

# INCREASE IN VOLUME

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The reaction of an acid and a base to produce a salt and water was most probably defined by Arrhenius in the first modern theory of acids and bases in 1884. When this reaction is run in the laboratory, there is an increase in volume of the resulting solution. In a search of the literature, this author could not find any article that specifically addressed this phenomenon. There is, however, a publication by Katz and Miller that examines the effects of denaturing agents on the effects of the volume changes in acid-base reactions<sup>1</sup>.

## MATERIALS NEEDED

2 volumetric flasks, 1000-mL  
volumetric flask, 2000-mL  
graduated cylinder, 25-mL or 50-mL  
food color  
water  
universal indicator  
2 M hydrochloric acid solution, HCl, (To make 1 L: measure 833 mL of water into a 1000-mL volumetric flask or larger flask or beaker. Add 167 mL of concentrated hydrochloric acid. Allow solution to cool to room temperature and adjust the final volume if necessary.)  
2 M sodium hydroxide solution, NaOH, (To make 1 L: add 80 g of sodium hydroxide to sufficient water to make 1000 mL of solution. Allow solution to cool to room temperature and adjust the final volume if necessary.)  
3 funnels, large (funnels should fit volumetric flasks)  
Bucket for waste (if no sink is available)  
optional: colored tape

## SAFETY PRECAUTIONS

Wear safety goggles while performing this experiment.

Hydrochloric acid is corrosive. In the event of contact, wash the affected areas well with water. If any irritation or burns are produced, seek qualified medical assistance. The hazard with 2 M hydrochloric acid is greatly reduced.

Sodium hydroxide is caustic. In the event of contact, wash the affected areas well with water. If any irritation or burns are produced, seek qualified medical assistance. The hazard with 2 M sodium hydroxide is greatly reduced.

This reaction will generate some heat. Take care in handling the reaction container.

## DISPOSAL

The solution produced in this experiment consists of sodium chloride, which can be safely poured down a drain with running water.

## EXPERIMENTAL PROCEDURE

To increase visibility, wrap a thin strip of colored tape around the fill line of each volumetric flask.

Fill both 1000-mL volumetric flasks with water. Add food color to each to increase visibility. (Note: use different colors for each flask such as blue and yellow which will form green on mixing.)

**Calibrate the 2000-mL volumetric flask.** Place a large funnel in the top of the 2000-mL volumetric flask and pour the water from the two 1000-mL flasks into the larger flask. (The change in color will indicate mixing.) Mark the volume of the water by placing a piece of colored tape at the water level. (NOTE: In general purpose volumetric flasks, the volume will be close to that printed on the flask, but not always accurate.)

Empty the 2000-mL flask.

**React the acid with the base.** Fill the 1000-mL flasks with 2 M HCl and with 2 M NaOH. Add some universal indicator to each and note the colors.

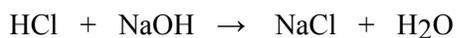


Place a large funnel in the top of the 2000-mL volumetric flask and pour the HCl and NaOH solutions into the larger flask. (The change in color will indicate mixing/reaction.) Note the volume of the solution. What is the final volume? (You can measure the final increase in volume using a graduated cylinder. Note: The volume will be slightly increased due to the warm solution. For an accurate measurement of the volume increase, allow the solution to cool to room temperature.)



## EXPLANATION

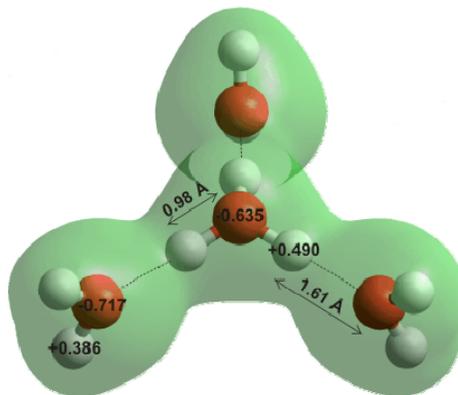
The reaction between hydrochloric acid and sodium hydroxide is:



One of the products produced is water.

Did you really make water? Yes, but by combining the  $\text{H}_3\text{O}^+$  and  $\text{OH}^-$  already in the solutions.

In water solution, hydrochloric acid ionizes to produce  $\text{H}_3\text{O}^+$  and  $\text{Cl}^-$  ions. These ions are hydrated, that is, they are surrounded by polar water molecules. The O-O bond distance between the  $\text{H}_3\text{O}^+$  and the surrounding water molecules is  $2.59\text{\AA}$  (0.259 nm).



The sodium hydroxide ionizes to produce  $\text{Na}^+$  and  $\text{OH}^-$  ions. These ions are hydrated. The O-O bond distance between the  $\text{OH}^-$  ions and the surrounding water molecules is  $2.50\text{\AA}$  (0.250 nm).

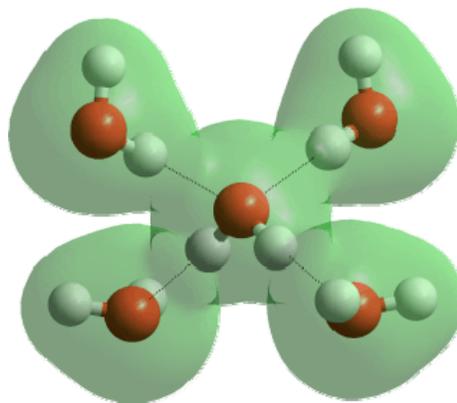
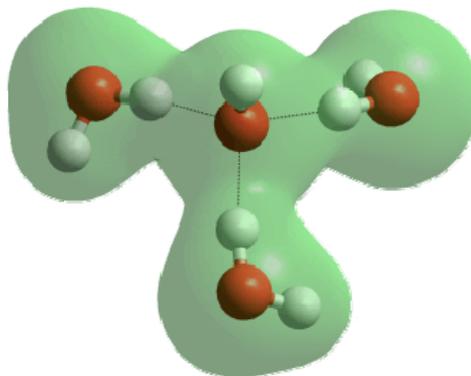
Due to the ion charge, these hydrated ion-water “clusters” take up less space than an equal number of water molecules alone.

In the reaction, the  $\text{H}^+$  and  $\text{OH}^-$  ions react to form water molecules, eliminating the corresponding ion-water “clusters”. The O-O bond distance in water is  $2.82\text{\AA}$  (0.282 nm) As a result, the normal spacing between the resulting water molecules produces an increase in volume.

The  $\text{Na}^+$  and  $\text{Cl}^-$  ions are spectator ions. They are not involved in the net reaction.

The increase in volume is  $18.6\text{ mL/mol}^1$ .

In addition, there is also an increase in volume due to the temperature increase of the reaction mixture. Upon cooling to room temperature, the volume of the reaction mixture will be greater than the sum of the individual solutions.



#### References:

<sup>1</sup>Katz, Sam, and Jane E. Miller, Medium effects of some denaturing agents on volume changes produced by acid-base reactions, *J. Phys. Chem.*, **1971**, 75 (8), pp 1120–1125

Source of hydrated ion diagrams and bond distances: Martin Chaplin,  
<http://www1.lsbu.ac.uk/water/index.html>