CONDUCTIVITY METER 4520

Application note: A02-001A

The effect of temperature on conductivity measurement

Introduction

Conductivity is the ability of a solution to pass an electric current. This depends on a number of factors including concentration, mobility of the ions, valence of the ions and temperature. As the temperature of a solution increases, the mobility of the ions in the solution also increases and consequently this will lead to an increase in its conductivity. Therefore it is mandatory to always associate conductivity measurements with a reference temperature, usually 20ºC or 25ºC.

Most conductivity cells and meters, including those in the Jenway range, have automatic temperature compensation (ATC). During ATC, the instrument applies a temperature coefficient of variation (a default value e.g. 1.91% in the model 4520, or a value entered by the user) to the measured conductivity and reports what the conductivity would be at the reference temperature, as illustrated in Figure 1. This is known as linear temperature compensation and can give a good approximation to the true conductivity when the temperature of the measured solution is close to the reference temperature.

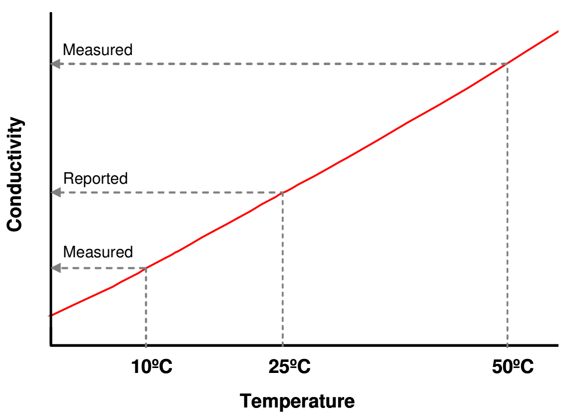

Figure 1: Temperature compensation uses a temperature coefficient of variation to convert the conductivity measured at a specific temperature to that at the reference temperature (25ºC).

Linear temperature compensation assumes that the temperature coefficient of variation is the same value for all measurement temperatures. This is not the case, as we demonstrate in this application note and this can lead to significant errors when the measurement temperature is very different to that of the reference. In addition, different ionic species do have different temperature coefficients. Therefore to get the most accurate results from conductivity measurements when using ATC, the temperature coefficient of variation value should be determined empirically or values used from published tables and entered into the conductivity meter.

Methods

To demonstrate the effect of temperature on conductivity measurements, five different solutions were used: 1413µS conductivity standard (part code 025 138), 0.5g/l NaCl, 0.5g/l NaOH, 1g/l NaCl and 10g/l NaCl. 25ml of each solution, in capped 50ml plastic tubes, were placed in a refrigerated water bath (Techne RB-5A with a TE-10D thermoregulator) set to 5ºC. The solutions were allowed to equilibrate to the set temperature for approximately 45 minutes before measurements were made.

A Jenway model 4520 conductivity meter fitted with a glass K=1 conductivity cell (part code 027 013) was used to take conductivity measurements. The meter was set up such that the temperature coefficient was set to zero and the value of the cell constant (0.96) entered in the calibration set up. The conductivity probe was temperature equilibrated by placing it in a tube containing deionised water in the water bath together with the other samples.

Conductivity measurements were taken of each solution with the water bath set at 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50ºC. The temperature recorded by the conductivity cell was also noted and used in the subsequent calculations. Between each change of temperature and before readings were made, the solutions and cell were allowed to equilibrate for at least 30 minutes until the temperature reading given by the cell remained stable.

Results

The measured conductivity values for each of the prepared solutions are shown in Table 1. For the 1413µS/cm standard solution, the manufacturer's values printed on the bottle label were compared with the experimental values and are shown in Figure 2A. Likewise, published values[1] for 0.5g/l NaCl were compared to those measured for the solution prepared in this experiment in Figure 2B.

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		Conductivity (µS/cm)				
Water bath (ºC)	Cell (ºC)	1413 std.	0.5g/l NaCl	0.5g/l NaOH	1g/l NaCl	10g/l NaCl
5.0	6.6	906	652	1869	1272	11140
10.0	11.6	1030	746	2080	1462	12760
15.0	16.4	1160	841	2300	1639	14340
20.0	21.0	1290	936	2490	1828	15910
25.0	25.7	1424	1037	2690	2030	17610
30.0	30.4	1558	1136	2880	2230	19180
35.0	35.1	1698	1246	3080	2440	20900
40.0	39.7	1829	1370	3290	2640	23000
45.0	44.4	1982	1470	3510	2870	25000
50.0	48.0	2130	1595	3710	3080	26800

Table 1: Measured conductivity values for each of the test solutions at various temperatures.

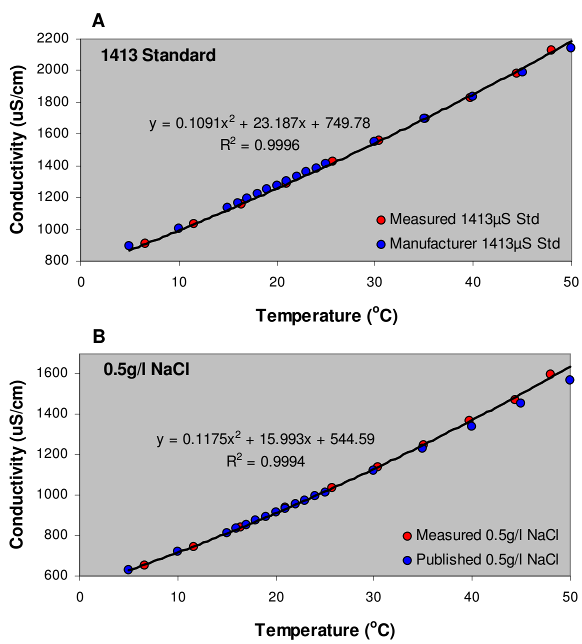

Figure 2: Comparisons between the experimental and published conductivity values for (A) 1413µS/cm standard and (B) a 0.5g/l NaCl solution. The trend line in each case is that for the experimental values and the equations of these were used to calculate the conductivities at 25ºC and other temperatures.

The calculated conductivity at 25ºC (derived from the trend line of the curve shown in Figure 2A) for the 1413µS standard was 1.09% lower (1398µS/cm) than the manufacturer's value; that for the 0.5g/l NaCl was 0.29% higher than the published[1] value. This may be accounted for by one or more of a number of factors including errors of accuracy of the temperature measurement by the probe (+/-0.5ºC). With a temperature coefficient of variation for the 1413µS standard, as printed on the bottle, of 1.93%, this uncertainty in temperature could lead to a range of between 1399 and 1427µS/cm. Other factors could include slight deviations from the cell constant and small errors in preparation of the test solution for the NaCl measurements.

Different ionic species show different effects with temperature which is due to the size of the ion and its charge density. Figure 3 shows the conductivity response to temperature of 0.5g/l NaCl compared to 0.5g/l NaOH. The OH^-, being smaller than Cl^-, has a higher charge density and hence the conductivity of a solution of the same concentration is greater.

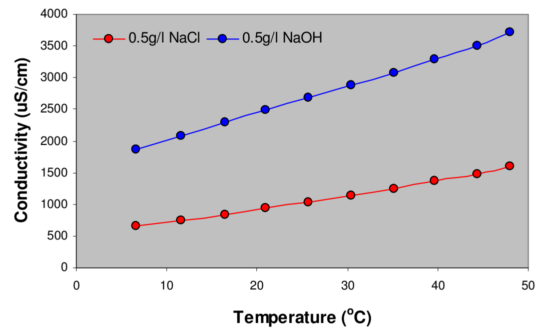

Figure 3: Effect of temperature on the conductivity of 0.5g/l NaCl and 0.5g/l NaOH.

Using the conductivity values obtained at different temperatures, the temperature coefficient of variation at 25ºC, $\alpha_{\theta,25}$, can be calculated for each solution at each temperature point using the following equation[2]:

$$\alpha_{\theta,25} = \frac{\kappa_\theta - \kappa_{25} \times 100}{\kappa_{25}\,(\theta - 25)}$$

where: κ_θ is the conductivity at temperature θ, and
κ_{25} is the conductivity at 25ºC.

Using this formula, the temperature coefficient of variation was calculated for each of the solutions and the values obtained are shown in Table 2.

	Temperature coefficient of variation at 25ºC				
Temp (ºC)	1413 std.	0.5g/l NaCl	0.5g/l NaOH	1g/l NaCl	10g/l NaCl
5	1.89	1.92	1.57	1.94	1.87
10	1.93	1.98	1.59	1.99	1.93
15	1.97	2.03	1.60	2.03	1.99
16	1.98	2.04	1.61	2.04	2.00
17	1.99	2.06	1.61	2.05	2.01
18	1.99	2.07	1.61	2.06	2.02
19	2.00	2.08	1.62	2.07	2.04
20	2.01	2.09	1.62	2.08	2.05
21	2.02	2.10	1.62	2.09	2.06
22	2.03	2.11	1.62	2.10	2.07
23	2.03	2.13	1.63	2.11	2.08
24	2.04	2.14	1.63	2.12	2.10
30	2.09	2.21	1.65	2.17	2.17
35	2.13	2.26	1.66	2.22	2.23
40	2.17	2.32	1.68	2.26	2.29
45	2.21	2.38	1.69	2.31	2.35
50	2.24	2.44	1.71	2.36	2.40

Table 2: Calculated temperature coefficients of variation.

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As can be seen from these values, the temperature coefficient of variation is not the same at each temperature or between different ionic species, although for different concentrations of a particular solution, the values are quite similar. Therefore if a single linear temperature compensation factor is used, the further the temperature of the sample from the reference temperature, the greater the error will be. Examples of this are shown in the bar charts in Figure 4.

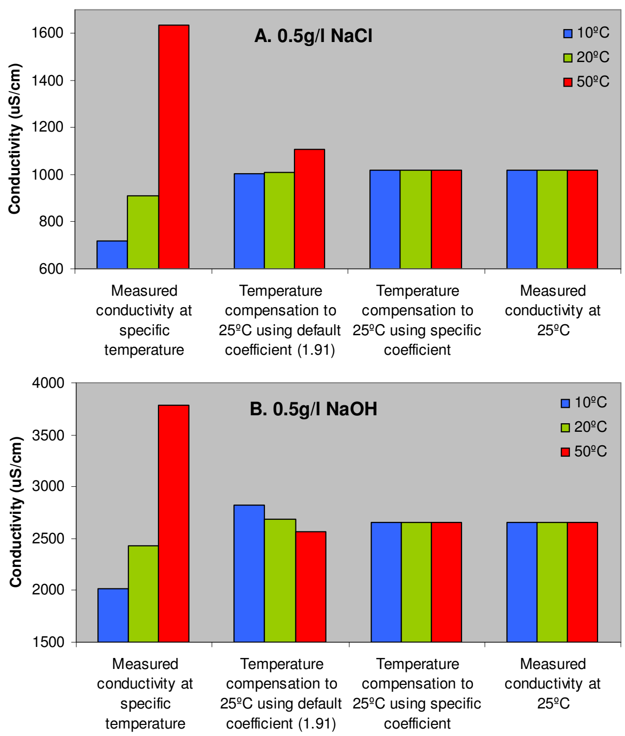

Figure 4: Temperature compensated conductivity values calculated using a default temperature coefficient and a specific temperature coefficient. The final columns of each graph show the actual conductivity of the same solution measured at 25ºC for comparison.

The results shown in Figure 4 were calculated using the default temperature coefficient pre-set on the instrument (in the case of the 4520, this is 1.91%), or the specific $\alpha_{\theta,25}$ from Table 2 using the formula[2]:

$$\kappa_{25} = \frac{\kappa_\theta}{1+(\alpha_{\theta,25}/100)\,(\theta-25)}$$

Table 3 illustrates the % errors obtained using different temperature coefficients for compensating the conductivity measurements at various temperatures and quite clearly shows that the error is much greater when the temperature of the solution is quite different from 25ºC.

0.5g/l NaCl	**% Error using default coefficient**	**% Error using specific coefficient**
10ºC	1.38	0.00
20ºC	1.08	0.10
50ºC	8.94	0.10
0.5g/l NaOH	**% Error using default coefficient**	**% Error using specific coefficient**
10ºC	6.72	0.00
20ºC	1.58	0.00
50ºC	3.40	0.00

Table 3: % Error at each temperature as a result of using a linear default temperature coefficient compared to a specific temperature coefficient.

Conclusions

We have demonstrated here the significant effect of temperature on the conductivity measurements of solutions. This highlights the importance of maintaining standard and test solutions close to the reference temperature when taking measurements in order to obtain the most accurate conductivity values. The temperature accuracy of most conductivity cells is about +/- 0.5ºC, therefore this also needs to be taken into consideration when analysing the results.

Although ATC is built in to all Jenway conductivity cells and meters, it is important to remember that each solution will have a different temperature coefficient of variation, so if this is known, it can easily be programmed into the instrument before readings are made.

For some applications, such as measuring conductivity to European Pharmacopoeia regulations, ATC must not be used. For these measurements, the standards and samples must be maintained at the required reference temperature while readings are taken.

References

1. G.F. Hewitt, Chemical Engineering Division, U.K.A.E.A Research Group Atomic Energy Research Establishment, HARWELL, U.K., Oct 1960.
2. Barron, J.J. and Ashton, C. The Effect of Temperature on Conductivity Measurement. http://www.reagecon.com/PerspectiveCMS/uploads/Effect_of_Temperature_TSP-07_Issue3.pdf.

__Disclaimer:__ The results presented here are experimentally determined values for demonstration purposes only and are not intended to represent tables of conductivity temperature coefficients of variation for the solutions tested.