

Properties of Acids and Bases *According to Boyle*

- In 1661 **Robert Boyle** summarized the properties of **acids** as follows:
- 1. **Acids have a sour taste.**
- 2. **Acids are corrosive.**
- 3. **Acids change the color of certain vegetable dyes, such as litmus, from blue to red.**
- 4. **Acids lose their acidity when they are combined with alkalies.**

Robert Boyle



Born: 25 Jan 1627
in Lismore,
County Waterford,
Ireland

Died: 30 Dec 1691
in London,
England

Properties of **Acids** and **Bases** *According to Boyle*

- The name "**acid**" comes from the Latin *acidus*, which means "**sour**", and refers to the sharp odor and sour taste of many **acids**.

Examples:

- **Vinegar** tastes sour because it is a dilute solution of **acetic acid** in water.
- **Lemon juice** tastes sour because it contains **citric acid**.
- **Milk** turns sour when it spoils because **lactic acid** is formed.
- The unpleasant, sour odor of **rancid butter** stems from **butyric acid** that form when fat spoils.

Properties of **Acids** and **Bases** *According to Boyle*

- In 1661 **Boyle** summarized the properties of **alkalies** as follows:
- **Alkalies** feel slippery.
- **Alkalies** change the color of litmus from **red** to **blue**.
- **Alkalies** become less alkaline when they are combined with **acids**.

Properties of **Acids** and **Bases** *According to Boyle*

- In essence, **Boyle** defined **alkalies** as **substances that consume, or neutralize, acids:**
- **Acids** lose their characteristic sour taste and ability to dissolve metals when they are mixed with **alkalies**.
- **Alkalies** even reverse the change in color that occurs when litmus comes in contact with an **acid**.

Properties of **Acids** and **Bases** *According to Boyle*

- Eventually **alkalies** became known as **bases** because they serve as the "**base**" for making certain salts.

Definition of **Acids** and **Bases** *According to Arrhenius*

- In 1884 **Svante Arrhenius** suggested that **salts** such as **NaCl dissociate** when they **dissolve in water** to give particles he called **ions**.



Svante Arrhenius (1859-1927)



Swedish chemist who explained the electrical conductivity of ionic solutions by presuming that **compounds dissociated into oppositely charged ions** whose motions constituted a current.

This conclusion was supported by observing that the freezing point depression of ionic solids were integer multiples larger than their concentrations would indicate according to Raoult's Law.

Svante Arrhenius (1859-1927)



He described his theory in his 1884 thesis, which passed the defense with the lowest passing grade.

However, it won him the Nobel Prize in chemistry in 1903.

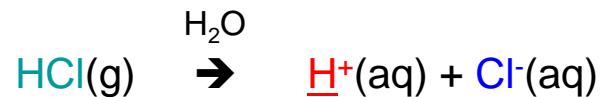
He also discovered the Arrhenius Rate Law, which describes the rate at which chemical reactions occur.

Definition of Acids and Bases According to Arrhenius

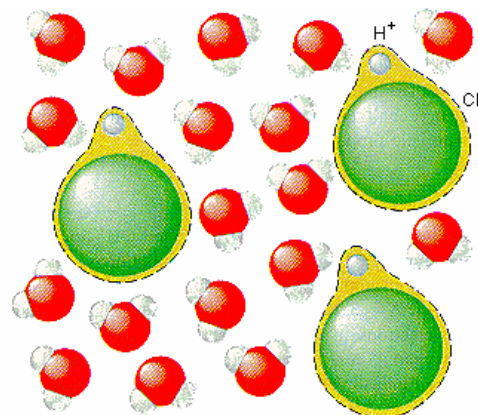
- Three years later *Arrhenius* extended this theory by suggesting that **acids are neutral compounds that ionize when they dissolve in water** to give **H⁺ ions** and a corresponding **negative ion**.

Definition of Acids and Bases According to Arrhenius

- According to his theory, **hydrogen chloride** is an **acid** because it **ionizes** when it **dissolves in water** to give **hydrogen (H⁺)** and **chloride (Cl⁻)** ions as shown below:

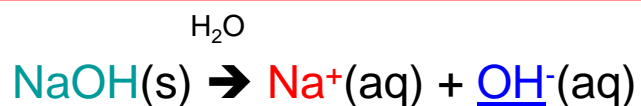


Definition of Acids and Bases According to Arrhenius



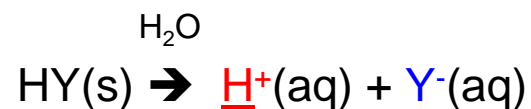
Definition of Acids and Bases According to Arrhenius

- Arrhenius argued that **bases** are **neutral compounds** that either **dissociate or ionize in water** to give **OH^- ions** and a **positive ion**.
- **NaOH** is an **Arrhenius base** because it **dissociates in water** to give the **hydroxide (OH^-)** and **sodium (Na^+) ions**.



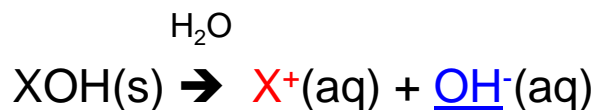
Definition of Acids and Bases According to Arrhenius

- An **Arrhenius acid** is therefore any substance that **ionizes** when it **dissolves in water** to give **H^+** , or **hydrogen ions**.



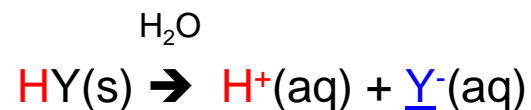
Definition of Acids and Bases According to Arrhenius

- An **Arrhenius base** is any substance that gives **OH^-** , or **hydroxide ions**, when it dissolves in water.



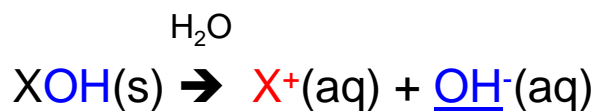
Definition of Acids and Bases According to Arrhenius

- **Arrhenius acids** include compounds such as **HCl**, **HCN**, and **H_2SO_4** that ionize in water to give the **H^+ ion**.



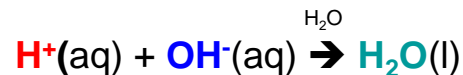
Definition of **Acids** and **Bases** *According to Arrhenius*

- **Arrhenius bases** include ionic compounds that contain the **OH⁻ ion**, such as NaOH, KOH, and Ca(OH)₂.



Definition of **Acids** and **Bases** *According to Arrhenius*

- This theory explains why all **acids** have similar properties: The characteristic properties of **acids** result from the presence of the **H⁺ ion** generated when an acid dissolves in water. It also explains why **acids neutralize bases** and vice versa:
 - **Acids** provide the **H⁺ ion**.
 - **Bases** provide the **OH⁻ ion**;
 - and these ions combine to form **water**.



Definition of **Acids** and **Bases** *According to Arrhenius*

The *Arrhenius* theory has several disadvantages:

- It can be applied only to **reactions that occur in water** because it defines **acids** and **bases** in terms of what happens when **compounds dissolve in water**.

Definition of **Acids** and **Bases** *According to Arrhenius*

- The *Arrhenius* theory doesn't explain **why some compounds**, - *in which hydrogen has an oxidation number of +1 (such as HCl)*, - **dissolve in water to give acidic solutions**, whereas others (such as CH₄) do not.

Definition of **Acids** and **Bases**
According to Arrhenius

- The *Arrhenius* theory doesn't explain why **only** the compounds that contain the **OH⁻** ion can be classified as **Arrhenius bases**.

Definition of **Acids** and **Bases**
According to Arrhenius

- The *Arrhenius* theory doesn't explain why **only** the compounds that contain the **OH⁻** ion can be classified as **Arrhenius bases**.
- The *Arrhenius* theory can't explain why other compounds (such as **Na₂CO₃**) have the characteristic properties of **bases**.

Definition of **Acids** and **Bases**
According to Brønsted

The Brønsted, or Brønsted-Lowry, model is based on a simple assumption:

Definition of **Acids** and **Bases**
According to Brønsted

The Brønsted, or Brønsted-Lowry, model is based on a simple assumption:

Acids donate H⁺ ions to other ions or molecules, which act as a base.

Some Remarks on the Concept of **Acids** and **Bases**

J. N. Brønsted
Recueil des Travaux Chimiques des Pays-Bas (1923),
Volume 42, Pages 718-728

We have held steadily to the idea that compound **A is an acid** if it is partly or completely broken down in solution according to the scheme



However, there have been attempts from various sides to modify our concept of bases. P. Pfeiffer, has presented the view that bases form salts by addition of acids, which in terms of the theory of electrolytic dissociation must lead to the idea of

- a definition of **bases** as substances that can add hydrogen ions.

<http://dbhs.wvusd.k12.ca.us/Chem-History/Bronsted-Article.html> (May 14, 2003)

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The formal advantages of the definition of a base as a substance that can bind a hydrogen ion are immediately apparent. In the scheme: $A \text{ ---> } B + H^+$, in which the **concept of an acid (A)** is established, the **concept of a base (B)** is equally defined and thus the **reciprocal connection of acidic and basic properties** is shown in the clearest and simplest way.

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The advantages of scheme $A \text{ ----> } B + H^+$ (1) as a basis for an equal definition of bases and acids are not merely of a formal nature.

For example, if we express the basic properties of ammonia in one case by the equation $NH_4^+ \text{ <====> } NH_3 + H^+$ (2)

and in another by $NH_3 + H_2O \text{ <====> } NH_4^+ + OH^-$ (3)

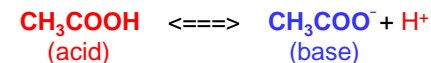
we can derive identical **equilibrium conditions**.

<http://dbhs.wvusd.k12.ca.us/Chem-History/Bronsted-Article.html> (May 14, 2003)

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It follows from the form of the expression that corresponding **acids** and **bases** do not have to have the same state of electrical charge. If **A is electrically neutral**, as an **ordinary acid** molecule is, **B has a negative charge**, e.g.



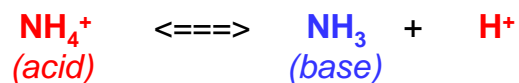
where the **acetate ion** thus functions as a **base**.

<http://dbhs.wvusd.k12.ca.us/Chem-History/Bronsted-Article.html> (May 14, 2003)

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If **A** has a **positive** charge, **B** must be electrically **neutral** as is the case, e.g., of the dissociation of the ammonium ion:



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Some Remarks on the Concept of **Acids** and **Bases**

J. N. Brønsted

Electrical charge	Naming of acid or base	Examples
Positive	cation acid	NH_4^+
Positive	cation base	$\text{NH}_2 \cdot \text{C}_6\text{H}_4 \cdot \text{C}_6\text{H}_4 \cdot \text{NH}_3^+$
Neutral	neutral acid	CH_3COOH
Neutral	neutral base	NH_3
Negative	anion acid	$\text{COO} \cdot \text{COOH}$ [Note added: there is a bar above the second O from the left as in the graphic above]
Negative	anion base	CH_3COO^-

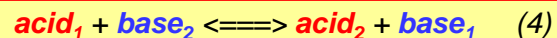
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The equilibrium formulated in **scheme (1)** between hydrogen ion and the corresponding acid and base can be called a **simple acid-base equilibrium**.

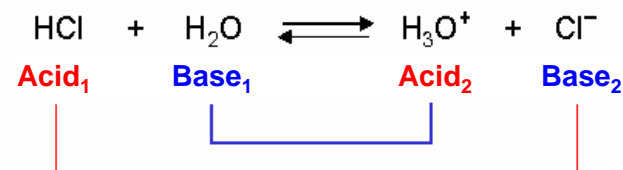
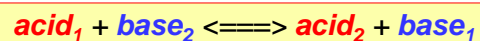
By **mixing two simple systems**, a **double acid-base system** and an acid-base equilibrium result that can always be formulated as follows:



<http://dbhs.wvusd.k12.ca.us/Chem-History/Bronsted-Article.html> (May 14, 2003)

Conjugated Acids and **Bases**

According to the concept:



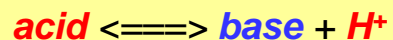
- Cl^- : **Conjugated base** to **acid HCl**
- H_3O^+ : **Conjugated acid** to **base H_2O**

Some Remarks on the Concept of **Acids** and **Bases**

J. N. Brønsted
Recueil des Travaux Chimiques des Pays-Bas (1923), Volume 42,
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Summary:

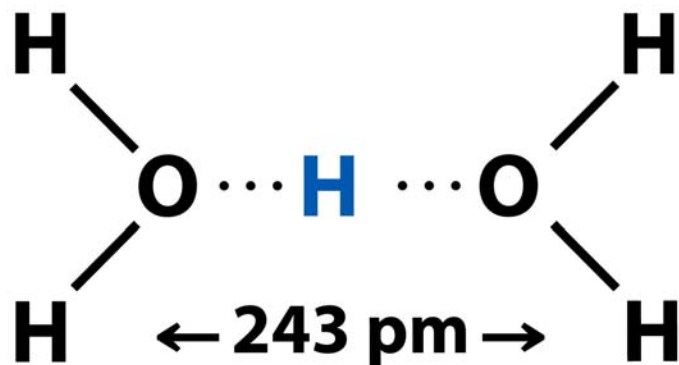
*The chemical character of **acids** and **bases** is most simply and generally defined by the scheme*



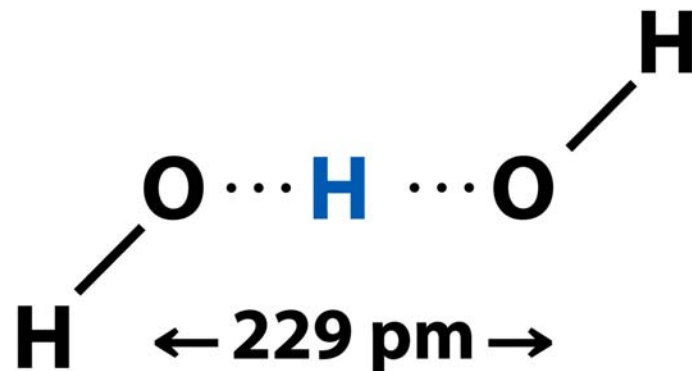
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Definition of **Acids** and **Bases** *According to **Brønsted***

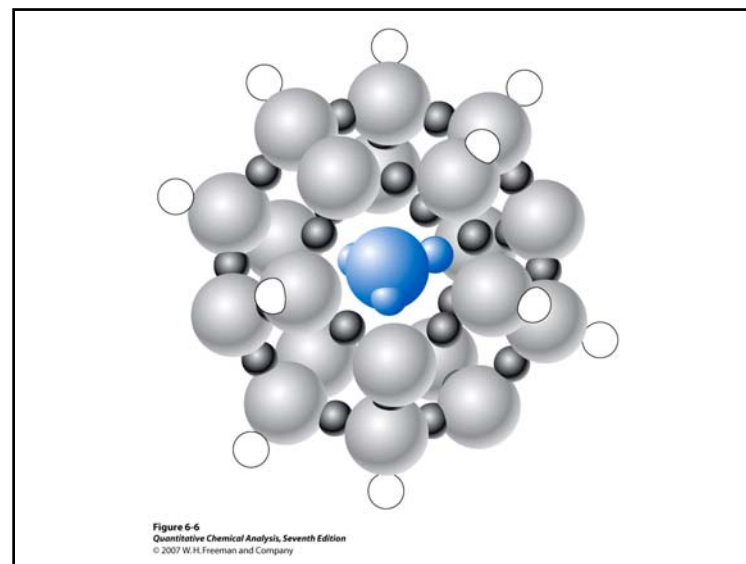
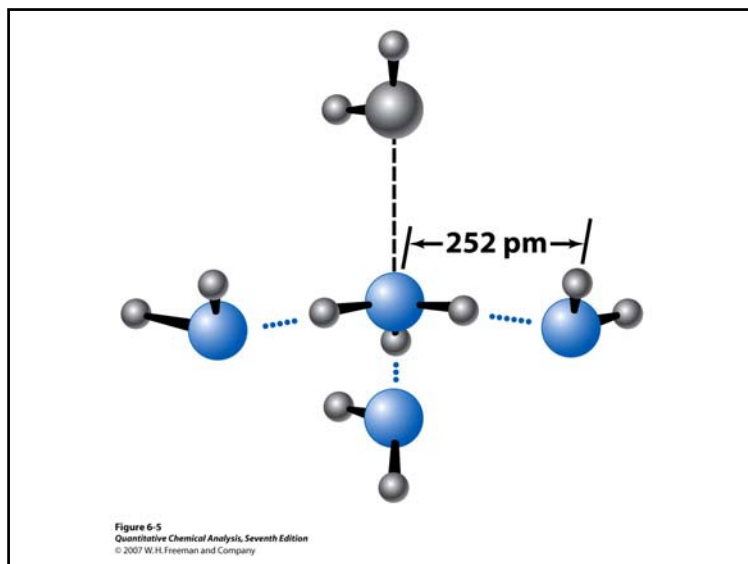
*The dissociation of water, for example, involves the transfer of an **H⁺** ion from one water molecule to another to form **H₃O⁺** and **OH⁻** ions.*



Unnumbered figure pg 106b
Quantitative Chemical Analysis, Seventh Edition
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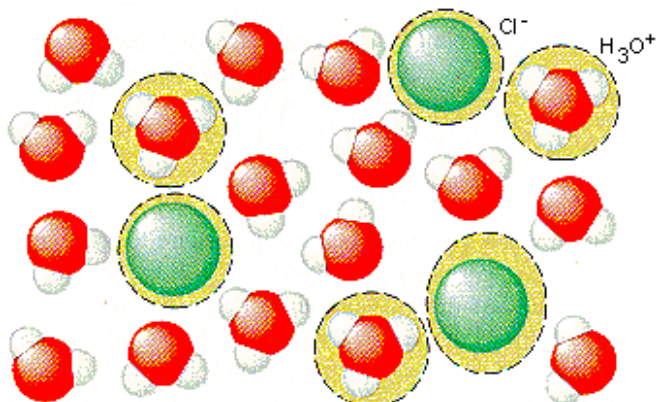
Definition of **Acids** and **Bases** According to **Brønsted**

- According to the **Brønsted** model and definition of **acids** and **bases**, **HCl doesn't dissociate in water** to form **H⁺** and **Cl⁻** ions.

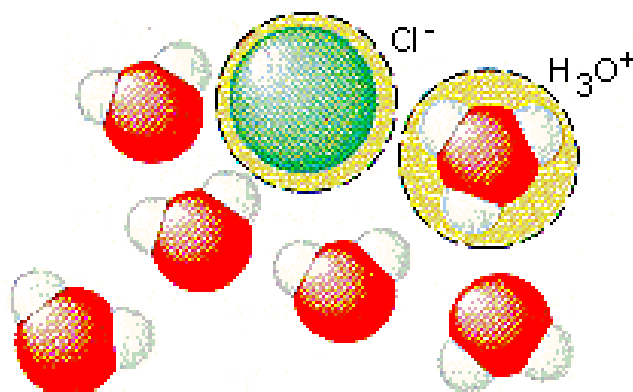
Definition of **Acids** and **Bases** According to **Brønsted**

- According to the **Brønsted** model and definition of **acids** and **bases**, **HCl doesn't dissociate in water** to form **H⁺** and **Cl⁻** ions.
- **Instead, an H⁺ ion is transferred** from HCl to a water molecule to form **H₃O⁺** and **Cl⁻** ions, *as shown in the following figure.*

Definition of **Acids** and **Bases**
According to Brønsted



Definition of **Acids** and **Bases**
According to Brønsted



The Role of **H⁺** and **OH⁻** Ions
in Aqueous Solutions

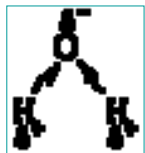
- Because **oxygen** ($EN = 3.44$) is much more **electronegative** than **hydrogen** ($EN = 2.20$), the electrons in the HO-bonds in water aren't shared equally by hydrogen and oxygen.

The Role of **H⁺** and **OH⁻** Ions
in Aqueous Solutions

- Therefore, the **electrons** are drawn toward the **oxygen** atom in the center of the molecule and away from the **hydrogen** atoms on either end.

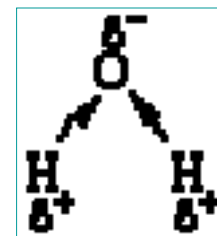
The Role of H^+ and OH^- Ions in Aqueous Solutions

The **oxygen** atom carries a partial **negative** charge (-), and the **hydrogen** atoms carry a partial **positive** charge (+).



The Role of H^+ and OH^- Ions in Aqueous Solutions

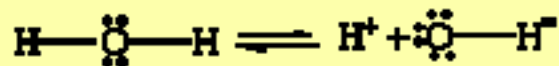
As a result, the water molecule is **polar** :



The Role of H^+ and OH^- Ions in Aqueous Solutions

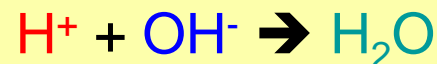
When water dissociates to form ions, the result is a

- **positively charged H^+ ion** and a
- **negatively charged OH^- ion**.



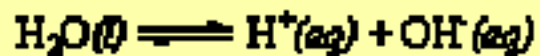
The Role of H^+ and OH^- Ions in Aqueous Solutions

The opposite can also occur:
 H^+ ions can combine with OH^- ions to form neutral water molecules.



The Role of H^+ and OH^- Ions in Aqueous Solutions

The fact that water molecules dissociate to form H^+ and OH^- ions, - which can then recombine to form water molecules, - is indicated by the following equation:



The Role of H^+ and OH^- Ions in Aqueous Solutions

To what extent does H_2O dissociate to form ions?

At 25°C, the density of water is 0.9971 g/cm³,
or 0.9971 g/mL.

$$\frac{0.9971 \text{ g H}_2\text{O}}{1 \text{ mL}} \times \frac{1000 \text{ mL}}{1 \text{ L}} \times \frac{1 \text{ mol H}_2\text{O}}{18.015 \text{ g H}_2\text{O}} = 55.35 \text{ mol H}_2\text{O/L}$$

The concentration of H_2O is 55.35 molar.

The Role of H^+ and OH^- Ions in Aqueous Solutions

To what extent does H_2O dissociate to form ions?

The Role of H^+ and OH^- Ions in Aqueous Solutions

To what extent does H_2O dissociate to form ions?

The **concentration** of the H^+ and OH^- ions formed by the dissociation of neutral H_2O molecules at this temperature is only **1.0×10^{-7} mol/L**.

The Role of H^+ and OH^- Ions in Aqueous Solutions

To what extent does H_2O dissociate to form ions?

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$$\frac{1.0 \times 10^{-7} \text{ M } H^+}{55.35 \text{ M } H_2O} = 1.8 \times 10^{-9}$$

The Role of H^+ and OH^- Ions in Aqueous Solutions

To what extent does H_2O dissociate to form ions?

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$$\frac{1.0 \times 10^{-7} \text{ M } H^+}{55.35 \text{ M } H_2O} = 1.8 \times 10^{-9}$$

Accordingly, the ratio of the concentration of the H^+ (or OH^-) ion to that of the neutral H_2O molecules is 1.8×10^{-9} .

The Role of H^+ and OH^- Ions in Aqueous Solutions

To what extent does H_2O dissociate to form ions?

At 25°C only about **2 parts per billion (ppb)** of the H_2O molecules **dissociate** into ions.

Definition of **Acids** and **Bases** The Operational Definition

The fact that **water dissociates** to form H^+ and OH^- ions in a **reversible reaction** is the basis for an **operational definition** of **acids** and **bases** that is **more powerful** than the definitions proposed by *Arrhenius*.

Definition of **Acids** and **Bases** *The Operational Definition*

In an **operational sense**:

- an **acid** is any substance that **increases the concentration of the H^+ ion** when it dissolves in water.
- a **base** is any substance that **increases the concentration of the OH^- ion** when it dissolves in water.

Definition of **Acids** and **Bases** *The Operational Definition*

These definitions tie the theory of **acids** and **bases** to a **simple laboratory test** for **acids** and **bases**:

- To decide whether a compound is an **acid** or a **base**, we **dissolve it in water** and test the solution to see whether the **H^+** or **OH^-** ion concentration **has increased**.

pH Meter Measures Acidity

- The U.S. Geological Survey analyzes hundreds of thousands of water samples every year. Many measurements are made right at the field site, and many more are made on water samples back at the lab. The pH is an important water measurement which is often measured both at the sampling site and in the lab. There are large and small models of pH meters. Portable models are available to take out in the field and larger models, such as this one, are used in the lab.



pH Meter Measures Acidity

So, how does this contraption work?

- The water sample is placed in the little cup and the glass probe at the end of the retractable arm is placed in the water. The back of the probe is connected to the main box by electrical wires, and at the tip of the probe there is a thin glass bulb. Inside the probe there are two electrodes that measure voltage. One electrode is contained in a liquid that has a fixed acidity, or pH. The other electrode responds to the acidity of the water sample.

pH Meter Measures Acidity

- In other words, the voltage of the second electrode responds to the amount of free hydrogen ions (the pH) in the sample.
- A voltmeter in the probe measures the difference between the voltages of the two electrodes.
- The meter then translates the voltage difference into pH and displays it on the little screen on the main box.

pH Meter Measures Acidity

- Before taking a pH measurement, the meter must be "calibrated." The probe is immersed in a solution that has a known pH, such as pure water with a neutral pH of 7.0. The knobs on the box are used to adjust the displayed pH value to the known pH of the solution, thus calibrating the meter.