Proceedings of the Iowa Academy of Science

Volume 71 | Annual Issue Article 69

1964

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Recommended Citation
Troxel, Verne A. (1964) "The Use of a Thermochemical Experiment in an Introductory Science Class," *Proceedings of the Iowa Academy of Science*: Vol. 71: No. 1 , Article 69.
Available at: https://scholarworks.uni.edu/pias/vol71/iss1/69

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Troxel: The Use of a Thermochemical Experiment in an Introductory Science

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The Use of a Thermochemical Experiment in an Introductory Science Class

VERNE A. TROXEL[1]

Abstract. An experimental method for determining heat of neutralization, in introductory science classes, with simple laboratory equipment is described. Measured values for heat of neutralization determined by this method are compared with the literature values. The experimental method used offers a suitable means for the determination of heat of neutralization.

The purpose of this investigation was to determine a simple experimental method by which the heat of neutralization of various acids and bases can be determined by persons in introductory science classes.

In the study of energy relationships of reacting substances one often finds theory which is difficult and mathematics which is beyond the scope of the student in the introductory science class. Because of these problems, very little has been done to set forth a clear understanding of these relationships for the student with a limited scientific education.

The basic reaction of neutralization has been known for some time. The reaction may be represented by ionic equations:

$$HA \rightarrow H^+ + A^-$$

$$BOH \rightarrow OH^- + B^+$$

$$H_2O + B^+ + A^- + \text{Energy}$$

If at the beginning of the reaction the acid and base are highly ionized, the only chemical reaction is:

$$H^+ + OH^- \rightarrow H_2O$$

EQUIPMENT

Simple and inexpensive equipment was needed for these experiments. A triple beam balance accurate to 0.01 gram was used

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Published by UNI ScholarWorks, 1964

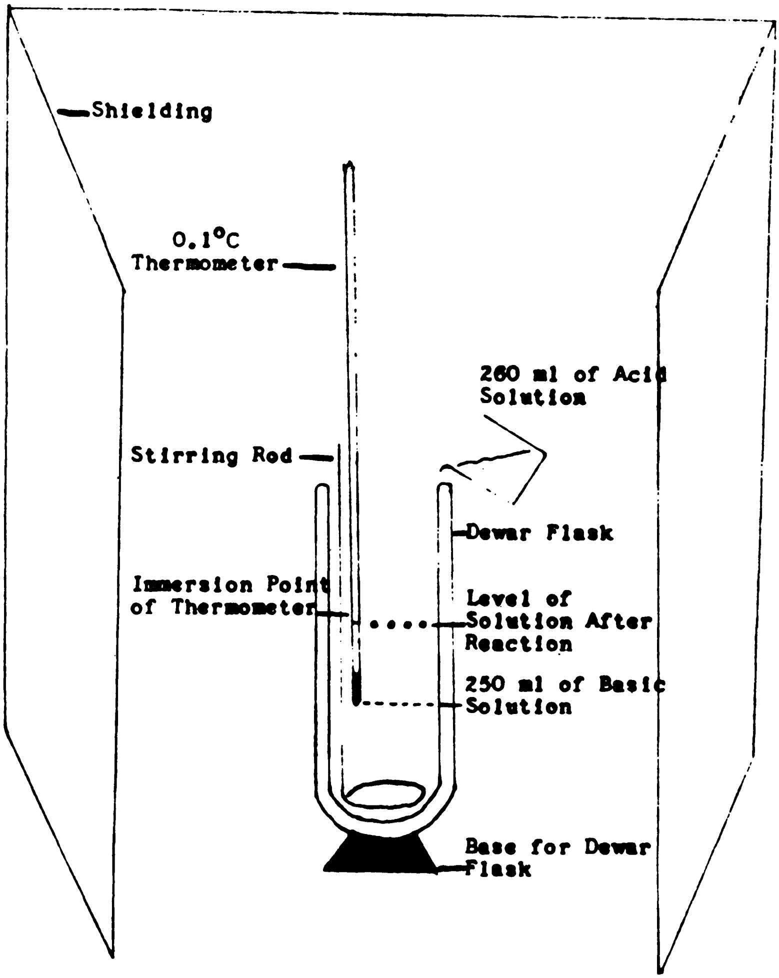

Figure 1. Experimental apparatus.

for weighing solids in the preparation of the standard solutions. Additional equipment included beakers, a one quart dewar flask, a 0.1°C thermometer, a stirring rod, and shielding if possible. The experimental apparatus is shown in figure one.

Investigative Procedures

Once the solutions have been prepared the following procedure may be carried out in a rather short time.

250 ml of 0.50 N (1.0 N) base is run into a dry calorimeter (dewar flask). In a 400 ml beaker which has been previously rinsed with the same acid solution, 260 ml of 0.50 N (1.0 N) acid is added to the calorimeter. Since the volume of the acid

is slightly greater than the volume of the base there is more than enough acid to neutralize the base. The exact amount of extra acid is not important except as it effects the heat capacity of the solution. Both solutions are placed in a 25°C water bath until they reach a constant temperature. The temperatures are measured by thermometers which are measured in tenth of a degree. After the correct temperature is reached, the acid is poured into the calorimeter containing the base. The temperature of the reaction is recorded as soon as it stabilizes. Phenolphthalein may be added to check the completion of the reaction.

The neutralizations accomplished by this technique include mixed pairs of both strong and weak acids and bases. The ones studied are as follows:

1. $K^+ + OH^- + H^+ + Cl^- \rightarrow H_2O + K^+ + Cl^-$
2. $Na^+ + OH^- + H^+ + Cl^- \rightarrow H_2O + Na^+ + Cl^-$
3. $K^+ + OH^- + H^+ + NO_3^- \rightarrow H_2O + K^+ + NO_3^-$
4. $Na^+ + OH^- + H^+ + NO_3^- \rightarrow H_2O + Na^+ + NO_3^-$
5. $Na^+ + OH^- + H^+ + F^- \rightarrow H_2O + Na^+ + F^-$
6. $K^+ + OH^- + HCN \rightarrow H_2O + K^+ + CN^-$
7. $NH_4OH + H^+ Cl^- \rightarrow H_2O + NH_4^+ + Cl^-$
8. $NH_4OH + HCN \rightarrow H_2O + NH_4^+ + CN^-$

The relative strengths of these acids and bases are seen by noting their degree of ionization or dissociation in dilute aqueous solutions, as shown in Table 1.

Table 1. Degree of Dissociation at 25°C and 0.05 N*

Hydrochloric Acid	0.86200
Nitric Acid	9.86200
Hydrocyanic Acid	0.00005
Potassium Hydroxide	0.82600
Sodium Hydroxide	0.79500
Ammonium Hydroxide	0.00680

The dissociation constant of HF is 7.2×10^{-4} when very dilute solutions are used.**

* T. M. Lowery and A. C. Cavell, *Intermediate Chemistry* (London: MacMillan and Company Ltd., 1958), p. 12.

** Adolph Norbert Lange, *Handbook of Chemistry* (Sandusky, Ohio: Handbook Publishers Inc., 1952), p. 1231.

The heat evolved during neutralization of gram equivalents of acids and bases used, as given in the literature, are as indicated in Table 2.

As indicated in Table 2, the heat of neutralization is very nearly constant for reactions between "strong" acids" and "strong" bases.

Table 2. Heats of Neutralization*

	Base	Acid	Calories
1	KOH aq.	HCl aq.	+13,695
2	NaOH aq.	HCl aq.	+13,700
3	KOH aq.	HNO_3 aq.	+13,705
4	NaOH aq.	HNO_3 aq.	+13,685
5	NaOH aq.	HF aq.	+16,400
6	KOH aq.	HCN aq.	+ 2,800
7	NH_4OH aq.	HCl aq.	+12,270
8	NH_4OH aq.	HCN aq.	+ 1,300

* T. M. Lowery and A. C. Cavell, *Intermediate Chemistry* (London: MacMillan and Co. Ltd., 1958), p. 552.

Treatment of Data

The treatment of data in determining the heat of neutralization may be performed in a variety of ways. However, with the equipment used a very rigorous calculation is not practical. The solution arrived at for determining the heat of neutralization of the reactions studied is as follows.

Equation 1

$$H\ \frac{Cal}{\text{g-eq}} = \frac{M_1 \times S_1 \times (t + .4)}{\text{g-eq}} + M_2 \times S_2 \times t$$

H + Heat in Calories/gram-equivalent

M_1 = Mass or grams of reaction mixture

S_1 + Specific heat of the reaction mixture

t + .4 = Measured change in temperature plus a correction factor

M_2 = Weight of inner liner of calorimeter glass

S_2 = Specific heat of calorimeter glass

t = Measured change in temperature

g-eq = Gram equivalents of base neutralized

There are several values in this equation which may be considered constant.

The specific heat (S_1) of all solutions may be considered to be 1 calorie / gram / °C. The specific heat of the calorimeter (S_2) is 0.19 calorie / gram/°C. 250 ml of base and 260 ml of acid are always used. Thus the volume of the reaction mixture is a constant 510 ml. The mass of the inner liner of the calorimeter (dewar flask), M_2, is equal to 140 grams.

The resulting formula, after all constants are substituted, leaves only one unknown to be determined before the equation may be solved. This unknown is the change in temperature (t).

Equation 2

$$\frac{\text{calories}}{H\ \text{g-eq}} = \frac{510 \text{ grams} \times 1 \text{ cal./c/°C } (t + 0.4°C)}{0.125 \text{ g-eq}}$$
$$+ 140 \text{ grams} \times 0.19 \text{ cal/g/°C} \times t$$

Table 3. Comparison of Measured Value for Heat of Neutralization.

Base	Normality	Acid	Normality	Measured Value for Heat of Neutralization	Literature Value for Heat of Neutralization
KOH	0.50 N	HCl	0.50 N	13.1 K-cal/g-eq ± 0.1 K-cal/g-eq	13,695 c/g-eq
KOH	1.00 N	HCl	1.00 N	13.4	13,695
NaOH	0.50 N	HCl	0.50 N	13.1	13,700
NaOH	1.00 N	HCl	1.00 N	13.6	13,700
KOH	0.50 N	HNO_3	0.50 N	13.5	13,705
KOH	1.00 N	HNO_3	1.00 N	13.8	13,705
NaOH	0.50 N	HnO_3	0.50 N	13.1	13,685
NaOH	1.00 N	HnO_3	1.00 N	13.6	13,685
NaOH	0.50 N	HF	0.50 N	15.6	16,400
NaOH	1.00 N	HF	1.00 N	16.7	16,400
KOH	0.50 N	HCN	0.50 N	2.9	2,800
KOH	1.00 N	HCN	1.00 N	2.9	2,800
NH^4OH	0.50 N	HCl	0.50 N	11.9	12,270
NH^4OH	1.00 N	HCl	1.00 N	12.2	12,270
NH^4OH	0.50 N	HCN	0.50 N	1.2	1,300
NH^4OH	1.00 N	HCN	1.00 N	1.2 K-cal/g-eq ± 0.1 K-cal/g-eq	1,300 c/g-eq

Results are calculated accurately only to = 0.1 K-Cal

This equation is for 250 ml of 0.50 N base. If 1.0 N base is used, the number of gram-equivalents will change from 0.125 to 0.250 g-eq.

Determination of Correction Factor

During experimentation it was found that simply pouring 250 ml of 25.0°C water into the empty dewar flask caused a temperature loss of 0.8°C. This temperature loss was consistent if care was taken to duplicate the pouring technique of succeeding tries. This means that each temperature reading is 0.4°C lower than it should be. The value is only 0.4°C lower because the other volume of the solution already contained in the dewar flask does not have a decrease in temperature.

The results of the experimentation show a reasonable degree of accuracy in determining the heat of neutralization by using simple, inexpensive equipment, provided care is taken during the experimentation. These results are indicated in Table 3.

Statistical Analysis of Results

In order to test the validity of the results obtained in the heat of neutralization experiments a brief statistical analysis was made, with the results students had with the experimental method previously stated. The results of this analysis are shown in Table IV.

Table 4. Summary of Statistical Calculations

	0.50 N acid and base	1.00 N acid and base
Mean	14.0 K-cal/g-equivalent	14.0 K-cal/g-equivalent
Median	13.9 K-cal/g-equivalent	14.3 K-cal/g-equivalent
Mode	13.9 K-cal/g-equivalent	14.6 K-cal/g-equivalent
Standard Deviation	1.5 K-cal/g-equivalent	1.1 K-cal/g-equivalent

The number of experiments involved with 0.50 N acid and base were 56. The number of experiments involved with 1.0 N acid and base were 72.

From these data it is concluded that a fairly high degree of accuracy can be obtained in heats of neutralization experiments using simple equipment.

Acknowledgment

The author wishes to express his appreciation to Dr. R. R. Haun, Department of Physical Science, Drake University and Dr. F. Jacob, Department of Chemistry, Drake University, for their helpful comments and constructive criticism, in preparing this work.

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