CHEMISTRY LAB REPORT ON ENTHALPY OF NEUTRALIZATION

Research question: How to investigate and compare the strength of 1 Molar of three acids namely hydrochloric acid (HCl), acetic acid (CH_3COOH), and nitric acid (HNO_3) by measuring their respective enthalpies of neutralization by calculating the temperature difference upon their reaction with 1 Molar of aqueous sodium hydroxide (NaOH) over a specific time period?

Hypothesis: According to former primary and secondary research, strength of acids is directly correlated to their enthalpy of neutralization with a constant base. The stronger the acid, the greater the amount of heat evolved from the reaction i.e. the enthalpy of neutralization. It is hypothecated that the acids, in terms of increasing enthalpies of neutralization with sodium hydroxide, are hydrochloric acid (HCl) followed by nitric acid (HNO_3) followed by acetic acid (CH_3COOH) if other external factors viz. temperature, pressure, and the measuring instrument are controlled. Hence, hydrochloric acid (HCl) should have the greatest strength (be the most acidic in nature) followed by nitric acid (HNO_3) followed by acetic acid (CH_3COOH).

Background information: The strength of an acid refers to the ease with which the acid loses a proton. A strong acid[1] ionizes completely in an aqueous solution by losing one proton.

The standard enthalpy change of neutralization[9] is the enthalpy change when solutions of an acid and an alkali react together under standard conditions to produce 1 mole of water. Notice that enthalpy change of neutralization is always measured per mole of water formed. Enthalpy changes of neutralization are always negative - heat is released when an acid and alkali react.

We make the assumption that strong acids[8] and strong alkalis are fully ionized in solution, and that the ions behave independently of each other. For example, dilute hydrochloric acid contains hydrogen ions and chloride ions in solution. Sodium hydroxide solution consists of sodium ions and hydroxide ions in solution. The equation for any strong acid being neutralized by a strong alkali is essentially just a reaction between hydrogen ions and hydroxide ions to make water. The other ions present (sodium and chloride, for example) are just spectator ions, taking no part in the reaction.

Therefore, these explained processes were used to measure and compare the acidic strength of hydrochloric acid (HCl), acetic acid (CH3COOH), and nitric acid (HNO3) by measuring their respective enthalpies of neutralization.

Variables: There was 1 independent variable, 1 dependent variable, and 5 controlled variables in this experiment:

- Independent – The three tested acids namely hydrochloric acid (HCl), nitric acid (HNO_3), and acetic acid (CH_3COOH). Their inclusion differentiated other factors in the experiment.
- Dependent – The temperature of the acids measured through a digital thermometer across a predetermined time period. These measurements were ultimately used to measure the rate at which temperature increased and thereby the relative enthalpy of neutralization of the acid.

- Controlled – Temperature in the lab, atmospheric pressure in the lab, the volume of the acids, the concentration of the acids, the digital thermometer, 4 x 100 cm^3 graduated beakers.

Apparatus:

- 30 cm^3 of 1M (Molarity indicator) Hydrochloric Acid (HCl), 1M Nitric Acid (HNO_3), and 1M Acetic Acid (CH_3COOH)
- 4 g of Sodium Hydroxide (NaOH) crystals
- 100 mL distilled water
- 4 x 100 cm^3 beakers with minuscule uncertainties
- 1 Digital thermometer (± 0.1 °C)
- 1 Digital balance (± 0.01 g)
- 1 Digital stopwatch (± 0.01 s)
- 1 Laptop
- 1 Spatula
- 1 Hollow wooden box with a hollow lid to isolate the measured system

Method:

1. Measure 4 grams of sodium hydroxide (NaOH) crystals on a digital balance using a standard lab spatula
2. Pour 100 mL distilled water and the crystals in a 100 cm^3 glass beaker and stir till the required 1M sodium hydroxide (NaOH) solution is formed.
3. Pour 10 cm^3 of 1M hydrochloric acid and 10 cm^3 of 1M sodium hydroxide (NaOH) solution in another 100 cm^3 glass beaker
4. Place the beaker inside the wooden box and insert the digital thermometer immediately after putting the hollow lid over the box
5. Record the initial temperature and note the temperature every 30 seconds (using the digital stopwatch) till it doesn't change for two consecutive time intervals i.e. 1 minute
6. Repeat steps 3-6 to measure 2 more trials by measuring the temperature change from the neutralization reaction
7. Repeat steps 3-7 for 30 cm^3 1M nitric acid (HNO_3) and 30 cm^3 1M acetic acid (CH_3COOH) (Choosing a set volume of the liquid is the experimenter's prerogative, however it is recommended to maintain the mentioned volume across selected acids)

Safety, Ethical and Environmental Aspects:

- **Safety –**
    - Hand gloves, lab goggles, lab coat, and face mask should be worn since the acids give out a pungent aroma. Long hair should be tied. These are general lab measures to prevent major chemical dangers. Liquid specific measures are explained below.
    - Hydrochloric acid[2] acts as a corrosive and its concentrated forms release acidic mists that hazardous. If the acid or mist comes into contact with the body by entering through the skin, eyes, or internal organs, the damage can be irreversible or even fatal in severe cases. Hence, a certain distance should be maintained from the acid.
    - Nitric acid[3] is also a corrosive acid capable of causing severe chemical burns very rapidly. If nitric acid mists are inhaled, health risks include corrosion of

mucous membranes, delayed pulmonary edema, and even death. Contact with eyes can cause permanent cornea damage. In addition, if ingested, nitric acid can produce severe, rapid corrosive burns of the mouth, throat and gastrointestinal tract. This chemical is also a strong oxidizer capable of causing fires if it comes in contact with organic material, hence should be treated while wearing a mask.

- Acetic acid[4] can be a hazardous chemical if not used in a safe and appropriate manner. This liquid is highly corrosive to the skin and eyes and, because of this, must be handled with extreme care. Acetic acid can also be damaging to the internal organs if ingested or in the case of vapour inhalation. PPE (personal protective equipment) should therefore be used while handling this chemical in an undiluted state.
- Sodium hydroxide[5] can also be corrosive. Sometimes, eye contact causes severe burns with redness, swelling, pain and blurred vision. Permanent damage including blindness can result from this as well. Its ingestion via skin, nose, or mouth can burn the lips, tongue, throat and stomach. Symptoms may include nausea, vomiting, stomach cramps and diarrhoea. Hence, a face mask should be worn while working with this base.

- **Ethical –** Wastage of residual acids and the base is ethically immoral. This can be improved by accurately calculating the required volume and thereafter measuring that amount of acid or base for the experiment. Submitting the glass beakers with residues of acids or bases stuck on their inner surfaces at the end of the experiment is unfavourable. This can be prevented by rinsing and drying the beakers with tissue papers at the end. Usage of more apparatuses viz. 3 graduated beakers for faster measurements is also ethically wrong considering the limitation and time spent by the chemistry lab officials for cleaning and rearranging them. This could be improved by cleaning the same beaker with distilled water before transferring another acid.
- **Environmental –** All the three acids and the base should be disposed of safely as they are chemically and environmentally hazardous, as elaborated above.

Observations: There were few qualitative observations made in this prescribed experiment. Since temperature is a part of the surrounding and we measured it, we observed an increase in temperature while the actual enthalpy change is negative/exothermic (for the system). We observed the colour of the sodium hydroxide solution change from cloudy (when the crystals were added) to colourless (when they complete dissolved in the solvent). Since we crushed the crystals before adding them, they dissolved faster, owing to the faster rate of reaction. Although all three acids were pungent, acetic acid had the strongest pungency (due to being a weak acid) and had to be operated while wearing a face mask. Relatively being the strongest acid, hydrochloric acid had stronger intermolecular forces and was hence more adhesive to the beaker. All three acids provided different time periods for temperature changes. Hence, after the first trial of the second acid, we measured the temperature changes for the other trials of acids for five minutes, irrespective of whether the temperature stopped changing earlier or later. Due to this, we observed systematic discrepancies in our temperature values for one out of the three trials for every acid. Also, due to the fans being on in the chemistry lab and the hollow wooden lid not completely covering the beaker, the temperature measurements were affected, thereby increasing systematic errors[7] and reducing the values' accuracy.

First set of measured data (the temperature values are expressed in degree Celsius):

Name of Acid	Initial temperature 1	Final temperature 1	Initial temperature 2	Final temperature 2	Initial Temperature 3	Final temperature 3
Hydrochloric Acid (HCl)	25.0	28.2	26.3	28.9	26.0	28.1
Nitric Acid (HNO_3)	25.0	28.1	24.0	27.2	24.2	28.5
Acetic Acid (CH_3COOH)	24.5	25.6	24.3	26.6	24.2	26.7

Table 1: First set of measured temperature values

Calculation and error propagation (The final values are in accordance with the significant figures and decimal points rules. For the final error, one significant figure has been used):

The neutralisation reactions have been enlisted below:

1. $HCl\ (aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$ (hydrochloric acid)

2. $HNO_3\ (aq) + NaOH\ (aq) \rightarrow NaNO_3(aq) + H_2O(aq)$ (nitric acid)

3. $CH_3COOH\ (aq) + NaOH\ (aq) \rightarrow CH_3COONa\ (aq) + H_2O\ (aq)$ (acetic acid)

Uncertainties: When we add or subtract values, absolute uncertainties get added. When we multiply or divide values, relative (percentage) uncertainties get added. These uncertainties get added even when we associate an integer with them in an operation. All the operations are performed arithmetically. To maintain consistency and coherence in the results, absolute uncertainties have been considered for all temperature values and percentage errors have been calculated to five decimal places.

Category	Absolute Uncertainties (±)
Digital thermometer	0.1°C
Digital Stopwatch	0.01 s
Digital Balance	0.01 g

Table 2: Raw data of uncertainties

$$Percentage\ Uncertainty = \frac{Uncertainity\ of\ Instrument}{Average\ Volume\ Measured} \times 100$$

$Q = mc\Delta T$, where Q is the amount of heat/thermal energy liberated (change in enthalpy), m is the mass of the reactants, c is the specific heat capacity of water $(4.18\ KJ\ Kg^{-1}K^{-1})$, and ΔT is the change in temperature in Kelvin or Centigrade.

The total mass of the acid and base for every trial (after the volume-mass conversions) $= 10.00 + (10.00 \pm 0.01) = 20.00 \pm 0.01\ g = 0.02000 \pm 0.00001\ kg$

Percentage uncertainty for the mass $= \frac{0.00001}{0.02000} * 100 = 0.05\%$

For the 10 cm^3 1M Hydrochloric acid:

Average temperature difference for trials (ΔT) - $\frac{((28.2\pm0.1)-(25.0\pm0.1))+((28.9\pm0.1)-(26.3\pm0.1))+((28.1\pm0.1)-(26.0\pm0.1))}{3} = \frac{(3.2\pm0.2)+(2.6\pm0.2)+(2.1\pm0.2)}{3} = \frac{7.9\pm0.6}{3} \approx 2.6 \pm 0.2℃$

Percentage uncertainty for the temperature change $= \frac{0.2}{2.6} * 100 \approx 7.7\%$

Therefore, $Q = (0.02 \pm 0.05\%) * (4.18) * (2.6 \pm 7.7\%) = 0.21736 \pm 7.75\%$

Since $\frac{7.75*0.21736}{100} = 0.0168454$, $Q = 0.21736 \pm 0.0168454 \approx 0.22 \pm 0.02\ KJ$

$Number\ of\ Moles = \ Concentration \times Volume$

10 cm^3 of hydrochloric acid[6] $= \frac{10}{1000} = 0.01 dm^3$

Therefore, for hydrochloric acid, $Number\ of\ Moles = \ 0.01 * 1 = 0.01\ mol$

Since approximately $220\ J$ of thermal energy was produced using $0.01\ mol$ of hydrochloric acid, its molar enthalpy $= \frac{(0.22\pm0.02)}{0.01} = 22 \pm 2\ KJmol^{-1}$

This calculation and conclusion process was used for nitric acid and acetic acid as well.

Process data table:

Name Of The Acid (10 cm^3) (1M)	Temperature difference (°C)	Change in enthalpy of neutralization (KJ)	Change in Molar enthalpy of neutralization (KJ mol^{-1})
Hydrochloric Acid	2.6 ± 0.2	0.22 ± 0.02	22 ± 2
Nitric Acid	3.5 ± 0.2	0.29 ± 0.02	29 ± 2
Acetic Acid	2.0 ± 0.2	0.17 ± 0.02	17 ± 2

Table 3: Process data of tested acids

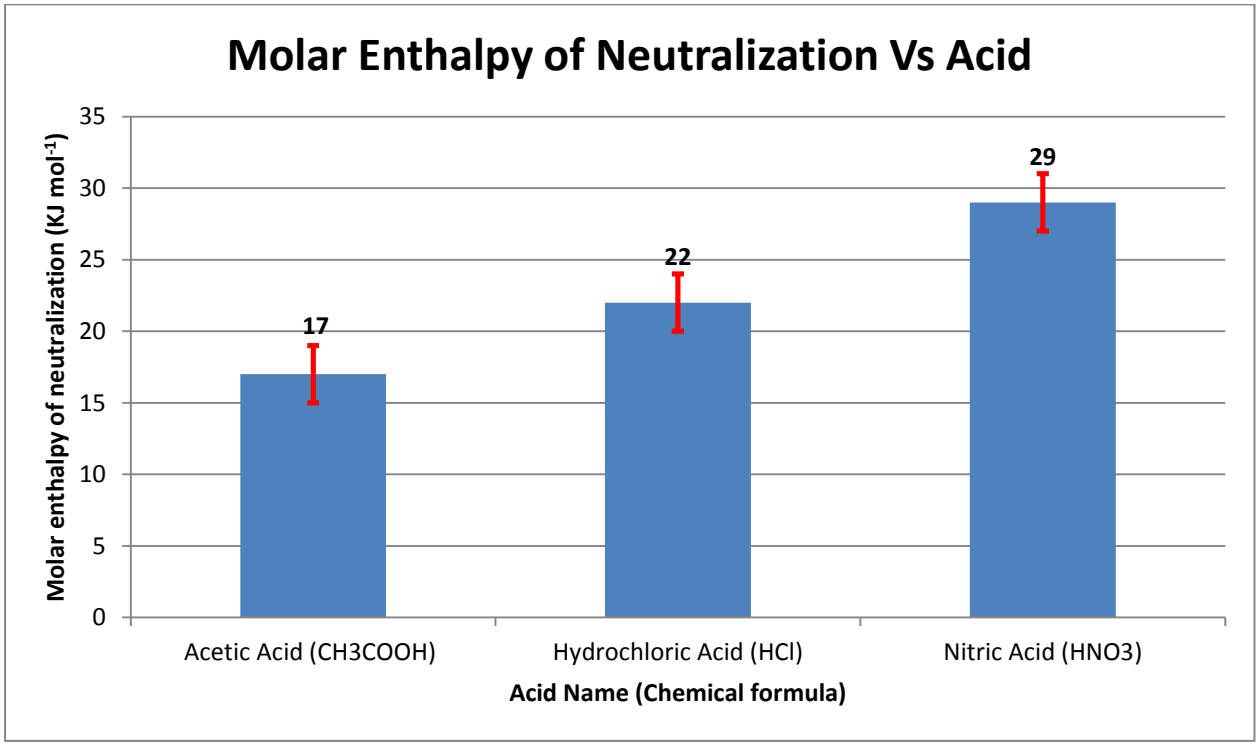
Graph:

As covered in the background information, the strength of an acid depends on its enthalpy of neutralization with a constant base. As the temperature difference at the end of the reaction increases, the amount of heat energy evolved from the reaction (enthalpy of neutralization)

increases. This indicates that the acid can relatively easily donate a proton and thus facilitate a more vigorous reaction.

Hence, a bar graph is plotted below - it shows the molar enthalpy of neutralization with respect to the tested acid. The bar graph is helpful in analysing the enthalpy and therefore the strength of the respective acid.

Through the incremental change in enthalpy of neutralization, it can be deduced that greater the magnitude, stronger is the acid. Also, an important graphical observation is the approximately equal relationship between the enthalpy of neutralization and magnitude of error percentage.



Graph 1: Bar graph of Molar Enthalpy of Neutralization Vs Acid

Conclusion: We observed higher levels of precision after taking more trials for every colour. Certain random errors may have been incorporated to the results since, in order to save time, one of us operated the thermometer and the acid-base beakers while the other noted the time, temperature values, and reset the apparatus after every trial. There may have been some systematic errors in some results, especially for the trials under nitric acid (which disrupted the trend). This may have happened due to the inability of completely drying the beakers before re-measuring the values, keeping the fan on during the experiment, leaving the lab during two trials of nitric acid neutralisation and subsequently failing to note the accurate final temperature, and using a digital thermometer that had been calibrated wrong, resulting in great standard deviances in the trial values and greater inaccuracy. However, since all the erroneous values were less than the literature value expected, it qualified under a systematic error. Apart from that and specific to the measured temperatures, the percentage uncertainties of the rate of increase were minuscule relative to all experiments done in the past which makes this an astute experiment to compare and measure the strength of an acid under the realm of thermochemistry.

Through the graph, we observed that the nitric acid is relatively the strongest in nature since it had the greatest change in the enthalpy of neutralization (29kJ) while hydrochloric acid had a moderate change (19 kJ) and acetic acid had the lowest change (17kJ) which makes it relatively, the weakest acid. Although the absolute errors have been rounded off to the same value (in accordance with the significant figures rules), they decrease as the molar mass of the compound increases (0.0168454 for HCl, 0.0168245 for HNO_3, and 0.0168036 for CH_3COOH). Hence, heavier the molecule, more accurate is its final enthalpy of neutralization value. This may be due to stronger intermolecular forces in those molecules that may reduce the chance of them donating protons easily and creating discrepancies in the result. Hence, they have lower enthalpy values along with lower standard deviation values. Also, the difference in the enthalpy of neutralization between acids with higher strength increases except including nitric acid, which breaks the trend. After comparing the trends and finding direct relationships between the variables, based on our experiment, nitric acid is the strongest acid followed by hydrochloric acid followed by acetic acid.

Reflection on Hypothesis: The qualitative conclusions given above indirectly support the hypothesis but the quantitative conclusions do not support the hypothesis. The measured and stated values are direct evidences to support this statement

Overall Reflection: We could successfully evaluate the change in enthalpy of neutralization for all 3 acids using simple, economical apparatuses viz. wooden box, digital thermometer, digital stopwatch, and glass beakers. Each one of us took at least 1 trial per acid and around 4 trials in total. We made some intrinsic qualitative and quantitative observations and calculated the average percentage uncertainties associated with the change in enthalpy of neutralization. Thereafter, we observed and analysed trends between the general change in enthalpy, molar change in enthalpy and the strength of the acid. This correlation helped us find loopholes that ought to be corrected to verify our hypothesis.

We could have modified the experiment by rinsing the beakers thoroughly after each trial with distilled water/tissue papers or put it over a Bunsen burner to evaporate the residual liquid. Since we had to handle more apparatuses (such as measuring temperatures while noting the time and adjusting the apparatus) among lesser people, we increased the inaccuracy of the results. We could have used a single beaker instead of three different beakers for conducting the reaction and could have rinsed it with the next acid to be tested so that it isn't cohesive to the glass surface when it comes into contact during the neutralisation process. We could have also used vegetable oil or a wet wire brush to remove the residue after all the trials to improve the environmental and ethical aspects of our experiment. Quite standardly otherwise, we could have taken more readings, bettered our reaction time (for the digital stopwatch), used a data logger for temperature rather than an inexpensive digital thermometer and could have noted all readings without rounding off the data values to reduce the random and systematic errors of the experiment.

Due to the time crunch, we could think efficiently and come up with this creative, economical experiment. We honed our time management, prioritization, and self-management skills in the process since we had to judiciously take time in breaks and compromise on socializing with friends to complete the experiment. Due to these skills, we were among the first groups to complete the experiment in time and successfully leave space for writing the lab report. We incorporated and developed several IB learner profiles during this time such as being

balanced, knowledgeable, risk-takers, communication, inquirers, reflective, thinkers, and open-minded.

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