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How do soda impurities affect distilled water?

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ABSTRACT
This research paper aims to answer the following research question: "How does the presence of 0 mL, 15 mL, 30 mL and 45 mL of soda water as an impurity affect the pH level of pure, distilled water?". The methodology involved careful consideration of control variables, as well as the use of accurate digital equipment, such as a pH sensor stick to measure the precisely added volumes of soda water. With 8 trials for each increment tested, 32 degrees of statistical freedom obtained and the ANOVA test suggesting a significant relationship between the independent variable of pH and the dependent variable of the amount of soda water, it was observed that, though there was not a very significant measurable difference between consecutive increments, there was a considerable difference between the 0 mL results and the results obtained from each increment. The majority of the data helped prove the alternative hypothesis that the pH will decrease as the amount of soda water increases, since soda contains carbonic acid, which has a pH below the neutral 7.

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I. RESEARCH QUESTION

How does the presence of 0 mL, 15 mL, 30 mL and 45 mL of soda water as an impurity affect the pH level of pure, distilled water?

II. INTRODUCTION

2.1 BACKGROUND RESEARCH

Physical properties of matter are properties that can be observed and measured without changing the chemical nature of matter. Some examples of physical properties are: color and density. [1] These physical properties can be further classified into intensive or extensive physical properties; intensive referring to those properties that do not change along with the size or amount of matter, like conductivity, and extensive referring to those properties that are dependent on the amount of matter in a sample, like volume. [2] On the other hand, chemical properties of matter are properties that become evident during or after a chemical reaction; they can only be seen by changing a substance's chemical identity. [3] Moreover, substances that are made up of only one kind of particle and have a fixed structure are called pure substances. Elements–like gold and oxygen–are considered to be pure substances, as they are made up of only one type of atom and cannot be broken down into simpler substances, and so are compounds, like water and table salt, as two or more elements are chemically bonded together, the only difference being that compounds can be broken down into simpler substances. Some characteristics and properties of pure substances are: they are homogenous, made up of only one kind of atom or molecule; they have a constant composition throughout; they have fixed boiling and melting points; the products they form through chemical reactions are usually predictable. Whereas, some characteristics and properties of impure substances–like water and oil, and sand and water–are: they do not have any specific properties, they are the result of the average properties of all the substances; they are formed due to physical changes; they have a variable composition; their melting and boiling points are different; they can be separated using separation methods. [4]

2.2 SCIENTIFIC RESEARCH

The potential of Hydrogen, or pH, is a measure of the acidity or basicity of a substance, usually an aqueous or liquid solution. It measures the concentration of the hydrogen ion, which ranges from 1 to 10^–14 gram-equivalents per liter, and presents it as a number between 0 and 14. The pH of pure water–which is neutral, meaning that it is neither acidic nor alkaline–is 7; the concentration of the hydrogen ion is 10^−7 gram-equivalents per liter. A substance with a pH less than 7 is considered to be acidic, and those more than 7 are considered to be alkaline, or basic. [5] The pH of soda water, on the other hand, has a value of 4.5 to 5.5 on the pH scale. [6] The pH is affected by several factors, some of which are: Carbon Dioxide, which forms a weak acid that can throw off the balance of the pH in pure water; organic minerals, like calcium and sulfide, that are acidic or alkaline; among many other elements and chemicals. [7] The pH is also affected by temperature–it decreases when temperature increases, as seen in the case of pure water. [8] And, the pH increases with an increase in volume in an acidic solution, whereas it decreases in an alkaline solution. [9] Furthermore, most soda drinks are acidic, because they undergo carbonation, where CO2 is dissolved within them and carbonic *acid* is produced. [10] Moreover, the pH of a substance is commonly measured using a pH sensor stick, which consists of a pH probe, a reference pH electrode, and a high input impedance meter. The sensor should always be set to exactly 7.00 using the ZERO OFFSET, STANDARDIZED or SET knobs. [11] The sensor should also be cleaned, especially between trials, as substances can accumulate on the electrode causing slower or faulty readings. [12]

3. HYPOTHESIS

Null / H_0 - **If** soda as an impurity is added to varying amounts of pure, distilled water, **then** their pH level will not be affected, **because** there is no significant relationship between the two variables. Therefore, the tests of 15 mL soda water, 30 mL soda water, and 45 mL soda water in 100 mL of distilled water each will be the same as the addition of 0 mL of soda in 100 mL of distilled water: ~7, or ~10^–7 gram-equivalents per liter, which is the pH for pure, neutral water, as it is neutral [5]. This is because the soda in soda water is already diluted with water, therefore, its pH has already increased and it is less acidic; and then when it is added to pure water, it becomes further diluted and comes even closer to neutrality.

Alternative / H_a - **If** varying amounts of soda as an impurity is added to pure, distilled water, **then** its pH level will decrease and the more impurities added to the water, i.e. the more soda water added to the water, the lesser the pH and more acidic the solution. This is **because** soda contains dissolved carbon dioxide and carbonic acid, both of which are acidic in nature, and when these acidic impurities will mix with pure water, they will decrease the overall pH of the solution due to the presence of acidic properties [10]. The more these acidic properties are present, the more the pH will tilt towards the decreased, acidic side of the scale. Therefore, 45 mL of soda in 100 mL of distilled water will be the most acidic, followed by the lesser acidic 30 mL of soda in 100 mL of distilled water, which is in turned followed by the even lesser acidic 15 mL of soda in 100 mL of distilled water. All of which will have a pH less than ~7, with 45 mL having the lowest, whereas the the non-acidic, neutral 0 mL of soda in 100 mL of distilled water will have a pH of ~7, or ~10^–7 gram-equivalents per liter, which is the pH of pure water [5].

4. VARIABLES

	Variable	How will you do it	Units
IV - x (What will you change)	*Soda Water*	*The salinity will be altered by dissolving a greater amount of salt in the same volume of fluid.* *We will conduct 8 trials by adding 15 mL of our Independent Variable to 100 mL of distilled water; 8 trials by adding 30 mL of the IV to 100 mL of distilled water; 8 trials by adding 45 mL of the IV to 100 mL of distilled water; and conduct 8 trials with 100 mL of water and 0 mL of the IV to serve as a base value.* *We will obtain 28 degrees of freedom using this method of manipulation.*	Milliliters
DV - y	pH Level	*We will measure the pH level using a pH sensor stick, which we will partially submerge into the water and/or solutions to obtain the pH level after we connect the stick to a computer.* *The unit we will use will be gram-equivalents per liter, but instead of writing 10^–X g-e/l, we will write X g-e/l.*	*gram-equivalents per liter*
Controlled Variables	1. The amount of pure, distilled water 2. The temperature of the substances 3. The type of soda water 4. The stirring of the solution after adding the soda water	1. Controlling the amount of pure, distilled water that each sample of soda water is mixed in will ensure that the experiment is fair. This is because if for one of the eight trials of 15 mL of soda with distilled water, we use 100 mL of water and for another we use 80 mL of water, the concentration of the soda water will be greater in the solution, meaning that it will be more acidic and there will be a lower pH. This will affect the experiment significantly, as we will need to take an average of the 8 trials for our data processing and this anomaly will incorrectly skew the results, which will lead to me drawing an incorrect solution. I will ensure that the amount of pure, distilled water is kept at 100 mL for all 8 trials of all 4 tests.	1. Milliliters (mL) 2. Degrees Celcius 3. Brand: *Rock - Mountain Soda Water* 4. Seconds & Times

	5. The environment under which the experiment is conducted 6. Amount of time after opening the container of soda water	2. It is very important to ensure that the temperature of the substances is the same for all the trials and tests, because pH decreases as temperature increases, as seen in the case of pure water. This would affect the validity of the results obtained because they would be inaccurate, which would hinder our entire experiment. I will ensure that the temperature of the substances are controlled by keeping both of them at room temperature for the entirety of the experiment. 3. Different manufacturers manufacture soda water differently, meaning that some brands make a more acidic kind of soda water and others make a less acidic kind of soda water. This suggests that if I use different kinds of soda waters, I will obtain different and inconsistent results, which will render this entire experiment inaccurate. I will ensure that the type of soda water is controlled by only using *Rock - Mountain Soda Water* to carry out the experiment. 4. After adding soda water to pure water, we will need to stir it in order for the two substances to mix properly and, to some extent, diffuse so that the concentration of each substance is the same throughout the solution; thus, the pH is the same throughout the solution. If the solution for one trial is stirred really well, while one is not, their pH levels are likely to differ, thereby, the results will likely be not fully correct. I will ensure this variable is controlled by continuously stirring the solution 10 times from the largest radius possible, and each rotation will last for 7 seconds. This will ensure that the solution is stirred properly, while not generating too much kinetic energy, as it can be converted to thermal energy and increase the temperature of the solution. 5. The environment under which the experiment is conducted can affect the experiment a lot. This is because if the environment is warmer for some trials than others of the same test, those conducted in the warmer environment will have a higher pH. This will mean that the test would be unfair, and the data collected would be unreliable. I will ensure the control of this variable by carrying out all the trials of all the tests in our school's science lab, setting the thermostat to 23ºC. 6. The amount of time after opening the container of soda water should be controlled, because the Carbon Dioxide inside the container will escape, which will decrease the acidity of the soda water. Meaning, that some trials and tests will be done with less acidic soda water and some will be done with more, which will make the experiment unfair and uncredible. I will ensure this variable is controlled by pouring the soda water into the pure water within 15 seconds of opening the container.	(frequency) 5. Degrees Celsius 6. Seconds

5. MATERIALS

Item	Quantity	Specifics (i.e. concentration)
Distilled Water	3,500 mL	The water should be pure and distilled, and all of the 3,500 mL should be from the same manufacturer.
Soda Water	750 mL	The manufacturer should be the company "Rock", and the name of the product should be "Mountain Soda Water"
pH Sensor Stick	1	N/A
Measuring Cylinder	2	It should be very accurate for smaller milliliter values; it should be accurate to 1 milliliter
Beaker	1	N/A
Computer/Laptop	1	It should have a port in which we could plug in the pH sensor stick to obtain the results

Stirring Rod	1	N/A
Safety Goggles	4	They should cover the entire eyes
Cloth	1	It should be white, clean, easily dry-able, and very good at wiping

6. SAFETY

Safety Categories	Description	How this can be avoided
Physical	A. The soda water may go into someone's eyes, which will burn due to its acidic nature and containment of carbonic acid. B. The soda water may ruin the clothes of us scientists due to the acid it contains. C. The beaker containing the solution may spill, which may cause some people to slip and injure themselves.	A. This can be avoided by wearing safety goggles at all times when soda water is being used, especially when it is being poured into any of the apparatus. B. This can be avoided by wearing a lab court at all times during the experiment. C. This can be avoided by making sure the apparatus is handled carefully, the beaker where much of the action occurs is placed in the middle of the table, and any and all spillages must be wiped immediately accompanied by a "CAUTION - Wet Floor" sign.
Cultural	A. The environmental safety concerns of this experiment, such as the disposal of solution(s) and glass bottles will also affect human beings on this planet by contributing to pollution and global warming, which will cause massive scale migration and many diseases, just to name a few implications.	A. This can be avoided by taking the measures mentioned in the Environmental "how can this be avoided?" section.
Environmental	A. We will need to dispose of the soda water and pure water solution(s) once we are done with them, which wastes scarce resources that many don't have access to, and the process of disposal will hurt the environment and the life on the planet, as the solution might not be neutral. B. The soda water will come in bottles of glass, which is a material that literally takes a million years to decompose, and after we use the soda water inside those bottles, we will need to dispose of them, which will immensely harm the environment.	A. We could try to recycle the solution(s), instead of disposing of them, so that they can be used in some way. B. This can be avoided by recycling those glass bottles instead of disposing of them.

7. METHODOLOGY

1. Start the experiment off by obtaining **3,500 mL of distilled water** and **750 mL of Rock Mountain Soda Water**.
2. Then, fill **a beaker** with 100 mL of distilled water using **a measuring cylinder**, and use **a pH Sensor Stick** to measure the pH level of the water. Clean the beaker with water and wipe it as dry as possible with a clean **cloth**.
3. Now, repeat step 2 seven more times, so that you have 8 pH level values in total, and record the quantitative observations in the quantitative data table and the qualitative observations in the qualitative data table so that they can then be processed.
4. After this, fill a beaker with 100 mL of distilled water using a measuring cylinder and add 15 mL of soda water in it using **a different measuring cylinder**.
5. Now, continuously stir the solution 10 times from the largest radius possible, each rotation lasting for 7 seconds, using **a stirring rod**, and use a pH sensor stick to measure the pH level of the solution. Then, clean the beaker with water and wipe it as dry as possible with a clean cloth.
6. Repeat steps 4 and 5 seven more times, so that you have 8 pH level values in total, and record the quantitative observations in the quantitative data table and the qualitative observations in the qualitative data table so that they can then be processed.
7. After this, repeat steps 4, 5 and 6 for 30 mL of soda water and then 45 ml of soda water instead of 15 mL.

8. RAW DATA

8.1 RAW QUANTITATIVE DATA TABLE

RAW QUANTITATIVE DATA TABLE				
The pH levels of 100 mL distilled water for 8 trials, 15 mL soda water added to 100 mL distilled water for 8 trials, 30 mL soda water added to 100 mL distilled water for 8 trials, and 45 mL soda water added to 100 mL distilled water for 8 trials				
The pH level, potential of Hydrogen, in units where 10^−X gram-equivalents per liter corresponds to X, for each:				
Trial #	100 mL Distilled Water	100 mL Distilled Water + 15 mL Soda Water	100 mL Distilled Water + 30 mL Soda Water	100 mL Distilled Water + 45 mL Soda Water
1	5.65	5.70	5.62	5.62
2	6.52	5.74	5.72	5.71
3	6.66	5.74	5.82	5.90
4	6.58	5.79	5.79	5.72
5	6.62	5.59	5.86	5.67
6	6.71	5.68	5.66	5.70
7	6.72	5.65	5.74	5.55
8	6.92	5.80	5.60	5.70

This raw quantitative data clearly depicts that the distilled water used is really close to neutral, and the solution gets more acidic as soda water is added. It can also be deduced that the acidity of the solution gradually increases as more soda water is added, with 45 mL soda water + 100 mL distilled water having the lowest, most acid-representing pH value. This suggests that this raw data is of significance, as it shows that there is a relationship between the two variables being tested; however, we need to perform a statistical analysis in order to ascertain if the relationship is statistically significant or not.

8.2 RAW QUALITATIVE DATA TABLE

QUALITATIVE DATA TABLE				
Qualitative observations from the 8 trials done for each: pH level of 0 mL soda water + 100 mL distilled water, 15 mL soda water + 100 mL distilled water, 30 mL soda water + 100 mL distilled water, and 45 mL soda water + 100 mL distilled water				
	Change in Color?	Fizzing?	Change in Opacity?	Scent Omitted?
0 mL Soda Water	N/A	N/A	N/A	N/A
15 mL Soda Water	N/A	Slight Fizzing	N/A	N/A
30 mL Soda Water	N/A	More Vigorous Fizzing	N/A	“Slight traces of a sort of metallic scent”
45 mL Soda Water	N/A	Even More Vigorous Fizzing	N/A	“Stronger metallic scent”

This table is significant, because it provides evidence that a reaction did take place, as some physical changes, like fizzing and scent, were observed. This increases the reliability of the data obtained. The fizzing observed exhibits that there was the presence of a gaseous substance, most probably carbon dioxide, thus, the more intense the fizzing observed, the more the acidity and less the pH level. The observation of a scent omitted only in the later stages of the experiment suggests that those later stages had a more vigorous reaction.

9. DATA PROCESSING

Process #	Method of processing	Reason for processing
1	Calculate Mean/Average for each data group {Sum of Observation} ÷ {Total numbers of Observations}	The reason that I am using the processing method of calculating the mean is due to its ability of incorporating all of the data points, being succinct, and being an accurate and appropriate estimate of the entire data set, which will help us easily make sense of the data.
2	Calculate the Standard Deviation for each data group	The main reason for using this method of standard deviation is to verify the validity of the data, so that I can trust it, as the standard deviation provides a precise picture of how the data is disseminated, with extreme values having less of an impact.
3	Calculate the percent change for each	The reason I am using this method of percent change is to understand if there is a significant relationship between the variables, which is indispensable to draw a conclusion and verify which hypothesis is correct.
4	Perform an ANOVA Test and Tukey Test	The reason I am processing my data using an ANOVA Test and Tukey Test is because the test tells us if there are any statistical differences between the means of the groups tested, which, therefore, tells us if there is any significant relationship between the variables. In this sense, the ANOVA test enables us to clearly interpret our data and its meaning, and use it to deduce if the data supports the NULL or the ALT hypothesis.

#1 PROCESSED MEAN DATA TABLE	
The arithmetic average of the pH levels of 100 mL distilled water for 8 trials, 15 mL soda water + 100 mL distilled water for 8 trials, 30 mL soda water + 100 mL distilled water for 8 trials, and 45 mL soda water + 100 mL distilled water for 8 trials, each	
100 mL Distilled Water	(5.65 + 6.52 + 6.66 + 6.58 + 6.62 + 6.71 + 6.72 + 6.92) / (8) = **6.5475**
100 mL Distilled Water + 15 mL Soda Water	(5.70 + 5.74 + 5.74 + 5.79 + 5.59 + 5.68 + 5.65 + 5.80) / (8) = **5.7113**
100 mL Distilled Water + 30 mL Soda Water	(5.62 + 5.72 + 5.82 + 5.79 + 5.86 + 5.66 + 5.74 + 5.60) / (8) = **5.7263**
100 mL Distilled Water + 45 mL Soda Water	(5.62 + 5.71 + 5.90 + 5.72 + 5.67 + 5.70 + 5.55 + 5.70) / (8) = **5.6963**

This table's showcase of how the average pH for distilled water is very close to neutral, and how the pH decreases for 100 mL distilled water + 15 mL soda water, but increases for 100 mL + 30 mL, to then decrease again for 100 mL + 45 mL, is extremely significant, as it shows that the alternative hypothesis may not be valid, because the values have not decreased continuously, they have actually also increased once. This table may also suggest that the NULL hypothesis may be valid, as the values for the averages of the trials where there is an addition of soda water are very close to each other and do not have a significant difference. However, this can not be deduced with full certainty, as there is a significant difference between the test for 0 mL of soda water when compared to the other tests.

#2 PROCESSED STANDARD DEVIATION DATA TABLE	
The standard deviation of the pH levels of 100 mL distilled water for 8 trials, 15 mL soda water + 100 mL distilled water for 8 trials, 30 mL soda water + 100 mL distilled water for 8 trials, and 45 mL soda water + 100 mL distilled water for 8 trials, each	
100 mL Distilled Water	$\sqrt{(\Sigma(x_i - 6.5475) \div 8}$ = **0.3818**
100 mL Distilled Water + 15 mL Soda Water	$\sqrt{(\Sigma(x_i - 5.7113) \div 8}$ = **0.071**
100 mL Distilled Water + 30 mL Soda Water	(5.62 + 5.72 + 5.82 + 5.79 + 5.86 + 5.66 + 5.74 + 5.60) / (8) = **0.0946**
100 mL Distilled Water + 45 mL Soda Water	(5.62 + 5.71 + 5.90 + 5.72 + 5.67 + 5.70 + 5.55 + 5.70) / (8) = **0.1001**

This table's exhibition that overall the standard deviation of the data is very minute shows that the data is reliable and verifies its validity, because a low standard deviation shows that the data are clustered closely around the mean. This means that the data gathered can be trusted and can be used to draw accurate and credible conclusions.

#3 PROCESSED PERCENT CHANGE DATA TABLE	
The percent change between the averages of the pH levels of 100 mL distilled water (A), 15 mL soda water + 100 mL distilled water (B), 30 mL soda water + 100 mL distilled water (C), and 45 mL soda water + 100 mL distilled water (D), each	
AB	((5.7113 – 6.5475) / 6.5475) × 100 = **~12.77% decrease**
BC	((5.7263 – 5.7113) / 5.7113) × 100 = **~0.2626% increase**
CD	((5.6963 – 5.7263) / 5.7263) × 100 = **~0.5239% decrease**
AD	((5.6963 – 5.7113) / 5.7113) × 100 = **~0.2626% decrease**

This table's exemplification of a high percent change between 100 mL DW and 100 mL DW + 15 mL SW shows that there is a change in pH and that soda water as an impurity makes pure water acidic. However, the very minute percent change from 100 mL DW to 100 mL DW + 45 mL DW shows that the predictions of a gradual decrease, and the 45 mL added solution being the most acidic may not have been very accurate.

#4 PROCESSED ANOVA DATA TABLE

The results of performing an ANOVA Test and Tukey Test on the data gathered in the form of the p-value

Summary of Data						
	Treatments					
	1	2	3	4	5	Total
N	8	8	8	8		32
$\sum X$	52.38	45.69	45.81	45.57		189.45
Mean	6.5475	5.7113	5.7263	5.6963		5.92
$\sum X^2$	343.9782	260.9823	262.3821	259.6483		1126.9909
Std.Dev.	0.3818	0.071	0.0946	0.1001		0.4169

Pairwise Comparisons		$HSD_{.05} = 0.2812$ $HSD_{.01} = 0.3518$	$Q_{.05} = 3.8612$ $Q_{.01} = 4.8296$
T_1:T_2	$M_1 = 6.55$ $M_2 = 5.71$	0.84	$Q = 11.48$ ($p = .00000$)
T_1:T_3	$M_1 = 6.55$ $M_3 = 5.73$	0.82	$Q = 11.28$ ($p = .00000$)
T_1:T_4	$M_1 = 6.55$ $M_4 = 5.70$	0.85	$Q = 11.69$ ($p = .00000$)
T_2:T_3	$M_2 = 5.71$ $M_3 = 5.73$	0.02	$Q = 0.21$ ($p = .99887$)
T_2:T_4	$M_2 = 5.71$ $M_4 = 5.70$	0.01	$Q = 0.21$ ($p = .99887$)
T_3:T_4	$M_3 = 5.73$ $M_4 = 5.70$	0.03	$Q = 0.41$ ($p = .99120$)

Result Details				
Source	*SS*	*df*	*MS*	
Between-treatments	4.1995	3	1.3998	$F = 32.98668$
Within-treatments	1.1882	28	0.0424	
Total	5.3877	31		

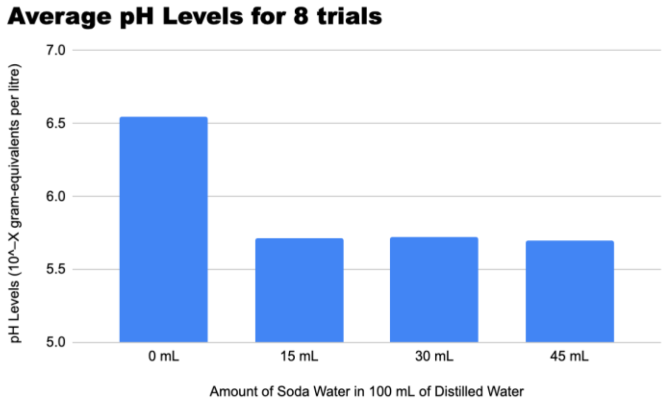
The *f*-ratio value is 32.98668. The *p*-value is < .00001. The result is significant at $p < .05$.

The p-value is below 0.00001

This table's showcase of the p-value being considerable below 0.05, with a value less than 0.00001, conveys that there is a sound statistical relationship between the data values, and the Alternative hypothesis is supported. Furthermore, the slight inconsistency between the results of this test compared with previous ones, which showed that there was not a very statistically significant relationship between the two variables, can be understood through the results of the Tukey test. The test shows that when the 0 mL test is compared with the other three tests, the results show an extremely significant relationship between the variables, but when the 15 mL, 30 mL and 45 mL tests are compared amongst themselves, the results show that there is no statistically significant relationship between the variables.

Graph of Processed Data

The graph I chose to represent my processed data is a bar chart, which will graphically display the averages. The reason for this choice was that my data is not continuous, it is as numbers which correspond with categories. Therefore, a bar chart was the perfect fit, as it shows each data category in a frequency distribution, proportionally displays multiple categories, visually summarizes an extensive data set, and identifies and clarifies trends amongst them. Meaning that it will easily let me perceive if the pH level decreased and the acidity increased gradually with the increase of the addition of soda water, and apply my learnings to validate the hypotheses.



(Fig. 1, Graph by Author, *Average pH Levels for 8 trials*)

This graph displays that the acidity increases with the addition of soda water, as the pH decreases. However, there is not a lot of change between the tested groups, the graph almost stabilized after the initial decrease.

10. CONCLUSION

10.1 DISCUSSION

The research question I investigated was: How does the presence of 15 mL, 30 mL and 45 mL of soda water as an impurity affect the pH level of pure, distilled water? The trends in the data I obtained through the performed experiments answered this Research Question, as they conveyed that there is a significant relationship between the two variables, because soda water as an impurity decreases the pH level of pure water from ~7, thus making it acidic. Even though there was not a considerable change in the pH levels between the results of the tested groups, 15 mL, 30 mL and 45 mL of soda water, there were very significant changes between the results of each of these values and those of 0 mL of soda water, the control group. Therefore, it can be concluded that the Alternative hypothesis is supported and validated, while the NULL hypothesis is not. This is evident in the p-value of less than 0.00001 obtained from the ANOVA Test, which clearly highlights the extremely significant relationship between the two variables. This is further supported by the ~12.77% change between the pH of the 0 mL test and that of the 15 mL test, which the bar graph also graphically represents, with the first bar of 0 mL being considerably higher than the bars of the other tested groups. This is evident in the raw quantitative data, as well, which shows how the values of the control group are centered around 6.5, which is considerably more than the values of the tested groups, which are all below 5.91, the mean more specifically exemplifies that the averages of the tested groups are all around ~5.7. The Alternative hypothesis is also supported by my qualitative observations, which clearly show that reactions of increasing intensity took place between the soda water and distilled water, as the vigorousness of fizzing and the intensity of the metallic scent omitted increased with an increase in the amount of soda water added. However, some aspects of the data and the data processing are inconsistent with these results, such as the heights of the tested groups, 15 mL, 30 mL and 45 mL being almost equal to each other in the bar graph; the means of the tested group all being almost the same at around ~5.7; the very minute percent changes between the tested groups, with the highest being only ~0.5%. This inconsistency can be explained by the results of the Tukey test, which show that when the control group is compared with the tested groups, the results show an extremely significant relationship between the variables, but when the control groups are compared amongst themselves, there is no significant relationship found between the variables at all. This is supported by science, as for experiments with pH, the data tends to level off and become stable around the pH level of the acidic substance–as very clearly seen in the graph after the initial decrease in the results of 0 mL to 15 mL–which, in this case, is around 5.5 on the pH scale [6]. This is why there was not a significant change observed amongst the tested groups, unlike the control group vs the tested groups. Furthermore, the alternative hypothesis and the trends in my data and findings can be validated using my scientific research: when acidic soda water is added to neutral distilled water as an impurity, the pH of the pure water decreases due to the presence of dissolved carbon dioxide [7] and carbonic acid in soda water, which are what make soda water acidic [10]. As soda water diffuses throughout the pure water, these substances dissolve, too, and decrease the overall pH level of the solution based on the amount of soda water in the solution, i.e. the amount of carbonic acid and dissolved CO_2. Therefore, to conclude, the data obtained from the experiments conducted to investigate how soda as an impurity affects pure water conveys that there is a significant relationship between the two variables and supports the Alternative hypothesis, as the p-value is considerably below 0.05, there are large percentage changes between the values of the control group and the tested groups, the bar graph clearly shows that the pH has been affected and there is a change, and the intensity of the qualitative, physical changes increases.

10.2 EVALUATION

My method and data are validated, because I have tested for the standard deviation as part of the data processing, which exhibits that this data can be relied upon, as the standard deviation values are extremely low, with the highest value being a mere 0.3818. This shows that the data is not very disseminated and is clustered around the mean. This lowers the chance of anomalies that can disproportionately skew the data, and shows that it is reliable and consistent and very accurate. My IV range was that I tested for 0 mL, 15 mL, 30 mL and 45 mL of soda water with 8 trials for each. This gives me 32 degrees of statistical freedom, further showing that the data collected is reliable, useful and accurate. Furthermore, as previously mentioned in the conclusion, the ANOVA Test performed on the data shows that there is a statistically significant relationship between the variables, with the p-value of <0.00001 being considerably below 0.05. However, the Tukey test shows that there is a statistically significant relationship between the variables when the control group is compared with the tested groups, but there is no relationship when the tested groups are compared amongst each other. This is why a very small minority of my data inconsistently seems to support the NULL hypothesis, while most of it supports the ALT. Overall, though, the Alternative hypothesis is acceptable.

10.3 SOURCES OF ERROR

Error	**Description of Significance (identify as low, moderate, high)**	**Improvement**
The volume of the solution is increasing as more soda water is added	The pH of an acidic solution increases with an increase in volume. This suggests that because the volume increased when more soda water was added, and because soda water is acidic, the pH would have increased unjustifiably, which makes the experiment inequitable. Therefore, this error is of high significance, as it directly changes the data we obtained, thus, changing the conclusion we drew.	This can be improved by keeping the volume constant/controlling it, because we would still be able to investigate the research question, form conclusions, and that too more accurately.
We used intervals of 0 mL, 15 mL, 30 mL and 45 mL, which upon looking at the data and results and looking back, may have been too little and not enough	This error is of moderate to high significance, as the small size of the intervals makes some of the tests insignificant, as there is not a lot of change between the results at all. This hinders our ability to explore properly the relationship of the two variables, and thus to answer the research question thoroughly accurately and in a fool-proof way.	This can be improved by using bigger intervals in the experiment, such as 0 mL, 30 mL, 60 mL and 90 mL, which would have allowed us to observe the changes more profoundly, on a larger scale.
The method did not include the cleaning of the pH sensor stick between tests.	This error is of high significance because substances can accumulate on the electrode, which can lead to faulty readings, which heavily decrease the reliability and credibility of the data obtained, as it may be inaccurate due to the lack of cleaning. Therefore, suggesting that the derived conclusion may also be inaccurate, and the experiment may need to be restarted.	This can be improved by properly cleaning the pH electrode using a pH electrode cleaning solution between every trial/test.
The pH sensor stick was not set to exactly 7.00, we did not ZERO the probe before every test using the ZERO OFFSET, STANDARDIZED or SET knobs	This error suggests that the pH sensor was not properly calibrated before every test, which is an error of high significance, as without calibration, the pH meter has no way of determining the pH value of the substance being tested. This hinders the accuracy and credibility of all our data values, because they may not all be calibrated, which means we cannot trust them, as they may be inaccurate. Therefore, decreasing the reliability and credibility of our conclusion and evaluation.	This can be improved by making sure to set the sensor to exactly 7.00 using the ZERO OFFSET, STANDARDIZED or SET knobs, and then using a second buffer for fool-proof accuracy.
Pouring the soda water in an arbitrary, indefinite, careless way	Soda water is acidic because it has the Carbon Dioxide gas trapped inside. As soon as a container of soda water is opened, the gas starts escaping, which happens even more so when it is being poured. Therefore, due to the lack of a definite procedure of pouring the soda water, and due to it being poured twice, once in the measuring cylinder and once in the beaker, a lot of the gas may have escaped, which	This can be improved in multiple ways, such as creating a definite way of pouring which minimizes gas release–touching the pouring side of the soda container to the measuring cylinder, tilting it, and then slowly pouring it. Then, without any delay, doing the same with the measuring cylinder and the beaker. Another way

	means that the pH would have become closer to neutral and acidity would have decreased. This error is of high significance, because this means that our data may be inaccurate, which in turn means that the conclusions we have formed are not very reliable, and the research question cannot be answered with a lot of certainty.	is to use a carbonator to add carbon dioxide to the designated sample of pure, distilled water directly into the measuring cylinder making the pouring process only one step, then seal it, and then pour the carbonated soda water into the beaker where distilled water is present to do the test.

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