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Diffusion of a Salt in an Aqueous Media

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DIFFUSION OF A SALT IN AN AQUEOUS MEDIA

HONORS THESIS

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ABSTRACT

Diffusion is defined as the net transfer of a molecule from a high concentration region to a low concentration region. The concept of diffusion is used in a very important process called "desalination." Desalination is a separation process used to reduce the salt content dissolved in brackish water to make it suitable for human consumption, irrigation, and industrial use.

In desalination plants, it is important to monitor the constantly changing salt content of water, partly due to the diffusive effect. The main purpose of this experiment was to study the diffusion of NaCl in water at two NaCl concentrations. The diffusion was studied by measuring the change in conductivity of pure water as the brine diffuses into the water through the diffusion cell. In this experiment, the diffusion of 1M and 2M NaCl solutions was conducted and the diffusion coefficient of the NaCl determined experimentally. The experimental diffusion coefficients were compared at each NaCl and with a theoretical value. To conduct the experiment, an Armfield Diffusion Apparatus was used with a conductivity meter attached to a PC computer to take measurements of the conductivity over the course of 30 minutes. At 1M, the theoretical value was 2.2×10^{-5} cm^2s^{-1},while the experimental results ranged from 2.20×10^{-5} cm^2s^{-1} - 3.20×10^{-5} cm^2s^{-1}. At 2M, the theoretical value was 1.48×10^{-5} cm^2s^{-1} and the experimental results ranged from 1.10×10^{-5} cm^2s^{-1}-2.80×10^{-5} cm^2s^{-1}. The percent error at 1M ranged from 0.25-45 % and at 2M, the percent error ranged from 3.27-89%. The cause of error for both experiments was determined to be more random than systematic since the coefficients varied significantly from each other. Recommendations for future experiments are to increase the run time, possibly change the solution mixing method, and take extra care to ensure the concentration of solution is not disrupted.

INTRODUCTION

Diffusion is defined as the net transfer of a molecule from a high concentration region to a low concentration region. Gas, liquid, or solid molecules are constantly moving because of their kinetic energy. Molecules are constantly moving and colliding with each other. These collisions cause the molecule to move in random directions. However, over time, molecules are thrown into the less concentrated regions. Therefore, the net movement of the molecule always moves from the denser regions to the less dense regions. Many can spread. Smell diffuses through the air, nutrients diffuse from blood to body tissues, and salt diffuses through water. The concept of diffusion is used in a very important process called "desalination" [2].

Desalination is a separation process used to reduce the salt content in brackish water to make it suitable for human consumption, irrigation, industrial uses, and other uses. Membrane techniques such as reverse osmosis are the most common methods of treating salt water. In reverse osmosis desalination, very high-pressure saline flows through thousands of tightly wound semipermeable membranes. Membranes allow small water molecules to pass through, leaving salts and other contaminants behind. In desalination plants, it is important to monitor the constantly changing salt content of water, partly due to the diffusive effect [4].

The main purpose of this experiment was to study the diffusion of NaCl in water at two salt concentrations. Diffusion was studied by measuring the change in conductivity of pure water as the salt solution diffuses into the water through the diffusion cell. Since pure water is constantly circulating, the salt concentration in the diffusion vessel remains well mixed. The salt diffuses from the diffusion cell to the diffusion vessel due to the concentration gradient. As the salt diffuses from high to low concentrations, the conductivity increases.

The learning objectives of this experiment are:

- Study the diffusion of a salt using the Armfield Liquid Diffusion Apparatus.
- Apply mass transfer theory to determine the diffusion coefficient of a salt.
- Determine the diffusion coefficient of a NaCl solution at two different concentrations (1M and 2M).
- Compare the experimental value of the diffusion coefficient with the expected value.
- Evaluate the effect of the solution concentration on the diffusion coefficient.

EQUIPMENT LIST AND CHEMICALS

1. Analytical balance
2. 100 mL volumetric flask
3. 100 mL Beaker
4. Sodium chloride (NaCl)
5. Milli-Q ultra-pure water
6. Filter paper
7. 1 L plastic measuring beaker
8. Plastic syringe
9. Magnetic stir bar
10. Magnetic stirrer
11. Armfield Liquid Diffusion Apparatus
    1. Glass diffusion cell
    2. Acrylic diffusion vessel
    3. Acrylic diffusion vessel lid

4. Conductivity meter

12. PC for logging conductivity reading

EQUIPMENT DESCRIPTION

The Armfield Liquid Diffusion Apparatus as shown in Figure 1A consists of a glass diffusion cell attached to the lid of the acrylic diffusion vessel. A magnetic stirrer is used to ensure constant agitation. A conductivity meter attached to the diffusion vessel measures the changes in conductivity as a function of time. The diffusion cell as shown in Figure 1B consists of a honeycomb of accurately dimensioned cylindrical pores that allows the diffusion of the solute into the diffusion vessel.

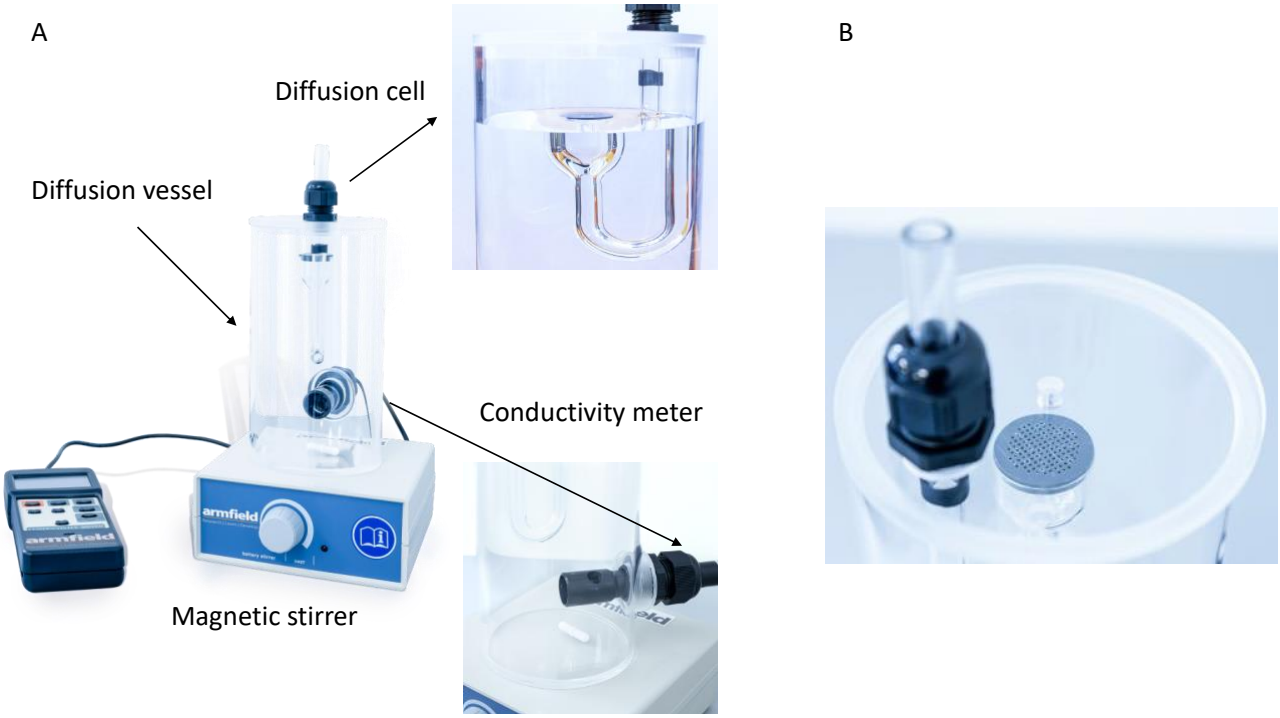


Figure 1: A) Armfield Liquid Diffusion Apparatus and B) Diffusion cell.

EXPERIMENTAL APPARATUS

The equipment apparatus is show in Figure 2. The Armfield Liquid Diffusion Apparatus consists of a glass diffusion cell attached to the acrylic lid of the diffusion vessel. The diffusion cell contains a honeycomb of dimensioned cylindrical pores that allow the diffusion of the solvent to the diffusion vessel. A magnetic stir bar is placed withing the vessel to ensure constant agitation. Attached towards the bottom of the vessel is a conductivity meter to measure the change in conductivity as a function of time. Figure 3 shows the final set up of the equipment list and experimental apparatus.

Figure 2. Armfield Liquid Diffusion Apparatus with Diffusion Cell on top

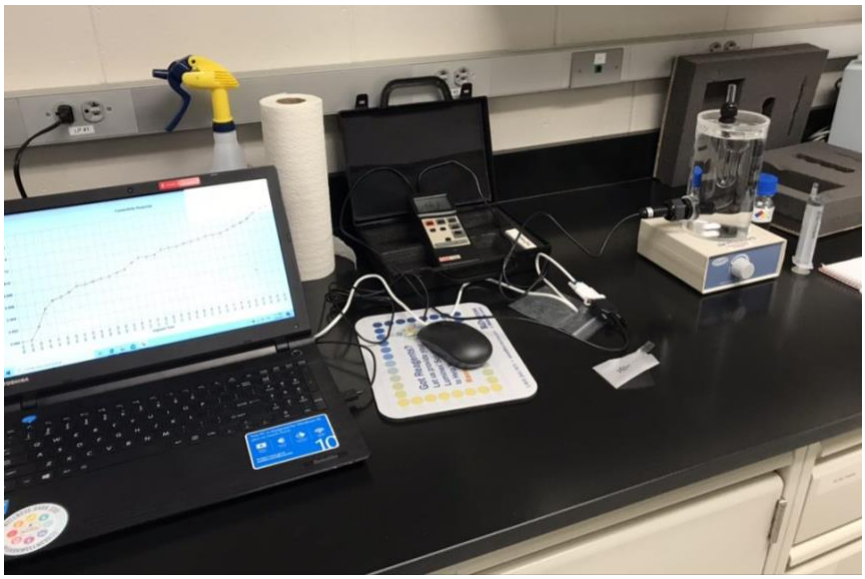


Figure 3: Experimental set up.

PROCEDURE

Preparing the Salt Solution

1. Calculate the amount of solute required to prepare the desired solution.
    a. Formula: $V(L) \times C(M) \times MW\left(\frac{g}{mol}\right) = m(g)$ where V is the volume, C is the desired concentration, MW is the molecular weight of salt, and m is the mass of the salt in grams.
    b. Applying the formula to an example: 5.844 g of solute (NaCl) are needed for 100 mL of a 1M NaCl solution
        i. $0.100\ L \times 1.0M \times 58.44\frac{g}{mol} NaCl = 5.844\ g\ NaCl$
2. Transfer the salt to a 100 mL beaker.
3. Add 50 mL of ultra-pure water and a magnetic stir bar to the beaker.
4. Place the beaker in a magnetic stirrer.
5. Turn on the magnetic stirrer and stir continuously until the salt is dissolved.
6. Once the salt is dissolved, transfer the solution carefully to a 100 mL volumetric flask.
7. Add distilled or deionized water until the mark etched on the neck of the flask is reached. Use a wash bottle or dropper if necessary.
8. Close the volumetric flask with the stopper and mix the solution by inverting it ten to twelve times.
9. Label the solution with your name, substance, concentration, and date.

Equipment Set Up

1. Wash the diffusion vessel with warm soapy water and rinse with ultra-pure water to remove grease or contamination.
2. Check that the conductivity electrode is located centrally in the diffusion vessel with the holes in the shield aligned vertically.
3. Fill the diffusion vessel with 1 L of ultra-pure using the 1 L plastic measuring beaker.

4. Locate the lid (with the glass diffusion cell fitted) on top of the diffusion vessel in a position so that the tops of the capillaries lie parallel with the graduation mark on the vessel and 5 mm below it.
5. Steady the lid on top of the diffusion vessel and check that the top of the honeycomb of capillaries is flush with the surface of the water. If necessary, adjust the height of the glass diffusion cell by unscrewing the gland nut that secures it.
6. After making any adjustments, ensure that the gland nut is tightened to clamp the glass diffusion cell at the correct height.
7. Remove the lid/diffusion cell and dry the cell to remove any excess water. Check that the collar on the vertical shaft is located 5 mm above the tops of the capillaries to assist when filling the cell.
8. Place the stirrer bar into the bottom of the diffusion vessel and locate the diffusion vessel on top of the battery-operated stirrer.
9. Connect the conductivity electrode to the socket at the top of the conductivity meter.

   Note: If using the CERB data logging software, connect the lead supplied from the jack socket on the meter (under a sealing grommet) to the USB port connector on the PC using the in-line RS232 to the USB adapter supplied.
10. Set the range switch to 199.9 µS on the conductivity meter and switch the meter on by pressing the POWER button.

    Note that if the conductivity reading displays '---' then the reading is out of range and the range switch should be adjusted.

Handling the Diffusion Cell

1. Wash the glass diffusion cell with warm soapy water and rinse with ultra-pure water to remove grease or contamination.
2. Before filling the diffusion cell with the NaCl solution, flush it with the NaCl solution and discard the solution.

   Note: the diffusion cell is very delicate and expensive. Act with caution.

3. Fill the glass diffusion cell with the salt solution using the syringe supplied.
4. Once the diffusion cell is filled with the NaCl solution, rinse the outside of the diffusion cell carefully with Milli-Q water and dry it with a Kimwipe.
5. Make sure that there are no air bubbles in the diffusion cell, especially near the capillaries.
6. Wipe off any excess solution from the top of the capillaries using filter paper or similar absorbent material but take care not to absorb the solution through the capillaries.

   Note: Do not place the diffusion cell into the diffusion vessel until the CERB software is started.

Experimental Procedure

1. Verify that the timer or CERB data logging software is ready to be used.
2. Turn on the magnetic stirrer and adjust the speed control until the liquid in the diffusion vessel is gently agitated without any excessive motion at the surface of the liquid.

   Note: The speed must be sufficient to allow for good mixing within the vessel but not allow a vortex to form.
3. Carefully place the lid with the diffusion cell on top of the diffusion vessel ensuring that it is located squarely into the recess.

   Note: Do not tilt the diffusion cell as it is immersed into the water to prevent loss of the salt solution.
4. Start the data logger so that it can record the conductivity reading over a 60-minute period.

   Note: Press the REC button to leave the meter permanently powered (if REC is not indicated on the display the meter will automatically switch off after 10 minutes to save the battery).

   Note: If using a stopwatch record the conductivity reading at 3 minutes interval.
5. Record conductivity readings for 30 minutes.

Shutdown Procedure

1. Stop the data logger and save your results as a Excel file and text file.

   Note: Make sure that the excel file opens before starting a new run or closing the software.
2. Turn off the magnetic stirrer.
3. Carefully remove the diffusion cell from the diffusion vessel and rinse it with ultra-pure water.
4. Remove the stir bar from the diffusion vessel.
5. Empty the liquid inside the diffusion vessel into the drain and rinse it with ultra-pure water.
6. Remove the conductivity meter electrode from the diffusion vessel, rinse it with ultra-pure water, dry it with a Kimwipe and properly store it.
7. Clean all the glassware and wipe down your laboratory workspace.

SAFETY PRECAUTIONS

1. Safety glasses, lab coat, long pants, and closed-toed shoes must be always worn.
2. THINK FIRST OF SAFETY IN ANY ACTION YOU TAKE. If not sure, ask the TA or faculty member before you act.
3. Never pour chemical waste into the sink drains or wastebaskets.
4. Place chemical waste inappropriately labeled waste containers.
5. Never work in the laboratory without supervision.
6. Always precisely perform the experiments or work as directed by the TA or faculty member.
7. Immediately report any spills, accidents, or injuries to the TA or faculty member.
8. Never leave experiments while in progress.
9. Keep the floor clear of all objects.
10. Keep work area neat and free of any unnecessary objects.

11. Thoroughly clean your laboratory workspace at the end of the laboratory session. Do not block the sink drains with debris.
12. Inspect all equipment for damage (cracks, defects) before use; do not use damaged equipment.
13. Properly dispose of broken glassware and other sharp objects.

Calculations

To perform the calculations, the following equations were used

1. Conductivity

   Conductivity is very temperature dependent, increasing as the temperature increases. The typical reference temperature for conductivity measurements in the United States is 25.0°C, as the National Institute of Standards and Technology (NIST) reference standards for conductivity are certified at 25.0°C. Therefore, before starting data analysis, adjust the conductivity values obtained in the experiment to 25°C. A temperature coefficient of approximately 2.12%/°C is suitable for dilute sodium chloride solutions near 25°C. To make the adjustment to the conductivity, use the following equation:

   $$C(25°C) = C(Texp) + C(Texp) \times (25 - Texp) \times 0.0212 \quad (1)$$

   where:
   C(25°C) = conductivity at 25°C (Ω^{-1})
   C(Texp) = experimental conductivity at the measured temperature (Ω^{-1})
   Texp = measured temperature (°C)

   Note: Make the adjustment to each data point. The conductivity probe is measuring conductance in S, but it displays conductivity in S/cm. The probe has a cell that has a length of 1 cm. Therefore, the readings of conductivity and conductance, in this case, will be the same.

2. Diffusion Coefficient from Fick's Law of Diffusion

Fick's laws explain how particles tend to move under random thermal motion and spread from high-concentration areas to low-concentration areas. This principle can be demonstrated by opening a perfume bottle in the corner of the closed room. If enough time goes by, the scent of perfume will permeate the room as the perfume molecules diffuse from one side of the room to the other (high-concentration area to a low-concentration area). Mathematically, three-dimensional diffusion is characterized by Fick's law of diffusion, which indicates that the diffusion flux is proportional to the concentration gradient

$$F = D\nabla C \quad (2)$$

where C is the concentration of the diffusing particles, F is the diffusion flux (particles per square meter per second), and D is the diffusion constant, which has units of cm^2 per second [3].

The following assumptions are applied: perfectly mixed solutions, negligible volume available to the solute within the capillaries, and pseudo-steady-state conditions throughout the experiment.

From Fick's Diffusion law, the diffusion flux is defined as the amount of substance per unit area per time, or

$$\frac{dN_A}{dt} * \frac{1}{A} = D\nabla C \quad (3)$$

For N number of capillaries,

$$\frac{\mathrm{dN_A}}{\mathrm{dt}} * \frac{1}{\mathrm{N{*}A}} = \mathrm{D}\nabla\mathrm{C} \quad (4)$$

The definition of concentration gradient is the following $\nabla C = \frac{dC_{in}}{dL}$ where C_{in} is the concentration of the salt and L is the length of the capillaries. Since both are constant, Equation (4) becomes

$$\frac{dN_A}{dt} * \frac{1}{N*A} = D\frac{C_{in}}{L} \quad (5)$$

The amount of substance diffusing is defined as $N_A = Volume\ (V) * C_A$ and since V is constant

$$\frac{VdC_A}{dt} * \frac{1}{N*A} = D\frac{C_{in}}{L} \quad (6)$$

Solving for D,

$$D = \frac{VdC_A}{dt} * \frac{L}{N*A*C_{in}} \quad (7)$$

The area of the membrane surface is equal to πr^2 where r = d/2 because the area of a capillary is a circle. Equation (7) becomes

$$D = \frac{VdC_A}{dt} * \frac{4*L}{N*\pi*d^2*C_{in}} \quad (8)$$

Moreover, the electrical conductivity change per unit concentration change is defined as $\Lambda = \frac{dk}{dC_A}$. If the chain rule is applied to Equation (8), the following is obtained

$$D = \frac{dC_A}{dk} * \frac{dk}{dt} * \frac{V*4*L}{N*\pi*d^2*C_{in}} \quad (9)$$

In substituting Λ into the equation, the final equation that is used to calculate the experimental diffusion coefficient is obtained

$$D = \frac{4LV_{out}}{N\pi d^2 \Lambda C_{in}} \frac{d\kappa}{dt} \quad (10)$$

where:

L = length of the capillaries (cm) 0.45

V= volume of water in the diffusion vessel (cm^3) 1000

d = diameter of the capillaries (cm) 0.1

N = number of capillaries 121

C_{in} = concentration of the salt solution (M) 0.1, 1 or 2

$\Lambda =$ electrical conductivity change per unit concentration change ($\Omega^{-1}M^{-1}$) 0.112

$\frac{d\kappa}{dt}$ is the rate of change of conductivity with time ($\Omega^{-1}s^{-1}$)

The rate of change of conductivity with time is obtained by making a plot in Microsoft Excel of conductivity (Ω^{-1}) vs time (s). This is illustrated in Figure 4.

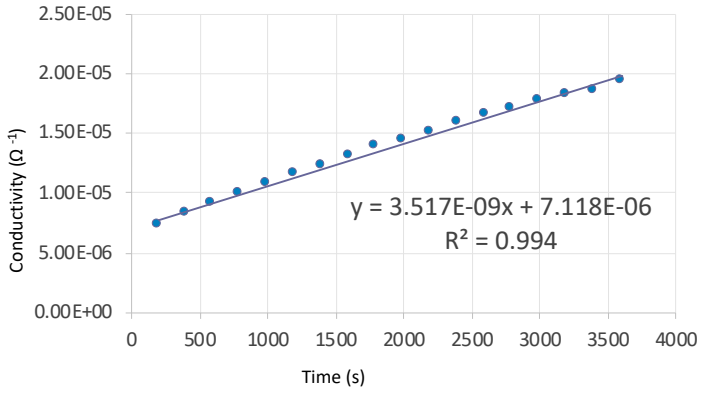
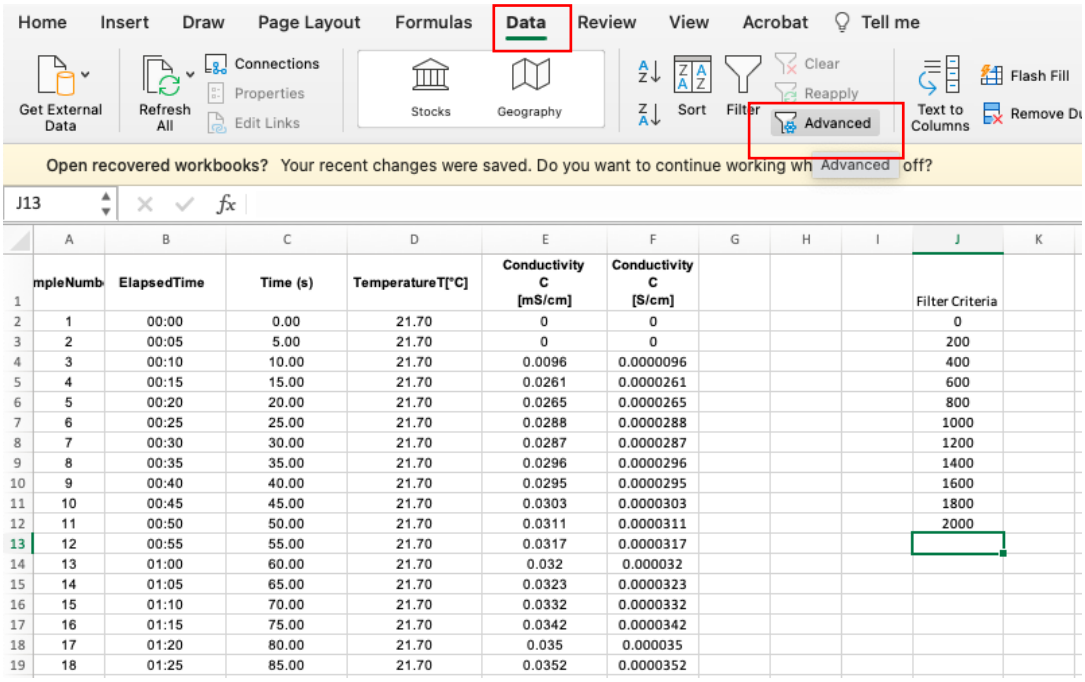


Figure 4: Plot of conductivity vs time.

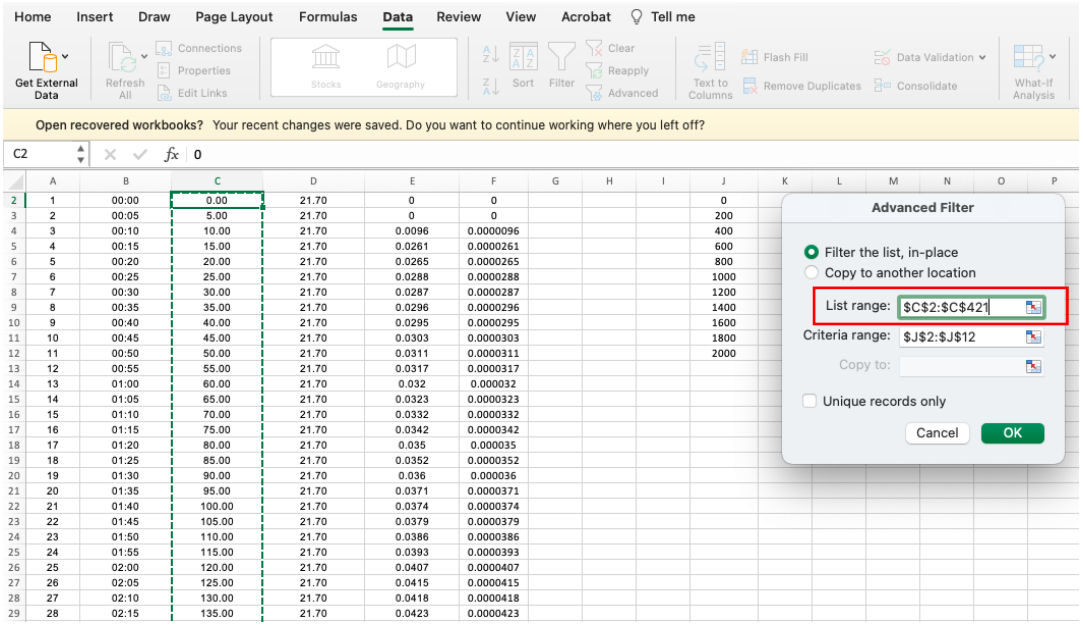
Before the plot is made, the elapsed time should be converted seconds. Also, a unit conversion is needed to convert mS to Ω^{-1}. The data should be filtered every 200 s.

To filter the data, go to Data and click Advance.

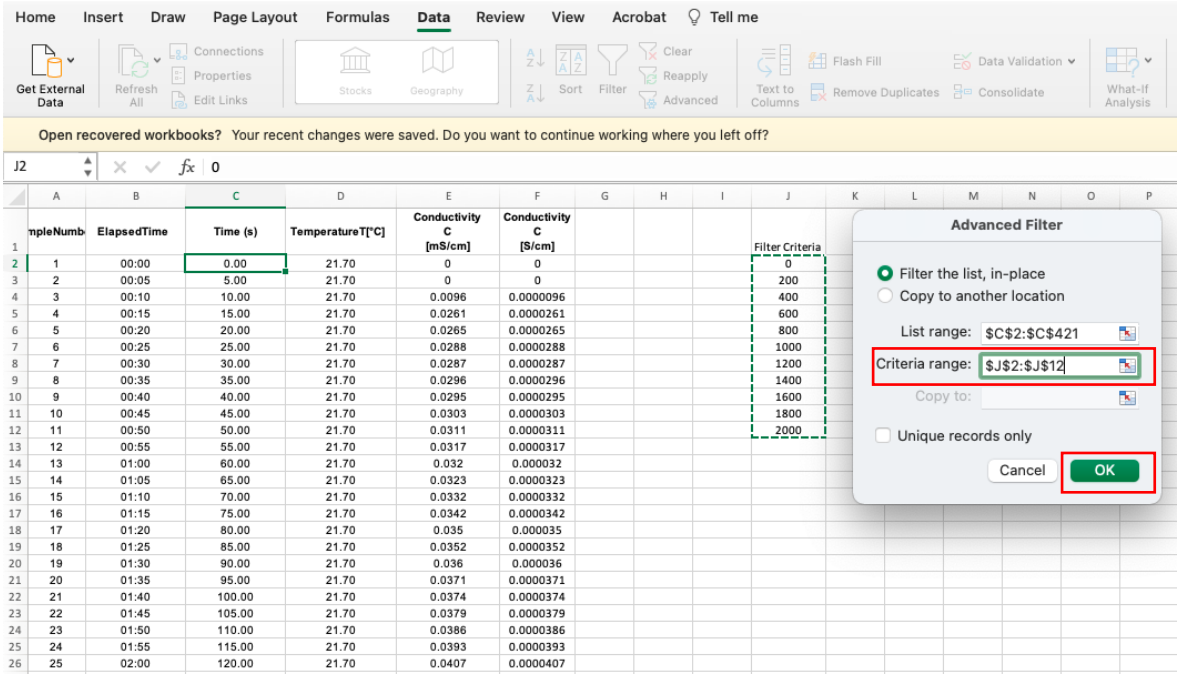


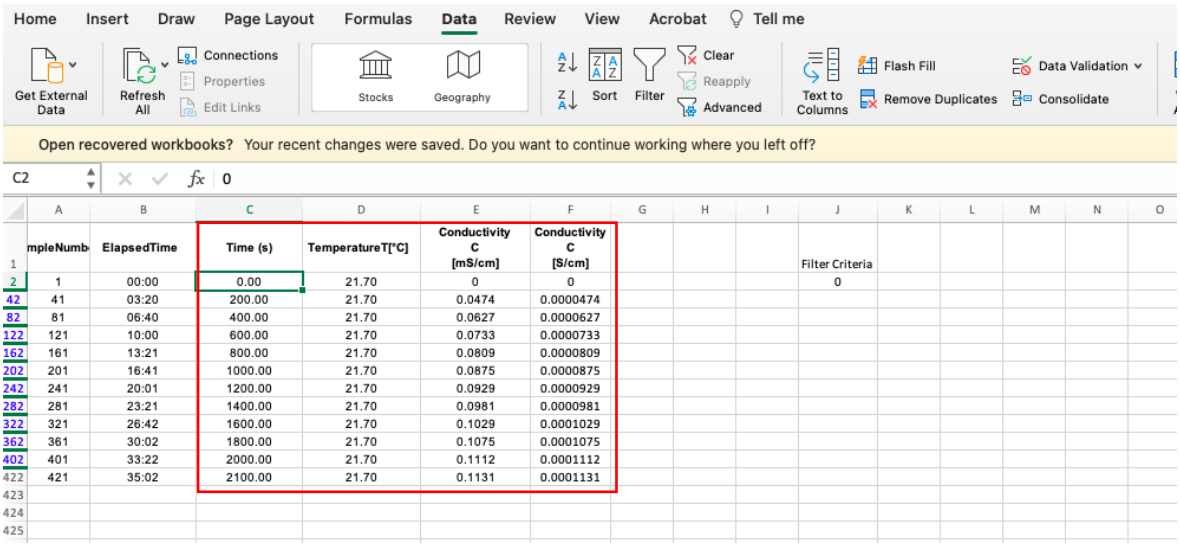
	A	B	C	D	E	F	G	H	I	J	K
1	mpleNumb	ElapsedTime	Time (s)	TemperatureT[°C]	Conductivity C [mS/cm]	Conductivity C [S/cm]				Filter Criteria	
2	1	00:00	0.00	21.70	0	0				0	
3	2	00:05	5.00	21.70	0	0				200	
4	3	00:10	10.00	21.70	0.0096	0.0000096				400	
5	4	00:15	15.00	21.70	0.0261	0.0000261				600	
6	5	00:20	20.00	21.70	0.0265	0.0000265				800	
7	6	00:25	25.00	21.70	0.0288	0.0000288				1000	
8	7	00:30	30.00	21.70	0.0287	0.0000287				1200	
9	8	00:35	35.00	21.70	0.0296	0.0000296				1400	
10	9	00:40	40.00	21.70	0.0295	0.0000295				1600	
11	10	00:45	45.00	21.70	0.0303	0.0000303				1800	
12	11	00:50	50.00	21.70	0.0311	0.0000311				2000	
13	12	00:55	55.00	21.70	0.0317	0.0000317					
14	13	01:00	60.00	21.70	0.032	0.000032					
15	14	01:05	65.00	21.70	0.0323	0.0000323					
16	15	01:10	70.00	21.70	0.0332	0.0000332					
17	16	01:15	75.00	21.70	0.0342	0.0000342					
18	17	01:20	80.00	21.70	0.035	0.000035					
19	18	01:25	85.00	21.70	0.0352	0.0000352					

For the list range, select the column with the time data in seconds. **Note: make sure that a data point at zero is included, although this data point will not be used in preparing the graph.**



For the criteria range, select the column with the filter criteria (time every 200 s) and click ok. **Note: make sure that a data point at zero is included, although this data point will not be used in preparing the graph.**





	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	mpleNumb	ElapsedTime	Time (s)	TemperatureT[°C]	Conductivity C [mS/cm]	Conductivity C [S/cm]				Filter Criteria					
2	1	00:00	0.00	21.70	0	0				0					
42	41	03:20	200.00	21.70	0.0474	0.0000474									
82	81	06:40	400.00	21.70	0.0627	0.0000627									
122	121	10:00	600.00	21.70	0.0733	0.0000733									
162	161	13:21	800.00	21.70	0.0809	0.0000809									
202	201	16:41	1000.00	21.70	0.0875	0.0000875									
242	241	20:01	1200.00	21.70	0.0929	0.0000929									
282	281	23:21	1400.00	21.70	0.0981	0.0000981									
322	321	26:42	1600.00	21.70	0.1029	0.0001029									
362	361	30:02	1800.00	21.70	0.1075	0.0001075									
402	401	33:22	2000.00	21.70	0.1112	0.0001112									
422	421	35:02	2100.00	21.70	0.1131	0.0001131									
423															
424															
425															

3. Example of Results

For 1 M, a table of results should look like the following after doing the filtration of data:

Table 1. Sample data for a 1M Run

SampleNumber	ElapsedTime	Temperature T [°C]	ConductivityC[mS/cm]	time s	conductivity in [S/cm]	Diffusion Coeffcient	% Error	Standard Deviation
1	00:00	22.00	0	0	0	2.16677E-05	1.510618	2.34997E-07
41	03:20	22.00	0.0035	200	0.0000035			
81	06:41	22.00	0.0051	400	0.0000051			
121	10:01	22.10	0.0062	600	0.0000062			
161	13:21	22.00	0.0074	800	0.0000074			
201	16:42	22.10	0.0083	1000	0.0000083			
241	20:02	22.10	0.0092	1200	0.0000092			
281	23:22	22.00	0.0102	1400	0.0000102			
321	26:43	22.10	0.011	1600	0.000011			
361	30:03	22.10	0.012	1800	0.000012			

For 2 M, a table of results should look like the following after doing the filtration of data:

Table 2. Sample Data for a 2M run

SampleNumber	ElapsedTime	TemperatureT[∞C]	ConductivityC[mS/cm]	Time in S	Conductivity in [S/cm]	Diffusion Coeffcient	%Error	Standard Deviation
1	00:00	21.40	0	0	0	1.10452E-05	25.57127	7.7462E-06
41	03:20	21.50	0.0052	200	0.0000052			
81	06:40	21.50	0.0064	400	0.0000064			
121	10:01	21.50	0.0073	600	0.0000073			
161	13:21	21.50	0.0081	800	0.0000081			
201	16:41	21.50	0.0091	1000	0.0000091			
241	20:01	21.50	0.0101	1200	0.0000101			
281	23:22	21.50	0.0114	1400	0.0000114			
321	26:42	21.50	0.0127	1600	0.0000127			
361	30:02	21.60	0.0136	1800	0.0000136			

RESULTS AND CONCLUSIONS

The results obtained for the diffusion coefficient for a 1 M NaCl at 25°C ranged between 2.20×10^{-5} cm^2s^{-1} and 3.20×10^{-5} cm^2s^{-1} with an average of 2.568×10^{-5} cm^2s^{-1}, and a standard deviation of 2.46×10^{-6}. For the 2 M NaCl at 25°C the diffusion coefficient ranged between 1.10×10^{-5} cm^2s^{-1} and 2.80×10^{-5} cm^2s^{-1} with an average of 1.455×10^{-5}

cm^2s^{-1}, and a standard deviation of 3.19×10^{-6}. Both results were within the range of the theoretical values of 2.2×10^{-5}
cm^2s^{-1} for the 1M solution and 1.48×10^{-5} cm^2s^{-1} for the 2M solution [6]. Thus, the percent error can be as high as 45% for the 1M solution and as high as 89% for the 2M solution. The average error for the 1M solution was 17.2% and the average error for the 2M solution was 25.6%.

Reasons for the error include:

1. It is likely that the solutions can be poorly mixed, thus having an uneven distribution of concentration. This would be a little more acceptable for an experiment that measured less sensitive variables, but the measurements taken here are several orders of magnitude below 1, meaning that slight variations in expected input can result in large variations in measured output.
2. At several points during the experiment, it is possible to disrupt the concentration of solution used for measurement, even if the right amounts of salt and water are measured out. Residue from past runs of the experiment on the vessels and the conductivity meter as well as absorption of solution by the filter paper when wiping off the capillaries can influence the concentration, if only slightly.
3. Another potential source of error is the relatively short time period for the experimental measurements. Such experiments are commonly performed over the course of more than two hours, allowing a more complete data set to be produced. When preparing the graphs themselves to obtain lines of best fit, the filtration method also resulted in many data points being thrown out.

With all this in mind, it can be concluded that this is a particularly sensitive experiment, and as such, precision and patience to ensure the accuracy of all measurements in the beginning of the experiment are the experimenter's greatest tools. In the future, some things to look into are the following: developing a better solution mixing method, taking extra care to ensure the concentration of experimental solution is not disrupted, and running the experiment itself for a longer period.

NOMENCLATURE

C(25°C)	conductivity at 25°C (Ω^{-1})
C(Texp)	experimental conductivity at the measured temperature (Ω^{-1})
Texp	measured temperature (°C)
L	Length of the capillaries, cm
V	Volume of water in the diffusion vessel, cm^3
d	Diameter of the capillaries, cm
N	Number of capillaries
C_{in}	Concentration of the salt solution, M
Λ	Electrical conductivity change per unit concentration change, $\Omega^{-1}M^{-1}$
$\frac{d\kappa}{dt}$	The rate of change of conductivity with time, $\Omega^{-1}s^{-1}$

AUTHORS CONTRIBUTION AND ACKNOWLEDGMENTS

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Appendix

The following 9 tables were data collected for 1 M Runs:

Table 3. 1 M run 1

SampleNumber	ElapsedTime	TemperatureT[∞C]	ConductivityC[mS/cm]	time in s	Conductivity in [S/cm]	Diffusion Coefficient	%Error	Standard Deviation
1	00:00	22.10	0	0	0	2.51311E-05	14.23231	2.21403E-06
41	03:20	22.40	0.0217	200	0.0000217			
81	06:41	22.40	0.0236	400	0.0000236			
121	10:01	22.40	0.0252	600	0.0000252			
161	13:21	22.30	0.0263	800	0.0000263			
201	16:41	22.30	0.0276	1000	0.0000276			
241	20:01	22.30	0.0287	1200	0.0000287			
281	23:22	22.30	0.0295	1400	0.0000295			
321	26:42	22.30	0.0304	1600	0.0000304			
361	30:02	22.20	0.0317	1800	0.0000317			

Table 4. 1 M run 2

SampleNumber	ElapsedTime	TemperatureT[°C]	Conductivity (mS/cm)	Time(s)	Conductivity in [S/cm]	Diffusion Coefficient	%Error	Standard Deviation
0	00:00	0.00	0	0	0	2.70371E-05	22.89581879	3.56175E-06
41	03:20	21.80	0.006300256	200	6.30026E-06			
81	06:41	21.70	0.008238692	400	8.23869E-06			
121	10:01	21.70	0.00962964	600	9.62964E-06			
161	13:22	21.70	0.011020588	800	1.10206E-05			
201	16:42	21.60	0.012221712	1000	1.22217E-05			
241	20:02	21.60	0.013401	1200	0.000013401			
281	23:23	21.50	0.0145017	1400	1.45017E-05			
321	26:43	21.50	0.01536106	1600	1.53611E-05			
361	30:03	21.40	0.017113488	1800	1.71135E-05			

Table 5. 1 M run 3

SampleNumber	ElapsedTime	TemperatureT[°C]	ConductivityC[mS/cm]	Time in S	Conductivity in [S/cm]	Diffusion Coefficient	%Error	Standard Deviation
1	00:00	21.50	0	0	0	3.19202E-05	45.09168	7.01462E-06
41	03:20	21.50	0.0089	200	0.0000089			
81	06:41	21.60	0.0113	400	0.0000113			
121	10:01	21.60	0.0132	600	0.0000132			
161	13:21	21.50	0.0149	800	0.0000149			
201	16:42	21.50	0.0161	1000	0.0000161			
241	20:02	21.50	0.0171	1200	0.0000171			
281	23:22	21.50	0.0186	1400	0.0000186			
321	26:42	21.50	0.0197	1600	0.0000197			
361	30:03	21.50	0.022	1800	0.000022			

Table 6. 1 M run 4

SampleNumber	ElapsedTime	TemperatureT[°C]	ConductivityC[mS/cm]	Time in S	Conductivity [S/cm]	Diffusion Coefficient	%Error	Standard Deviation
1	00:00	19.80	0	0	0	2.34645E-05	6.656794	1.03555E-06
41	03:20	19.60	0.0027	200	0.0000027			
81	06:40	19.60	0.0041	400	0.0000041			
121	10:01	19.60	0.0056	600	0.0000056			
161	13:21	19.60	0.0064	800	0.0000064			
201	16:41	19.60	0.0076	1000	0.0000076			
241	20:01	19.60	0.0088	1200	0.0000088			
281	23:22	19.70	0.0096	1400	0.0000096			
321	26:43	19.70	0.0107	1600	0.0000107			
360	29:58	19.70	0.0118	1800	0.0000118			

Table 7. 1 M run 5

SampleNumber	ElapsedTime	TemperatureT[°C]	ConductivityC[mS/cm]	Time in S	Conductivity [S/cm]	Diffusion Coefficient	%Error	Standard Deviation
1	00:00	20.50	0	0	0	2.20552E-05	0.251045	3.90534E-08
41	03:20	20.40	0.0074	200	0.0000074			
81	06:40	20.40	0.0084	400	0.0000084			
121	10:01	20.40	0.01	600	0.00001			
161	13:21	20.40	0.0108	800	0.0000108			
201	16:41	20.40	0.0121	1000	0.0000121			
241	20:01	20.40	0.0131	1200	0.0000131			
281	23:22	20.40	0.0139	1400	0.0000139			
321	26:42	20.40	0.0147	1600	0.0000147			
361	30:02	20.40	0.0158	1800	0.0000158			

Table 8. 1 M run 6

SampleNumber	ElapsedTime	TemperatureT[°C]	ConductivityC[mS/cm]	Time in S	Conductivity [S/cm]	Diffusion Coefficient	%Error	Standard Deviation
1	00:00	19.80	0	0	0	2.48033E-05	12.74238112	1.98225E-06
41	03:20	19.90	0.0027	200	0.0000027			
81	06:40	19.90	0.0047	400	0.0000047			
121	10:01	19.90	0.0062	600	0.0000062			
161	13:21	19.90	0.0076	800	0.0000076			
201	16:42	19.90	0.0086	1000	0.0000086			
241	20:03	20.00	0.0096	1200	0.0000096			
280	23:18	20.00	0.0106	1400	0.0000106			
320	26:39	20.00	0.0115	1600	0.0000115			
360	29:59	20.00	0.0125	1800	0.0000125			

Table 9. 1 M run 7

SampleNumber	ElapsedTime	TemperatureT[°C]	Conductivity [mS]	Time(s)	Conductivity in [S/cm]	Diffusion Coefficient	%Error	Standard Deviation
1	00:00	0.00	0	0	0	2.22342E-05	1.06475544	1.65637E-07
41	03:20	21.50	0.00526358	200	5.26358E-06			
81	06:41	21.40	0.006242656	400	6.24266E-06			
121	10:01	21.40	0.007211344	600	7.21134E-06			
161	13:21	21.40	0.008502928	800	8.50293E-06			
201	16:42	21.40	0.009794512	1000	9.79451E-06			
241	20:02	21.40	0.0107632	1200	1.07632E-05			
281	23:22	21.40	0.011624256	1400	1.16243E-05			
321	26:43	21.40	0.012592944	1600	1.25929E-05			
361	30:03	21.20	0.013507	1800	0.000013507			

Table 10. 1M run 8

SampleNumber	ElapsedTime	TemperatureT[∞C]	ConductivityC[mS/cm]	Time in S	Conductivity in [S/cm]	Diffusion Coefficient	%Error	Standard Deviation
1	00:00	21.90	0	0	0	2.76205E-05	25.54754	3.97426E-06
41	03:20	22.00	0.0005	200	0.0000005			
81	06:40	21.90	0.0015	400	0.0000015			
121	10:01	22.00	0.0021	600	0.0000021			
161	13:21	22.00	0.0035	800	0.0000035			
201	16:41	22.00	0.0047	1000	0.0000047			
241	20:02	22.00	0.006	1200	0.000006			
281	23:22	22.00	0.00805	1400	0.00000805			
321	26:42	22.00	0.0095	1600	0.0000095			
361	30:02	22.00	0.0105	1800	0.0000105			

Table 11. 1M run 9

SampleNumber	ElapsedTime	TemperatureT[∞C]	ConductivityC[mS/cm]	Conductivity in S/cm	time, s	Difussion Coefficient	%error	Standard Deviation
1	00:00	22.10	0	0	0	3.12861E-05	42.20939	6.56624E-06
41	03:20	22.10	0.0377	200	0.0000377			
81	06:41	22.10	0.0398	400	0.0000398			
121	10:01	22.10	0.0403	600	0.0000403			
161	13:21	22.00	0.0414	800	0.0000414			
201	16:41	22.00	0.0426	1000	0.0000426			
241	20:02	22.00	0.0446	1200	0.0000446			
281	23:22	22.00	0.0458	1400	0.0000458			
321	26:42	22.00	0.048	1600	0.000048			
361	30:02	22.00	0.0502	1800	0.0000502			

Table 12. 1M run 10

SampleNumber	ElapsedTime	Temperature T [°C]	ConductivityC[mS/cm]	time s	conductivity in [S/cm]	Diffusion Coeffcient	% Error	Standard Deviation
1	00:00	22.00	0	0	0	2.16677E-05	1.510618	2.34997E-07
41	03:20	22.00	0.0035	200	0.0000035			
81	06:41	22.00	0.0051	400	0.0000051			
121	10:01	22.10	0.0062	600	0.0000062			
161	13:21	22.00	0.0074	800	0.0000074			
201	16:42	22.10	0.0083	1000	0.0000083			
241	20:02	22.10	0.0092	1200	0.0000092			
281	23:22	22.00	0.0102	1400	0.0000102			
321	26:43	22.10	0.011	1600	0.000011			
361	30:03	22.10	0.012	1800	0.000012			

The following 9 tables were data collected for 2 M Runs:

Table 13. 2M run 1

SampleNumber	ElapsedTime	TemperatureT[∞C]	nductivityC[mS/cn	time s	conductivity in [S/cm]	Diffusion Coefficient	%Error	Standard Deviation
1	00:00	21.30	0	0	0	1.11577E-05	24.81345	2.60379E-06
41	03:20	21.30	0.0259	200	0.0000259			
81	06:40	21.30	0.0272	400	0.0000272			
121	10:01	21.30	0.0284	600	0.0000284			
161	13:21	21.30	0.0295	800	0.0000295			
201	16:41	21.30	0.0304	1000	0.0000304			
241	20:01	21.30	0.0316	1200	0.0000316			
281	23:21	21.30	0.0326	1400	0.0000326			
321	26:42	21.30	0.0335	1600	0.0000335			
361	30:02	21.40	0.0344	1800	0.0000344			

Table 14. 2M run 2

ElapsedTime	Time [s]	TemperatureT[°C]	Conductivity C [mS/cm]	Conductivity C [S/cm]	Diffusion Coeffcient	%Error	Standard Deviation
00:00	0.00	22.10	0.0001	0.0000001	1.41633E-05	4.560062663	4.78509E-07
03:20	200.00	22.10	0.0116	0.0000116			
06:41	400.00	22.10	0.0136	0.0000136			
10:01	600.00	22.10	0.0153	0.0000153			
13:21	800.00	22.10	0.0168	0.0000168			
16:42	1000.00	22.00	0.0181	0.0000181			
20:02	1200.00	22.00	0.0194	0.0000194			
23:22	1400.00	22.00	0.0204	0.0000204			
26:43	1600.00	22.00	0.0216	0.0000216			
30:03	1800.00	22.00	0.0225	0.0000225			

Table 15. 2M run 3

SampleNumber	ElapsedTime	TemperatureT[°C]	ConductivityC[mS/cm]	Time [s]	Conductivity C [S/cm]	Diffusion Coefficient	%Error	Standard Deviation
1	00:00	22.10	0.0001	0.00	0.0000001	1.53259E-05	3.274559	3.43615E-07
41	03:20	22.10	0.0087	200.00	0.0000087			
81	06:40	22.10	0.011	400.00	0.000011			
121	10:01	22.10	0.013	600.00	0.000013			
161	13:21	22.10	0.0145	800.00	0.0000145			
201	16:41	22.10	0.0158	1000.00	0.0000158			
241	20:02	22.10	0.0172	1200.00	0.0000172			
281	23:22	22.10	0.0184	1400.00	0.0000184			
321	26:42	22.00	0.0195	1600.00	0.0000195			
360	29:58	22.00	0.0207	1800.00	0.0000207			

Table 16. 2M run 4

SampleNumber	ElapsedTime	TemperatureT[°C]	ConductivityC[mS/cm]	Time in S	Conductivity in [S/cm]	Diffusion Coefficient	%Error	Standard Deviation
1	00:00	23.30	0	0	0	1.101E-05	25.80873	2.70823E-06
41	03:20	23.10	0.0043	200	0.0000043			
81	06:40	23.10	0.0054	400	0.0000054			
121	10:01	23.10	0.0063	600	0.0000063			
161	13:21	23.10	0.0074	800	0.0000074			
201	16:41	23.10	0.0083	1000	0.0000083			
241	20:01	23.00	0.0095	1200	0.0000095			
281	23:22	23.00	0.0106	1400	0.0000106			
321	26:42	22.90	0.0116	1600	0.0000116			
361	30:02	22.90	0.0126	1800	0.0000126			

Table 17. 2M run 5

SampleNumber	ElapsedTime	TemperatureT[°C]	ConductivityC[mS/cm]	Time in S	Conductivity in [S/cm]	Diffusion Coefficient	%Error	Standard Deviation
1	00:00	21.50	0	0	0	1.1609E-05	21.7722	2.28466E-06
41	03:20	21.40	0.0035	200	0.0000035			
81	06:40	21.40	0.0049	400	0.0000049			
121	10:01	21.40	0.0058	600	0.0000058			
161	13:21	21.40	0.0069	800	0.0000069			
201	16:41	21.40	0.0078	1000	0.0000078			
241	20:01	21.40	0.0086	1200	0.0000086			
281	23:21	21.40	0.0104	1400	0.0000104			
321	26:42	21.40	0.0115	1600	0.0000115			
361	30:02	21.40	0.0123	1800	0.0000123			

Table 18. 2M run 6

SampleNumber	ElapsedTime	TemperatureT[°C]	ConductivityC[mS/cm]	Time in S	Conductivity [S/cm]	Diffusion Coefficient	%Error	Standard Deviation
1	00:00	21.80	0	0	0	1.42865E-05	3.729818	3.91387E-07
41	03:20	22.00	0.0028	200	0.0000028			
81	06:40	22.00	0.0036	400	0.0000036			
121	10:01	22.00	0.0045	600	0.0000045			
161	13:21	22.00	0.0057	800	0.0000057			
201	16:41	22.00	0.0076	1000	0.0000076			
241	20:01	22.00	0.0089	1200	0.0000089			
281	23:22	22.10	0.0108	1400	0.0000108			
321	26:42	22.10	0.0119	1600	0.0000119			
361	30:02	22.10	0.0129	1800	0.0000129			

Table 19. 2M run 7

SampleNumber	ElapsedTime	Time [s]	TemperatureT[°C]	ConductivityC[mS/cm]	Conductivity in [S/cm]	Diffusion Coefficient	%Error	Standard Deviation
1	00:00	0.00	22.10	0	0	2.80433E-05	88.97108	9.33615E-06
41	03:20	200.00	22.10	0.0125	0.0000125			
81	06:41	400.00	22.10	0.0138	0.0000138			
121	10:01	600.00	22.10	0.0158	0.0000158			
161	13:22	800.00	22.10	0.0171	0.0000171			
201	16:42	1000.00	22.10	0.0185	0.0000185			
241	20:02	1200.00	22.10	0.0198	0.0000198			
281	23:23	1400.00	22.10	0.0208	0.0000208			
321	26:43	1600.00	22.10	0.0221	0.0000221			
360	29:58	1800.00	22.10	0.023	0.000023			

Table 20. 2M run 8

SampleNumber	ElapsedTime	TemperatureT[°C]	ConductivityC[mS/cm]	Time in s	Conductivity in [S/cm]	Diffusion Coefficient	%Error	Standard Deviation
1	00:00	21.30	0	0	0	1.06928E-05	27.94586	2.93249E-06
41	03:20	21.20	0.0009	200	0.0000009			
81	06:40	21.20	0.0019	400	0.0000019			
121	10:01	21.30	0.0031	600	0.0000031			
161	13:21	21.30	0.0044	800	0.0000044			
201	16:41	21.30	0.0051	1000	0.0000051			
241	20:01	21.30	0.0065	1200	0.0000065			
281	23:21	21.40	0.0071	1400	0.0000071			
321	26:42	21.40	0.0081	1600	0.0000081			
361	30:02	21.40	0.0089	1800	0.0000089			

Table 21. 2M run 9

SampleNumber	ElapsedTime	TemperatureT[∞C]	Conductivity C [mS/cm]	Time(s)	Conductivity C [S/cm]	Diffusion Coefficient	%error	Standard Deviation
1	00:00	22.10	0.0009	0.0	9.55332E-07	1.92175E-05	29.4980351	3.09537E-06
41	03:20	22.20	0.0111	200.0	1.17589E-05			
81	06:41	22.20	0.0141	400.0	1.4937E-05			
121	10:01	22.20	0.0161	600.0	1.70557E-05			
161	13:21	22.20	0.0176	800.0	1.86447E-05			
201	16:41	22.10	0.0199	1000.0	2.11235E-05			
241	20:02	22.10	0.0213	1200.0	2.26095E-05			
281	23:22	22.10	0.0226	1400.0	2.39894E-05			
321	26:42	22.10	0.0239	1600.0	2.53694E-05			
361	30:03	22.10	0.0252	1800.0	2.67493E-05			

Table 22. 2M run 10

SampleNumber	ElapsedTime	TemperatureT[∞C]	ConductivityC[mS/cm]	Time in S	Conductivity in [S/cm]	Diffusion Coeffcient	%Error	Standard Deviation
1	00:00	21.40	0	0	0	1.10452E-05	25.57127	7.7462E-06
41	03:20	21.50	0.0052	200	0.0000052			
81	06:40	21.50	0.0064	400	0.0000064			
121	10:01	21.50	0.0073	600	0.0000073			
161	13:21	21.50	0.0081	800	0.0000081			
201	16:41	21.50	0.0091	1000	0.0000091			
241	20:01	21.50	0.0101	1200	0.0000101			
281	23:22	21.50	0.0114	1400	0.0000114			
321	26:42	21.50	0.0127	1600	0.0000127			
361	30:02	21.60	0.0136	1800	0.0000136			