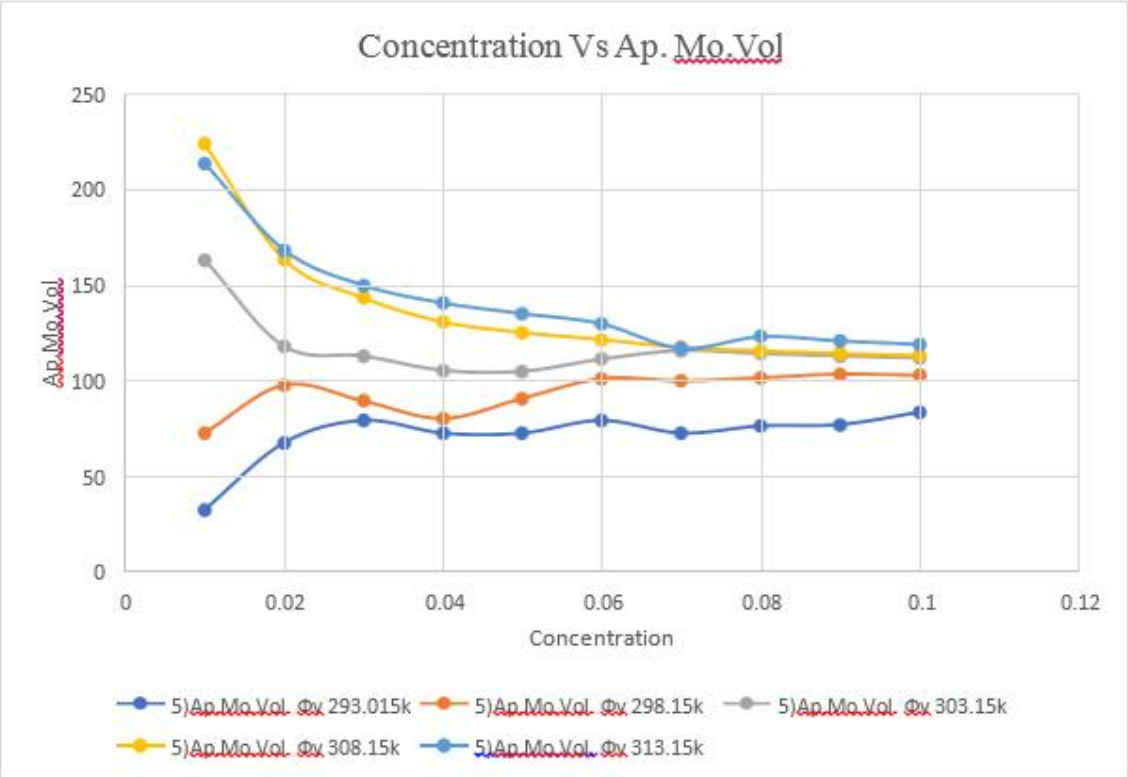

Fig No. 6 Concentration Vs Apperent Molar Volume

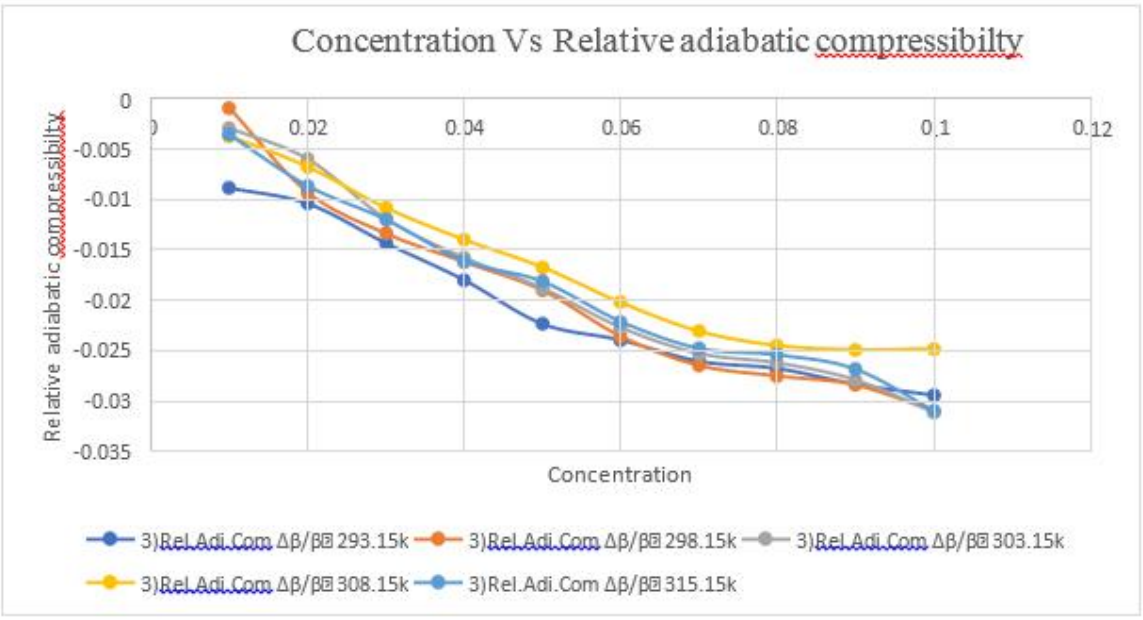

Fig No. 7 Concentration Vs Relative Adiabatic Compressibility

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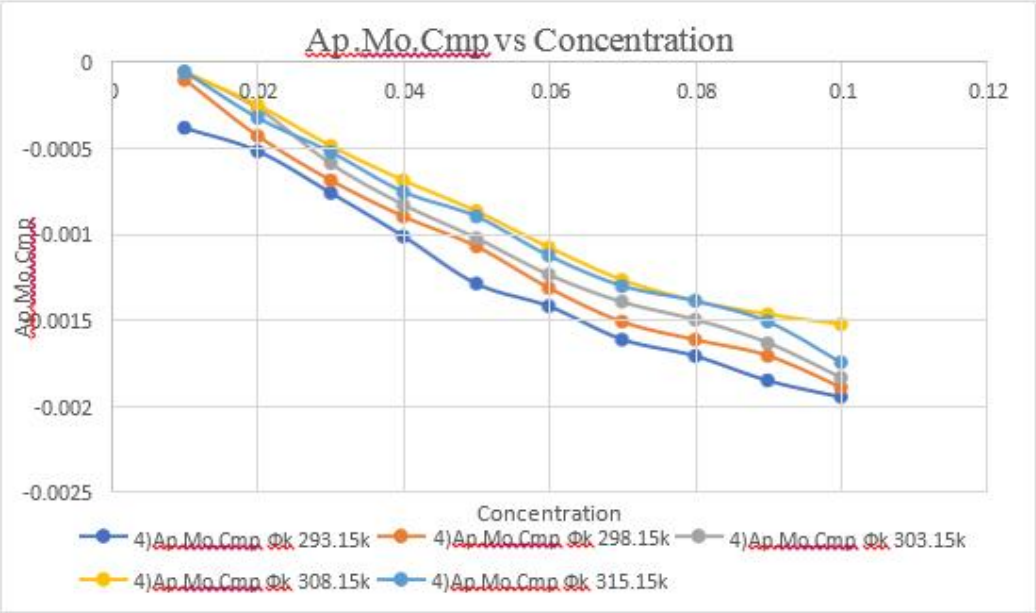

Fig No. 8 Concentration VS Apperent Molar Compressibility

5% Alcoholic solution of Cu(NO3)2 . 3H2O

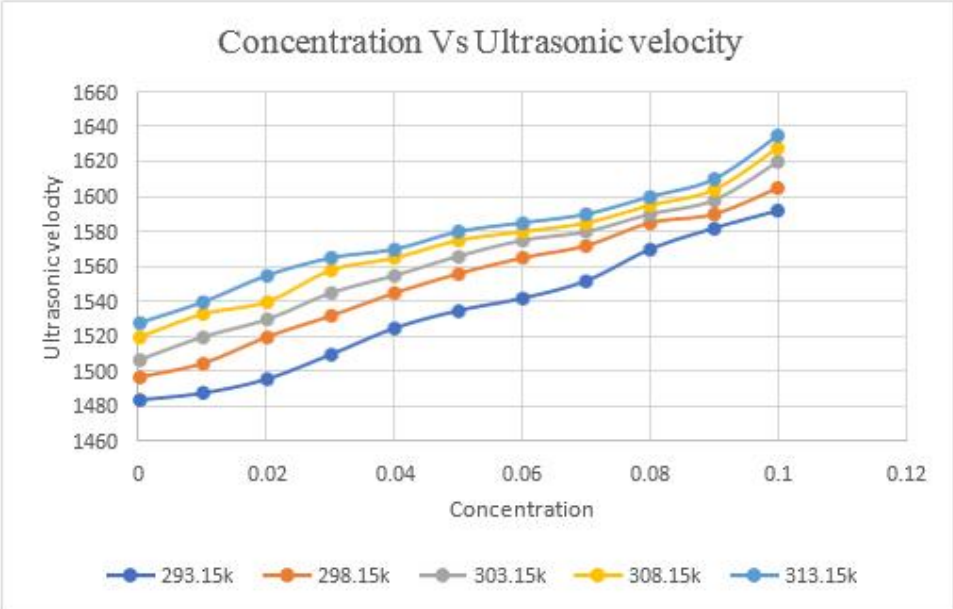

Fig No. 1 Concentration Vs Ultrasonic Velocity

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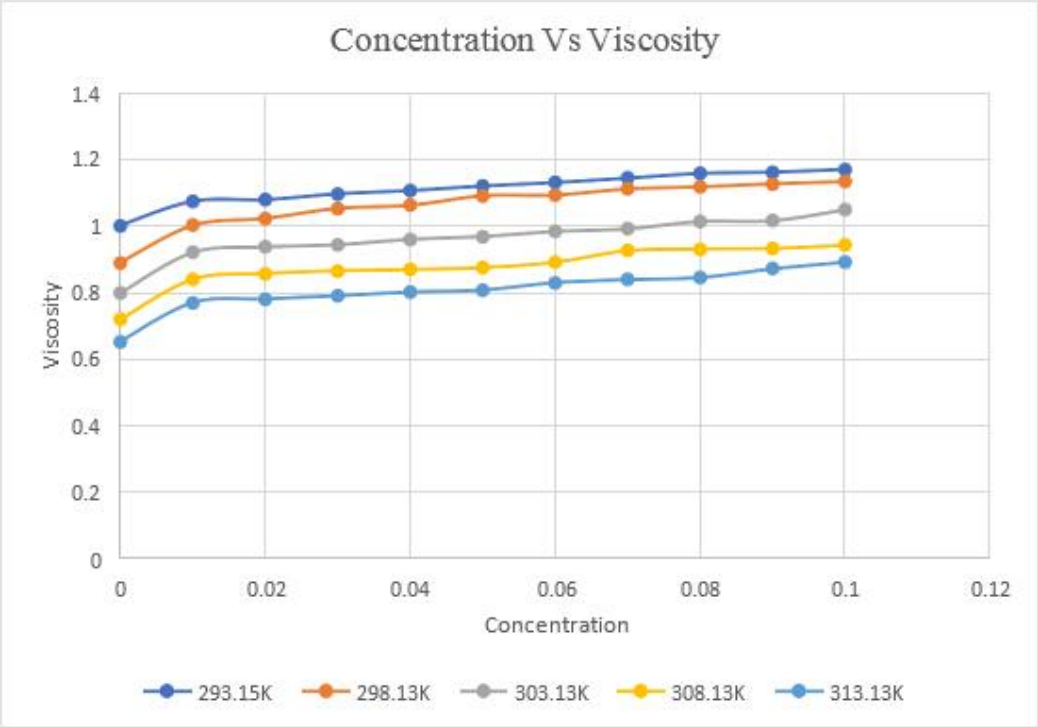

Fig No. 2 Concentration Vs Viscosity

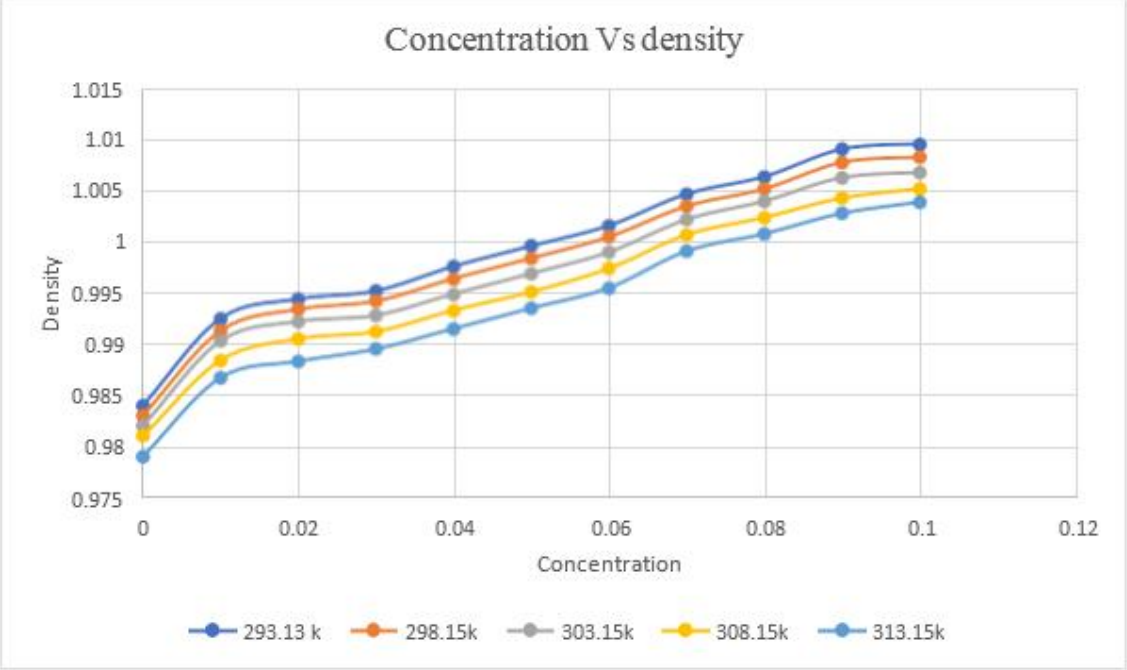

Fig No. 3 Concentration Vs Density

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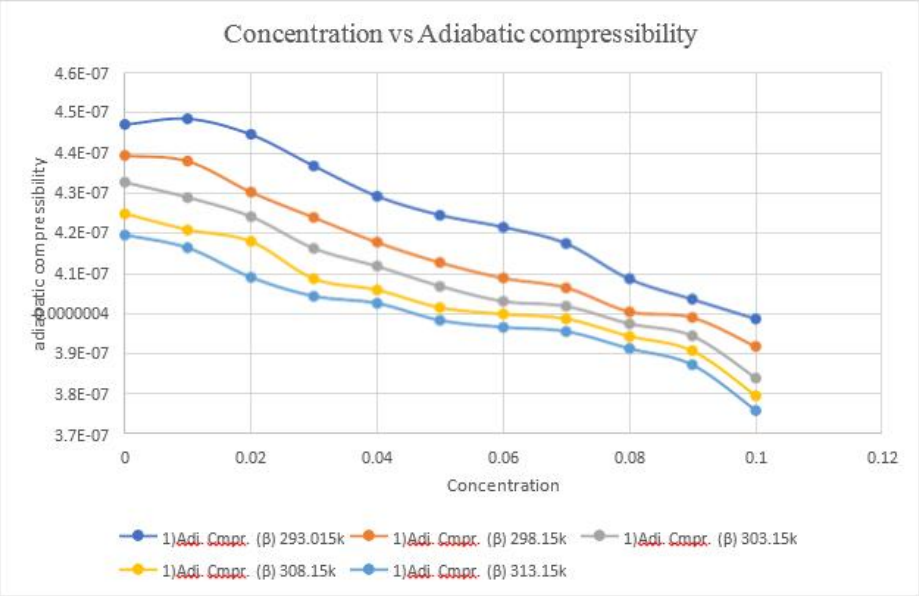

Fig No. 4 Concentration Vs Adiabatic Compressibility

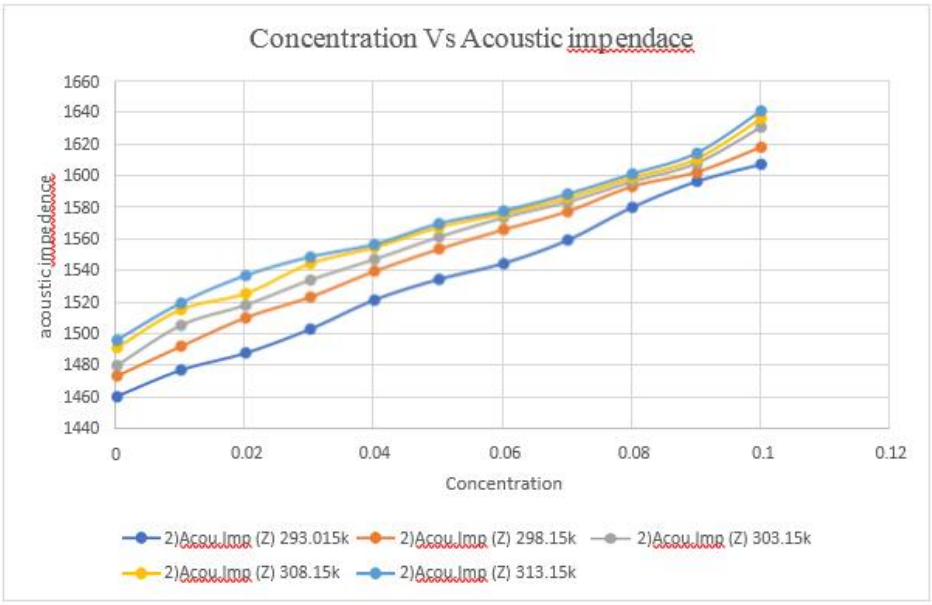

Fig No. 5 Concentration Vs acoustic impendace

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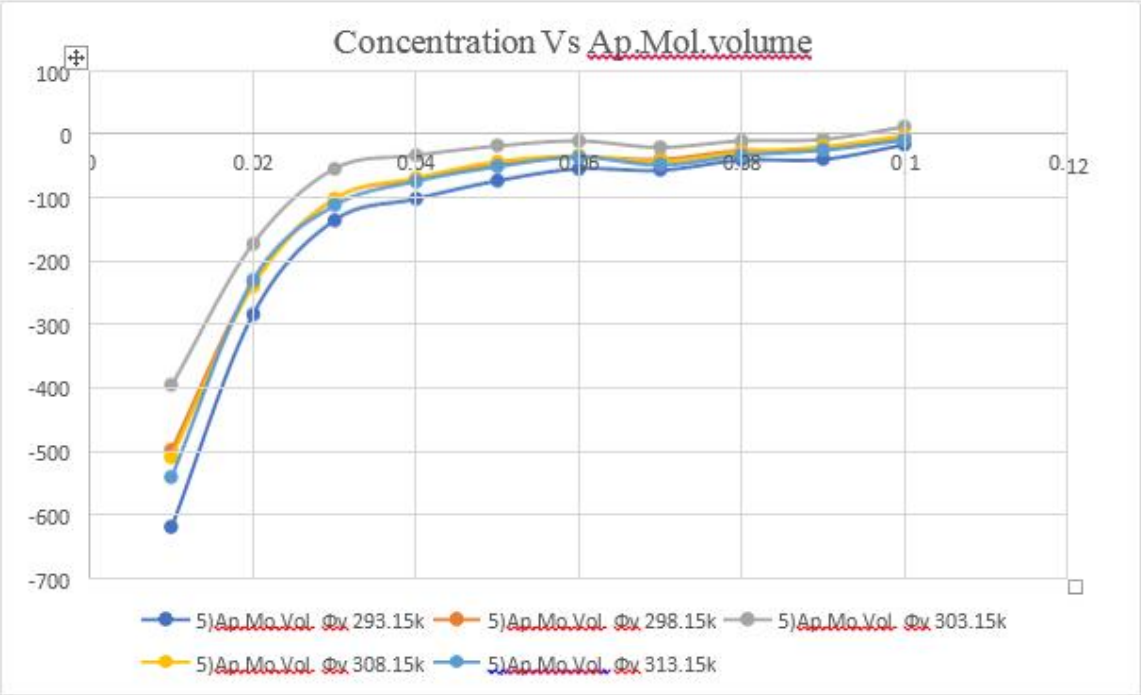

Fig No. 6 Concentration Vs Apperent Molar volume

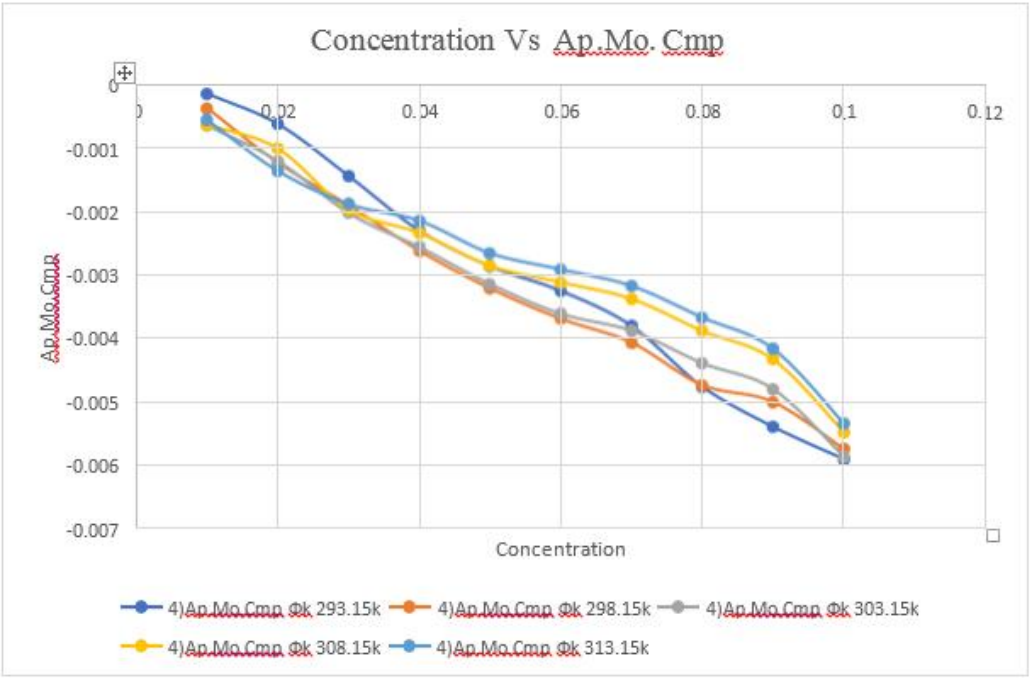

Fig No. 7 Concentration Vs Apperent Molar Compressibility

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Fig No. 8 Concentration Vs Relative Adiabatic Compressibility

The acoustic properties of copper(II) nitrate trihydrate were systematically investigated in aqueous and 5% ethanol–water solvent systems over the concentration range 0.01–0.10 M at temperatures between 293.15 and 313.15 K using an ultrasonic frequency of 5 MHz under atmospheric pressure. The evaluated parameters, including ultrasonic velocity, adiabatic compressibility, acoustic impedance, apparent molar volume, and apparent molar compressibility, provide comprehensive insight into solute–solvent and ion–solvent interactions in both media.

In both solvent systems, ultrasonic velocity increases progressively with concentration at all temperatures, indicating strengthening of solute–solvent interactions. This behaviour is attributed to the hydration of Cu^{2+} and NO_3^- ions, which promotes enhanced structural organization of surrounding solvent molecules and results in a more rigid medium that supports faster sound propagation. The observed decrease in ultrasonic velocity with increasing temperature arises from thermal disruption of hydration structures and weakened intermolecular interactions.

Adiabatic compressibility shows a decreasing trend with concentration, reflecting reduced compressibility of the solution due to electrostrictive effects around hydrated ions. The corresponding increase in compressibility with temperature is associated with enhanced molecular motion, which weakens ion–solvent interactions. These trends confirm increased rigidity and structural compactness of the solution with rising concentration.

Acoustic impedance increases steadily with concentration in both systems, resulting from the combined increase in ultrasonic velocity and density. This behaviour signifies enhanced molecular cohesion and compactness of the solution, further confirming the dominance of solute–solvent interactions.

The apparent molar volume exhibits a pronounced decrease at lower concentrations, indicating strong ion–solvent interactions governed by hydration and electrostriction effects. At higher concentrations, the variation in apparent molar volume becomes less significant due to the increasing contribution of ion–ion interactions. Apparent molar compressibility values remain negative throughout the concentration range, suggesting decreased compressibility and enhanced rigidity of the solution structure.

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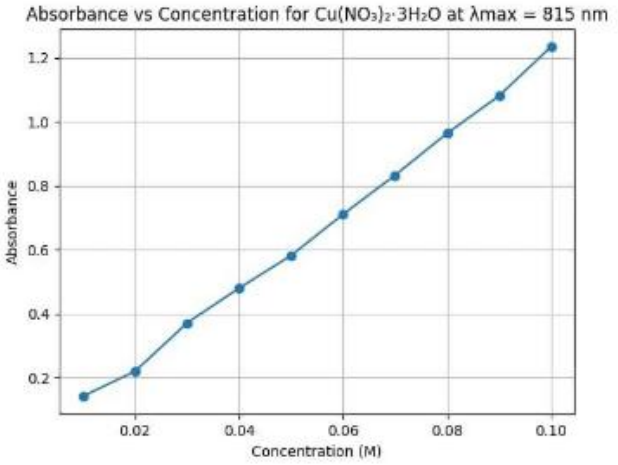
Comparatively, the 5% ethanol–water system shows slightly modified trends relative to pure water. The presence of ethanol alters solvent polarity and hydrogen-bonding characteristics, leading to changes in solvation dynamics and interaction strength. Although hydration effects are comparatively weaker than in pure aqueous medium, copper(II) nitrate trihydrate continues to exhibit structure-making behaviour in the mixed solvent system.

Overall, the combined acoustic, volumetric, and compressibility parameters confirm that copper(II) nitrate trihydrate exhibits strong solute–solvent interactions in both aqueous and 5% ethanol–water media. While increasing temperature weakens hydration effects, the fundamental interaction mechanism remains unchanged, highlighting the significant role of solvent composition in modulating molecular interactions.

Absorption spectra aq. Solution of Cu(NO3)2.3H2O $\boldsymbol{\lambda Max}$ 815 nm

Sr No.	Concentration	Absorbance /nm
1	0.01	0.142
2	0.02	0.220
3	0.03	0.371
4	0.04	0.480
5	0.05	0.582
6	0.06	0.711
7	0.07	0.833
8	0.08	0.964
9	0.09	1.081
10	0.10	1.235



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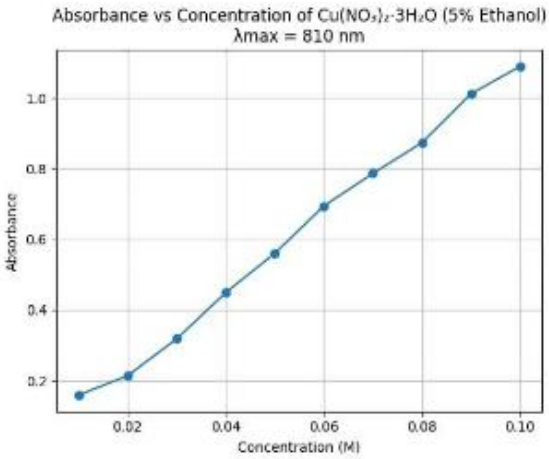
Absorption Spectra of 5%alcohol solution of Cu(NO3)2.3H2O λmax 810nm

Sr No.	Concentration	Absorbance/nm
1	0.01	0.139
2	0.02	0.214
3	0.03	0.318
4	0.04	0.449
5	0.05	0.560
6	0.06	0.694
7	0.07	0.786
8	0.08	0.873
9	0.09	1.011
10	0.1	1.089



Comparative Interpretation: Aqueous and 5% Ethanol–Water Systems

The absorbance–concentration plots of $Cu(NO_3)_2 \cdot 3H_2O$ in both aqueous and 5% ethanol–water media show a systematic increase in absorbance with increasing concentration. In both solvent systems, the data points lie close to a straight line, indicating that Beer–Lambert's law is obeyed over the studied concentration range.

In the aqueous medium, the absorbance values increase more uniformly with concentration, suggesting stronger solute–solvent interactions between Cu^{2+} ions and water molecules. The high polarity of water facilitates effective hydration of the ions, resulting in a more ideal linear response.

In contrast, the 5% ethanol–water system shows slightly lower absorbance values at corresponding concentrations along with a marginal deviation from perfect linearity at higher concentrations. This behavior can be attributed to the presence of ethanol, which reduces the overall dielectric constant of the medium and alters the solvation environment around the Cu^{2+} ions. The mixed solvent system therefore affects the electronic transitions responsible for absorption.

Overall, the comparison clearly indicates that while both systems follow Beer–Lambert's law, the aqueous medium provides a more ideal environment for absorption studies, whereas the ethanol–water mixture introduces subtle changes due to modified solute–solvent interactions.

CONCLUSION

Ultrasonic investigations demonstrate that copper(II) nitrate trihydrate exhibits strong solute–solvent interactions in both aqueous and 5% ethanol–water systems. The evaluated acoustic parameters, including ultrasonic velocity, compressibility, acoustic impedance, and apparent molar properties, indicate reduced free volume and enhanced structural organization of the solutions due to hydration and electrostrictive effects associated with Cu^{2+} ions.A distinct difference in solute–solvent interaction strength is observed between the two solvent environments. In the aqueous medium, the high polarity and extensive hydrogen-bonding network of water promote stronger hydration of Cu^{2+} ions, resulting in higher ultrasonic velocity, lower compressibility, and a more pronounced structure-making behavior. In contrast, the presence of ethanol in the mixed solvent reduces overall polarity and partially disrupts the hydrogen-bonded

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structure of water, leading to comparatively weaker hydration and modified ion–dipole interactions. Consequently, the ethanol–water system exhibits a less rigid but more heterogeneous solvation environment. Despite this reduction in interaction strength, solute–solvent interactions remain dominant in both media, confirming that copper(II) nitrate trihydrate behaves as a structure-forming solute in aqueous as well as ethanol-modified solutions.The UV–Visible absorption spectroscopic studies complement the ultrasonic results and further support the proposed interaction mechanism.

The linear absorbance–concentration relationship confirms adherence to Beer–Lambert's law, indicating the absence of significant aggregation within the studied concentration range. The observed slight bathochromic shifts in absorption maxima with temperature and solvent composition reflect changes in the electronic environment and ligand field symmetry of Cu^{2+} ions arising from variations in solvation. These spectral features provide additional evidence for solvent-dependent ion–solvent coordination and partial complex formation, particularly at elevated temperatures.Overall, the combined ultrasonic and spectroscopic findings provide a consistent and reliable understanding of how solvent polarity, hydrogen bonding, and dielectric properties govern molecular interactions and solution structure in transition metal salt systems.

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