Chapter 6
Acids and Acid Rain

An Introduction to Chemistry

by Mark Bishop

Arrhenius Acid Definition

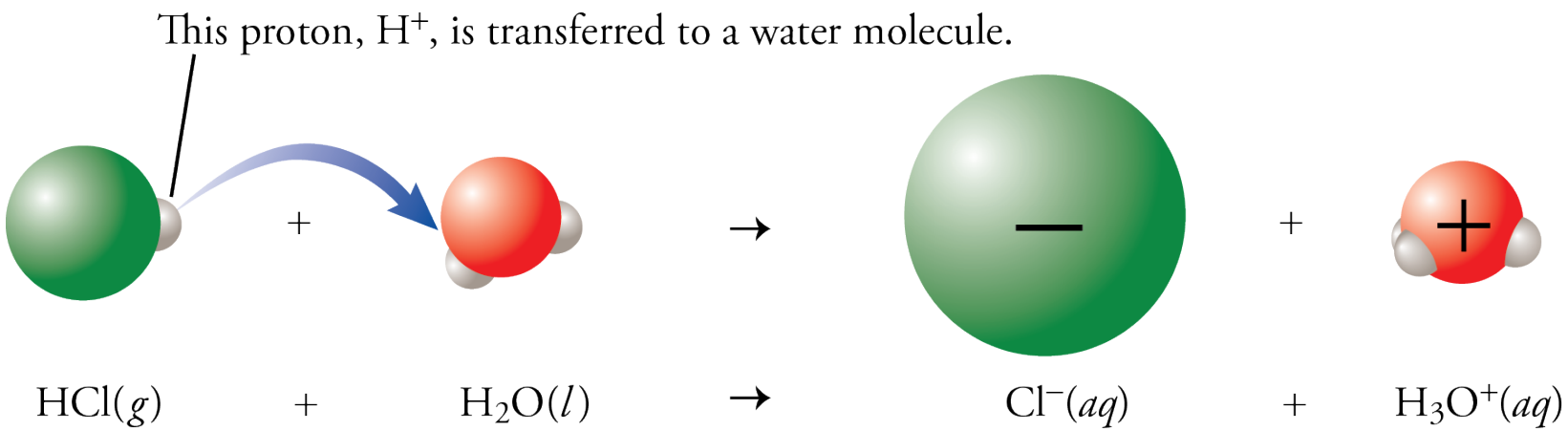
- An ***acid*** is a substance that generates hydronium ions, H_3O^+ (often described as H^+), when added to water.
- An ***acidic solution*** is a solution with a significant concentration of H_3O^+ ions.

Characteristics of Acids

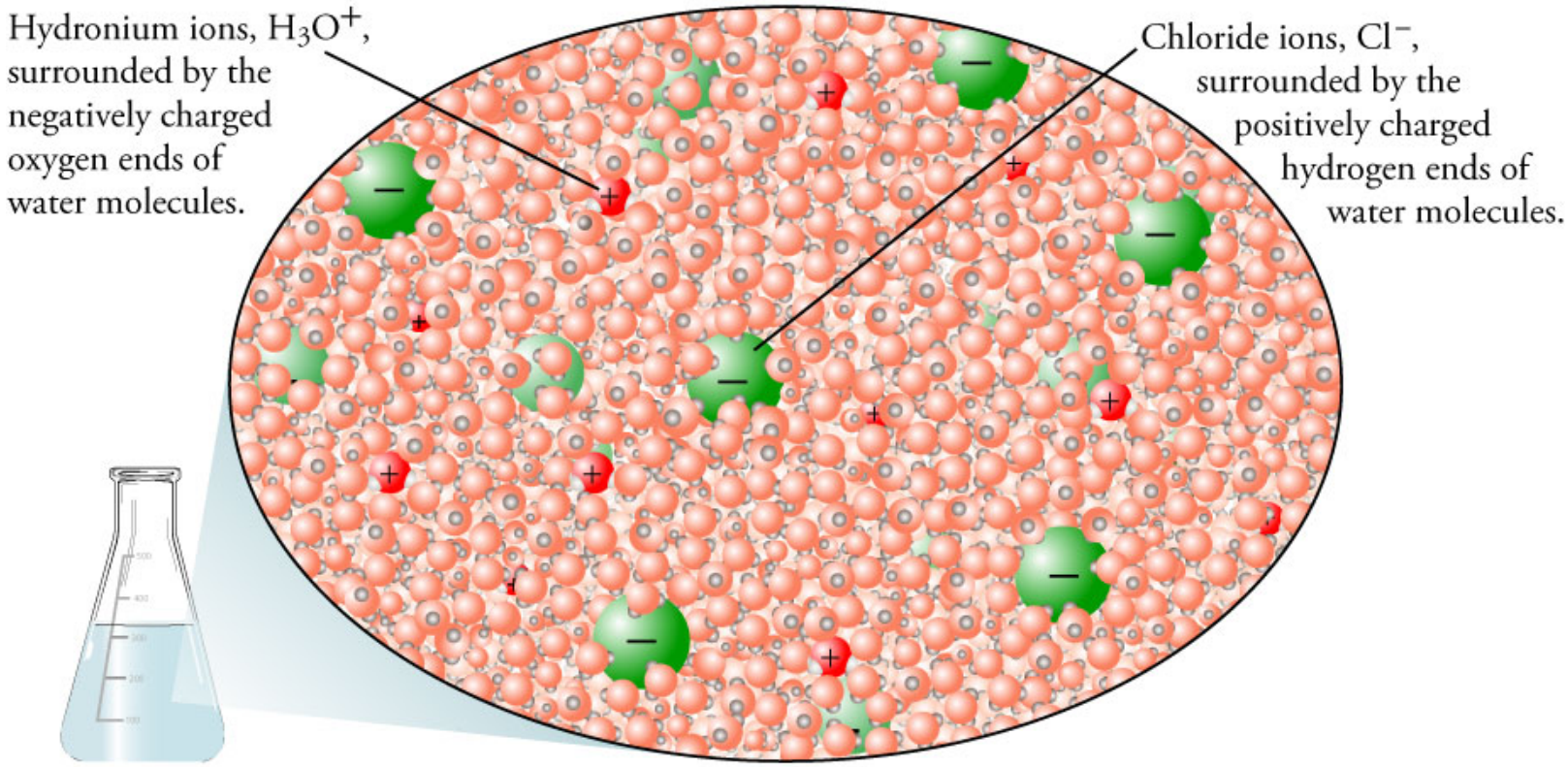
- Acids have a sour taste.
- Acids turn litmus from blue to red.
- Acids react with bases.

Strong Acid and Water

When HCl dissolves in water, hydronium ions, H_3O^+, and chloride ions, Cl^-, ions form.



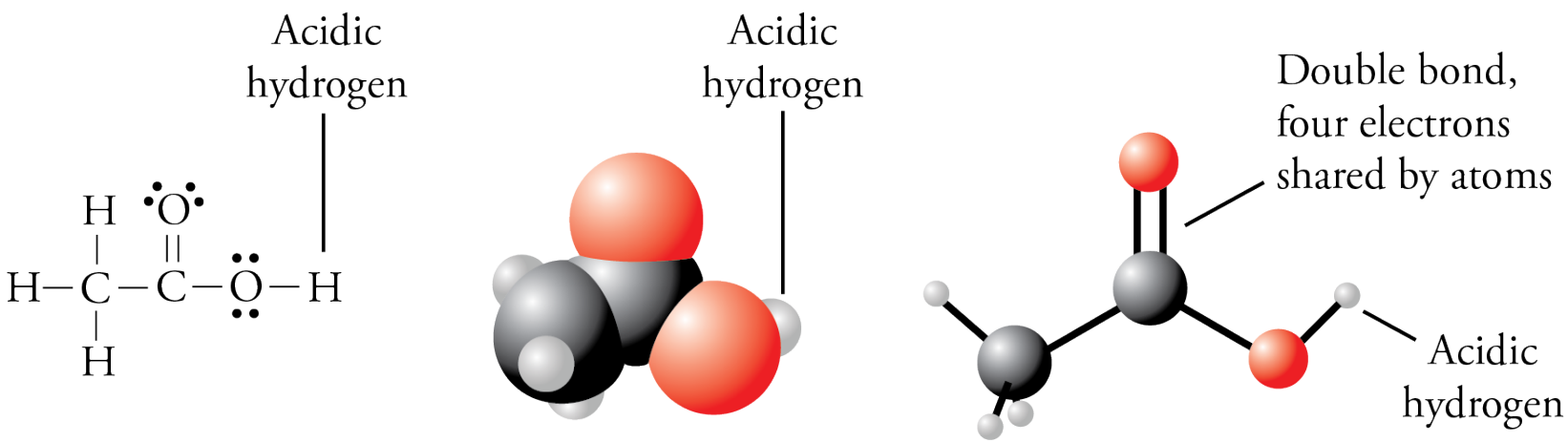
Solution of a Strong Acid



Types of Acids

- Binary acids have the general formula of HX(aq)
  - HF(*aq*) and HCl(*aq*)
- Oxyacids have the general formula $H_aX_bO_c$.
  - HNO_3 and H_2SO_4
- Organic acids, which are also called carbon-based acids or carboxylic acids
  - $HC_2H_3O_2$

Acetic Acid

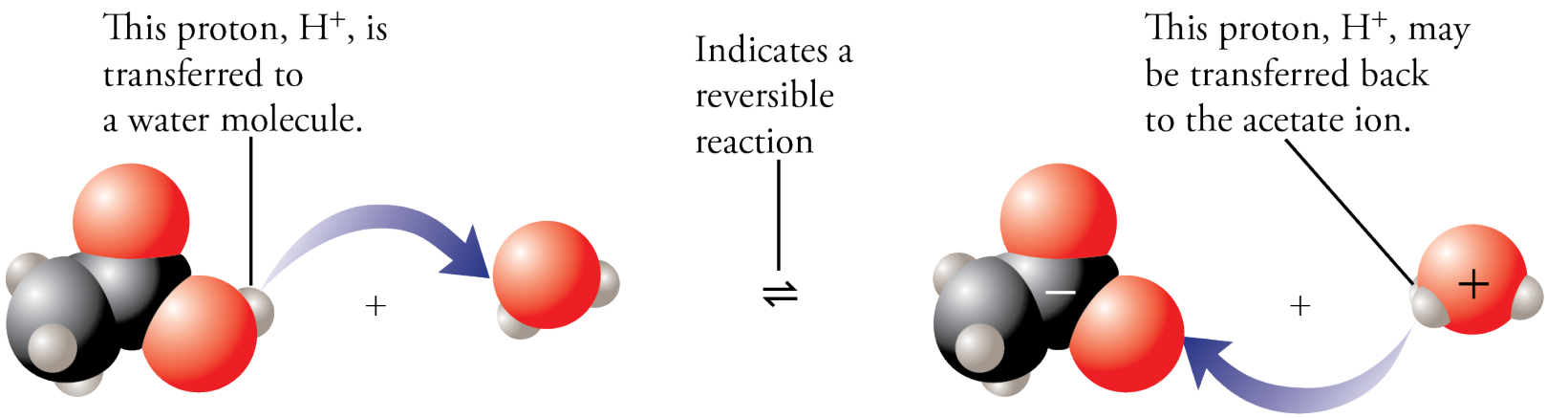

Acidic hydrogen
Acidic hydrogen
Double bond, four electrons shared by atoms
Acidic hydrogen

Monoprotic and Polyprotic Acids

- If each molecule of an acid can donate one hydrogen ion, the acid is called a **monoprotic acid**.
- If each molecule can donate two or more hydrogen ions, the acid is a **polyprotic acid**.
- A **diprotic acid**, such as sulfuric acid, H_2SO_4, has two acidic hydrogen atoms.
- Some acids, such as phosphoric acid, H_3PO_4, are **triprotic acids**.

Weak Acid and Water

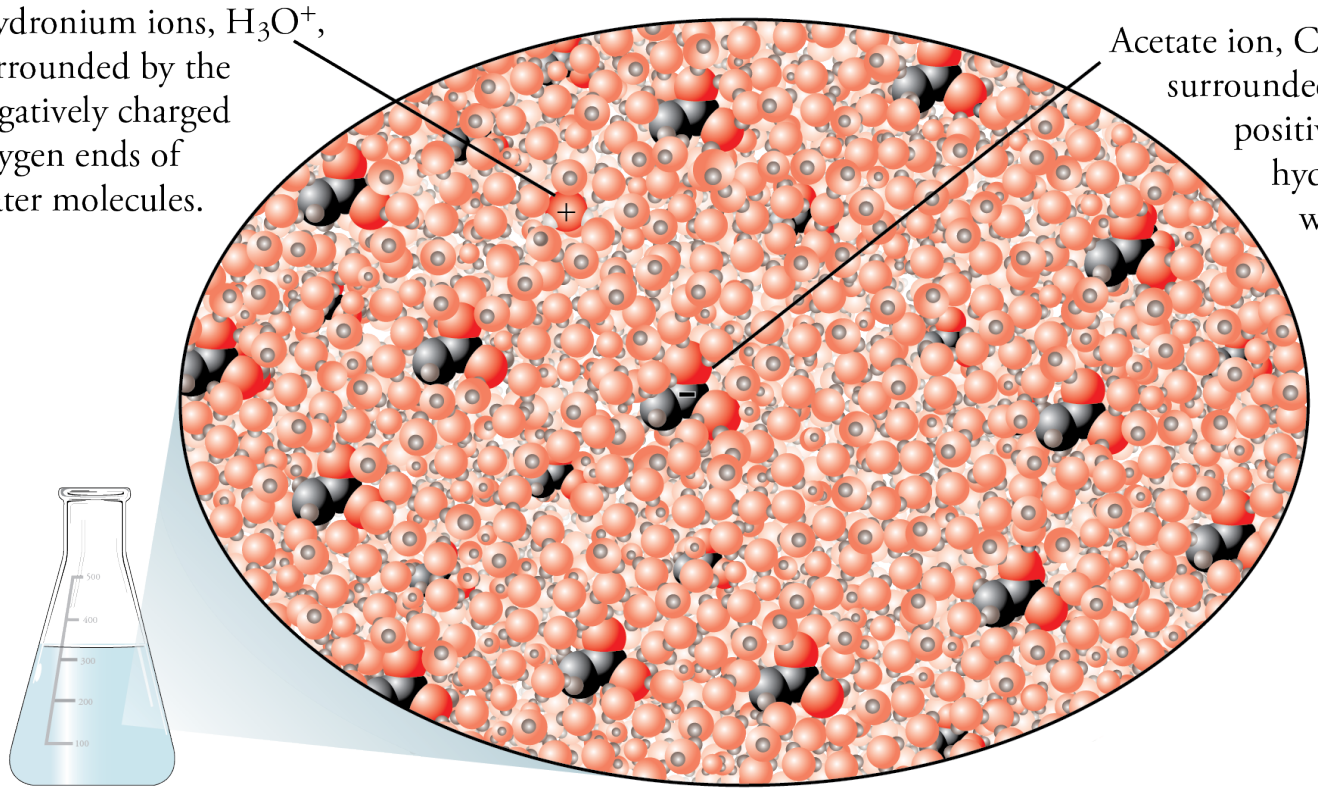
Acetic acid reacts with water in a reversible reaction, which forms hydronium and acetate ions.



$$HC_2H_3O_2(aq) + H_2O(l) \rightleftharpoons C_2H_3O_2^-(aq) + H_3O^+(aq)$$

Solution of Weak Acid

In a typical acetic acid solution, there are about 250 times as many uncharged acetic acid molecules, $HC_2H_3O_2$, as acetate ions, $C_2H_3O_2^-$.



Strong and Weak Acids

- ***Weak Acid*** = due to a reversible reaction with water, generates significantly less than one H_3O^+ for each molecule of acid added to water.
- ***Strong Acid*** = due to a completion reaction with water, generates close to one H_3O^+ for each acid molecule added to water.

Strong and Weak Acids

For every 250 molecules of the weak acid acetic acid, $HC_2H_3O_2$, added to water, there are about

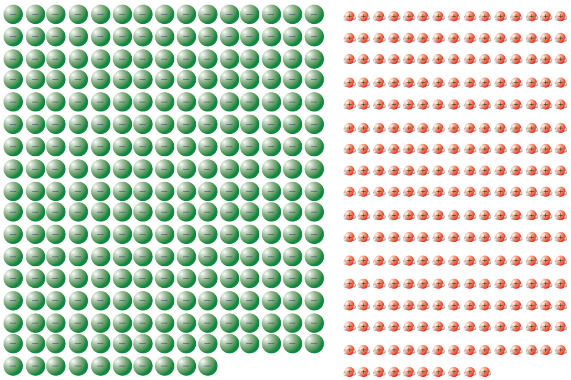
$$HC_2H_3O_2(aq) + H_2O(l) \rightleftharpoons C_2H_3O_2^-(aq) + H_3O^+(aq)$$

249 uncharged acetic acid molecules — One acetate ion — One hydronium ion

For every 250 molecules of the strong acid hydrochloric acid, HCl, added to water, there are about

$$HCl(g) + H_2O(l) \rightarrow Cl^-(aq) + H_3O^+(aq)$$

Zero uncharged HCl molecules — 250 chloride ions — 250 hydronium ions



Acid Animation and Tutorial

- There is an animation on the textbook's website that will give you a better understanding of weak and strong acids.

https://preparatorychemistry.com/acids_Canvas.html

Sulfuric Acid

$$H_2SO_4(aq) + H_2O(l) \rightarrow H_3O^+(aq) + HSO_4^-(aq)$$

$$HSO_4^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + SO_4^{2-}(aq)$$

Acid Summary

	Strong	Weak
Binary acid	hydrochloric acid, HCl(aq)	Hydrofluoric acid
Oxyacid	nitric acid, HNO_3 sulfuric acid, H_2SO_4	other acids with $H_aX_bO_c$
Organic acid	none	acetic acid, $HC_2H_3O_2$

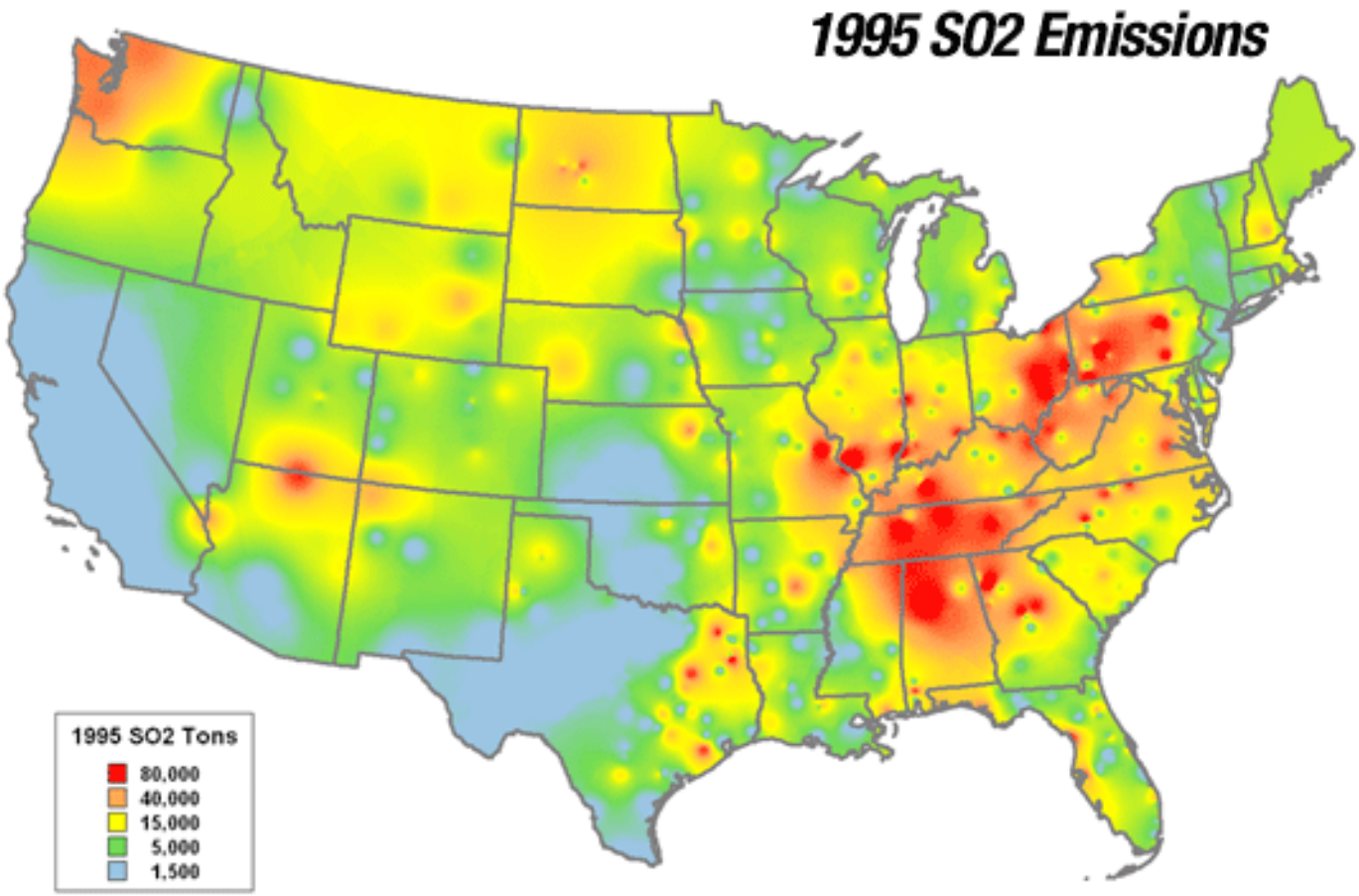
Acid Rain

- Large quantities of sulfur dioxide, SO_2, are formed and released into the air from burning sulfur-containing substances in coal in power plants and in metal ores in smelting, which involves heating of metal ores to extract metals.
- SO_2 forms sulfuric acid, H_2SO_4, in the atmosphere, which can dissolve in the clouds and form acid rain.
- Sulfuric acid forms hydronium ions.

$$H_2SO_4 + H_2O \rightarrow H_3O^+ + HSO_4^-$$

$$HSO_4^- + H_2O \rightleftharpoons H_3O^+ + SO_4^{2-}$$

1995 SO2 Emissions



NO_x and Nitric Acid

- The combination of air at high temperature, perhaps with a metal to act as a catalyst, leads to the formation of nitrogen monoxide, NO, and nitrogen dioxide, NO_2, often summarized as "NOx".
- Transportation and industry are major sources of nitrogen oxides.
- The NO_2 forms nitric acid in the atmosphere, which is a strong acid.

$$HNO_3 + H_2O \rightarrow H_3O^+ + NO_3^-$$

Acids and Acid Precursors

- Sulfur dioxide (SO_2) → sulfuric acid (H_2SO_4)
  - primarily from coal burning and smelting
- Nitrogen oxides (NO, NO_2) → nitric acid (HNO_3)
  - primarily from high-temperature combustion

strong acids

- Formic and acetic acids (HCO_2H, CH_3CO_2H)
  - primarily from biomass burning, mostly in Africa and South America
- Carbonic acid (CO_2 → H_2CO_3)
  - from CO_2 in atmosphere, responsible for acidity of pristine precipitation

weak acids

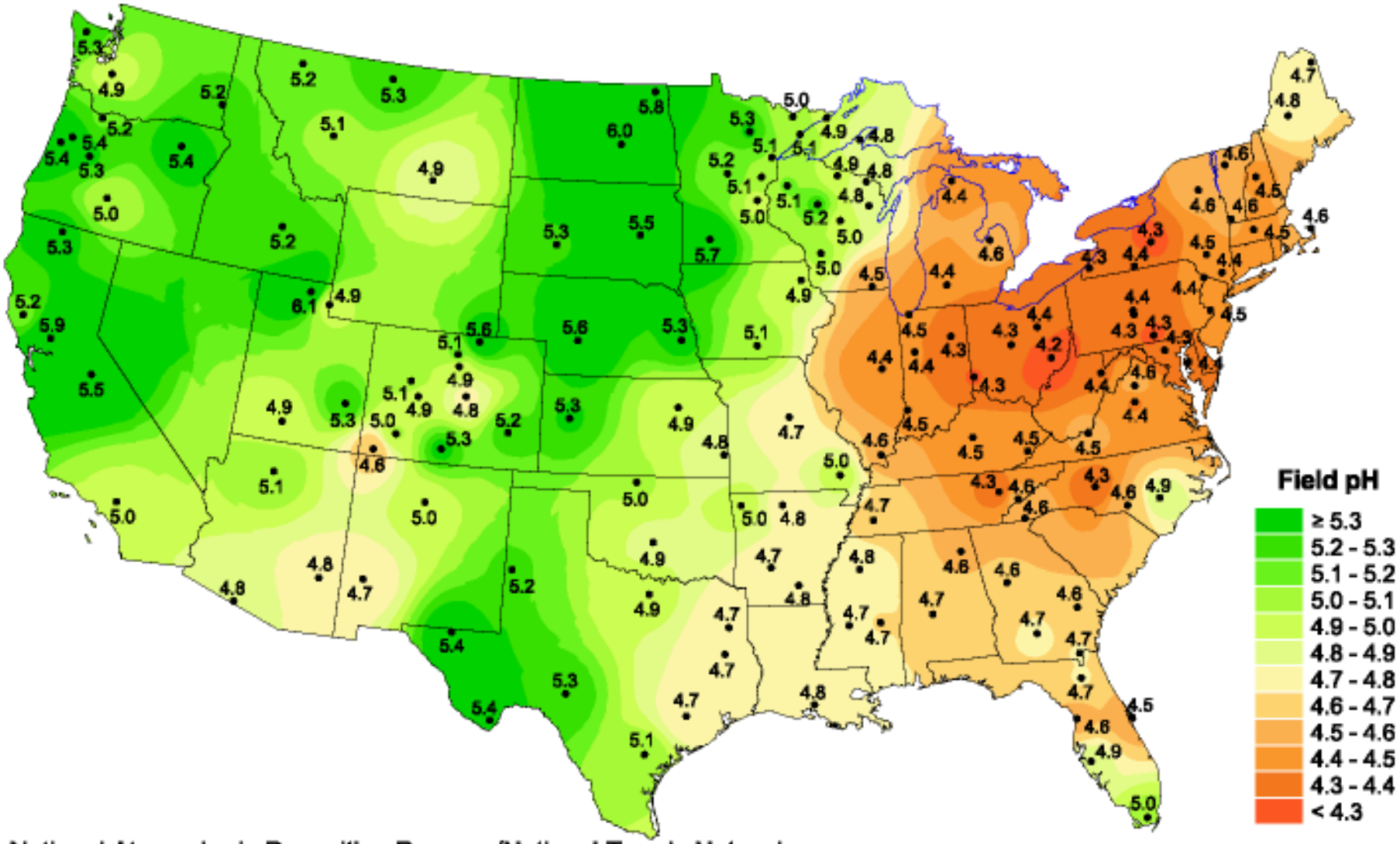
pH

- The pH scale can be used to describe the acidity and basicity of dilute solutions of acid and base.
- Acidic solutions have pHs from 0 to 7.
- The lower the pH, the more acidic the solution, and a decrease in one pH unit is associated with an increase of 10-times the hydronium ion concentration.
- Therefore, small changes in pH reflect significant changes in H_3O^+ concentration.

Pristine Rain and Acid Rain

- Due to acids dissolved in natural rain, such as the carbonic acid that forms when CO_2 dissolves in water, pristine or unpolluted rain has a pH of about 5.6.
- Acid rain can have a pH close to 4.

Rain pH 1999



National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

Impacts

- Lowering pH can damage freshwater ecosystems, forests, agriculture, human health, buildings, and other property.

Damage to Human Health

- More acidic rain dissolves more toxic metals in the soil, which increases the level of these metals in water systems, leading to consumption of fish with elevated concentrations of toxic metals (Al, Pb, Cd, Hg, Cu, Zn).
- Corrosion of pipes results in excess levels of Cu, Zn, Pb in drinking water.

Damage to Buildings and Property

- Acids etch glass, damage roofing and other building materials, and damage plastics and paint (especially automotive paint).
- Carbonate stones (marble, limestone, etc.), cement, mortar are dissolved by acids:

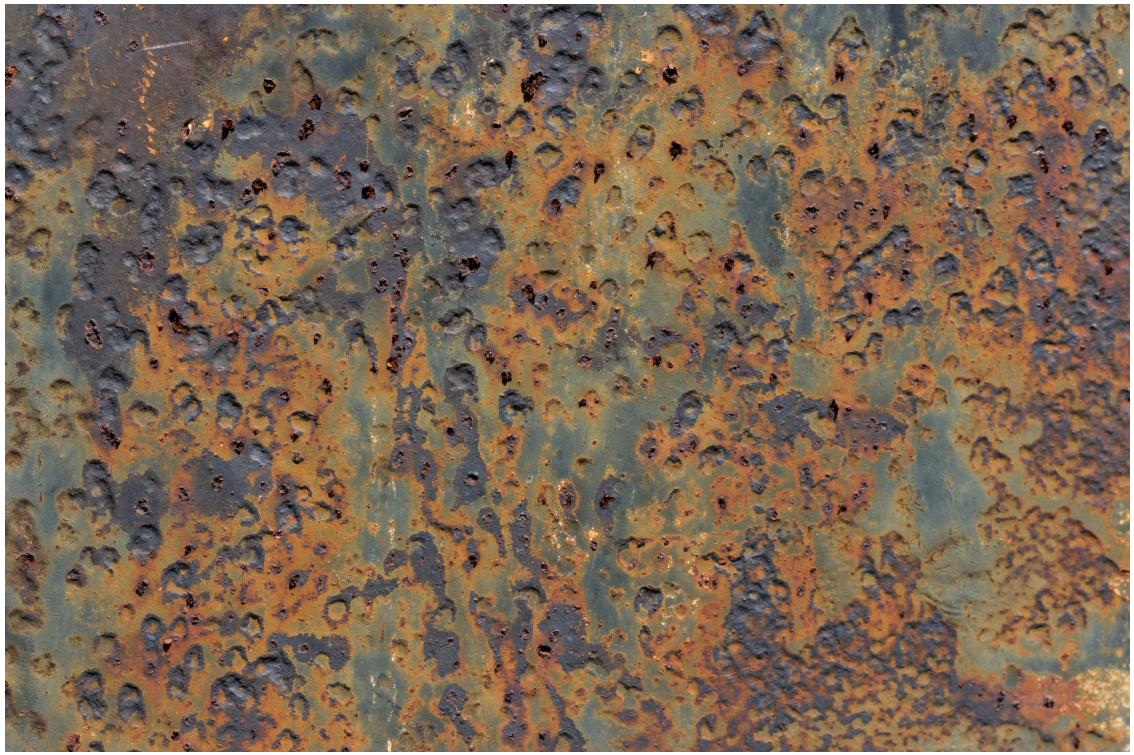
$$CaCO_3(s) + 2H_3O^+(aq) \rightarrow Ca^{2+}(aq) + CO_2(g) + 3H_2O(l)$$

Damage to Art

The statues on the left were transported by William Randolph Hearst to his home in San Simeon, California. Because it so rarely rains there, and because San Simeon is far from any major sources of pollution, these statues are in much better condition than the similar statues found elsewhere, such as the one on the right, that have been damaged by acid rain.

Effects on Metals

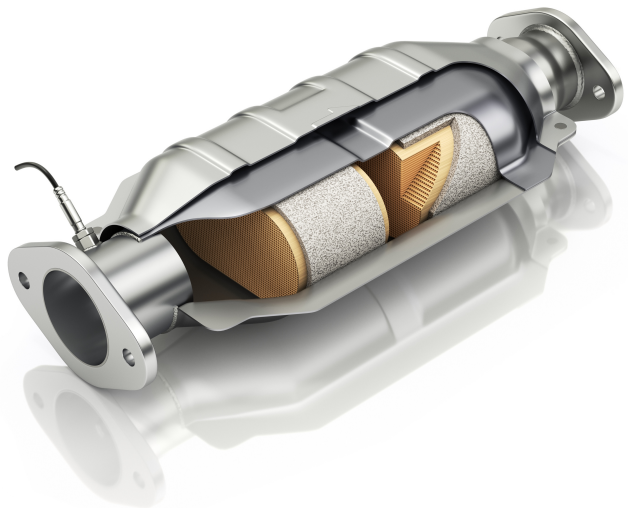
- Acid rain speeds the corrosion of metals.



Automobile Catalytic Converters

- Catalytic converters can convert up to 95% of the NO and NO_2 back to nitrogen and oxygen.

$$2NO \rightarrow N_2 + O_2 \qquad 2NO_2 \rightarrow N_2 + 2O_2$$



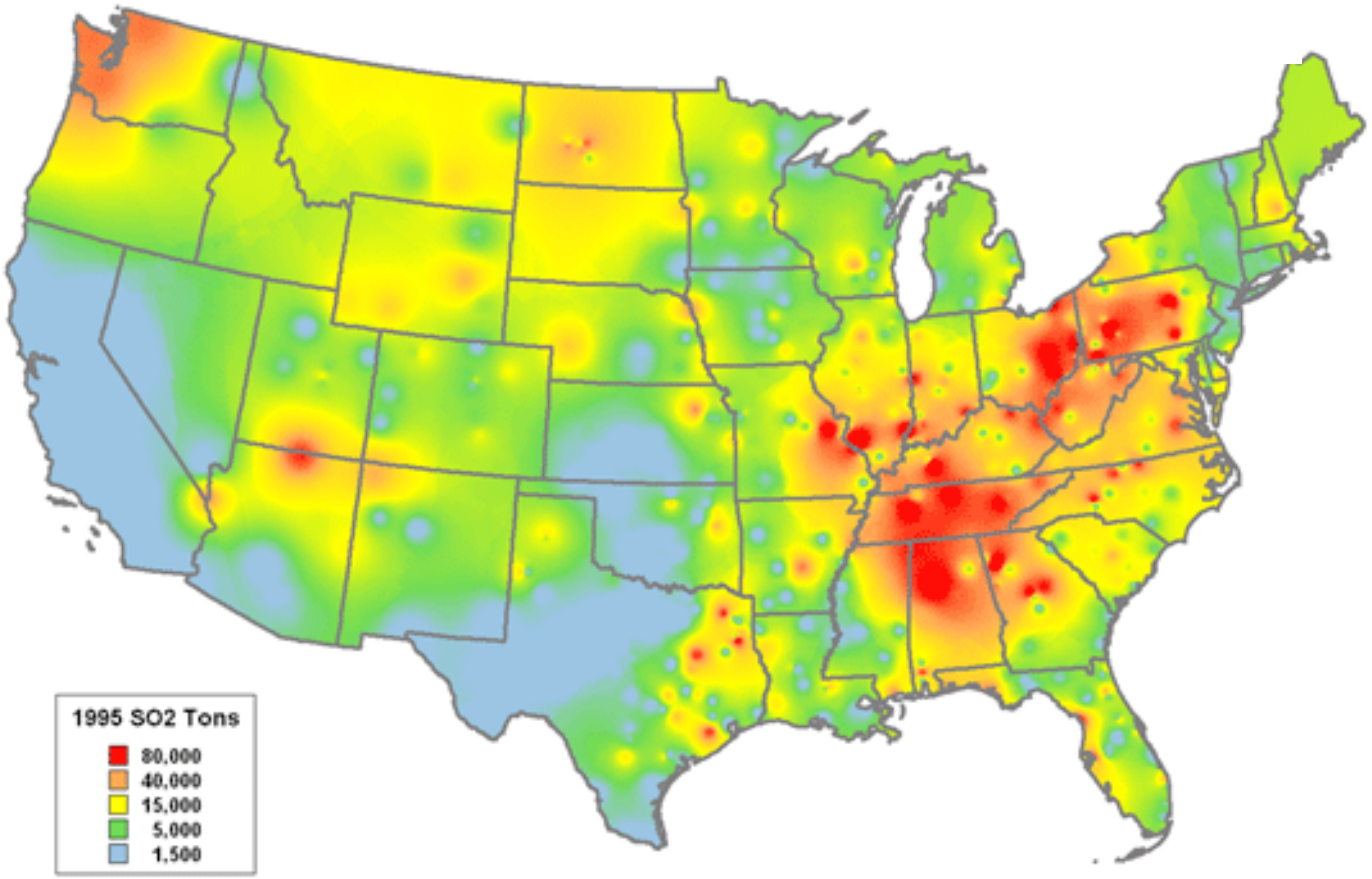
Mitigation - Sulfur

- Switch from coal to natural gas (0.001% S)
- Switch to low-sulfur coal
- Power plant scrubbers can use CaO (lime), $CaCO_3$ (limestone), or $Ca(OH)_2$ (lime) to remove SO_2 from the stack gases.

SO_2 Emissions Reduction

- Due largely to the US EPA's Acid Rain Program, the U.S. had a 33% decrease in SO_2 emissions between 1983 and 2002.

1995 SO_2 Emissions



2004 SO_2 Emissions