CHM107 Chapter 6
Neutralizing the Threat of Acid Rain; Acid / Base chemistry

Introduction
• Coral reefs are in danger, 25% already dead, ocean becoming more acidic

Ocean acidification and Acid Rain
• CO₂, SO₂ and NOₓ combine with H₂O to make H₂CO₃, H₂SO₃ and HNO₂ acids which are causing rain, snow, lakes, rivers, and the ocean to become more acidic.
• Oceans absorb 25-40% of CO₂ we produce.

Outline for Chapter 6
• Your assignment for this chapter
• What are acids and bases
• What is acid rain
• What is pH
• How acid rain is produced
• Effects of acid rain
• Household acids and bases

Effects of the EPA Acid Rain Program
• Research acid rain laws
• Write down 15 facts about the EPA's acid rain laws and the outcomes of the laws (effects and results)
• Write down your opinion on this program (good, bad, not enough, too much...)
• In ONE WEEK we will spend about 30-45 minutes having a DISCUSSION. The goal is to educate on acid rain laws and the effects they have had.
• You will be graded on turning in your paper BEFORE we discuss so make sure to make a copy of your paper.
• It can be typed (easier to print 2 copies) or hand written neatly.

Preparations for your paper
• Consider health, economic, scientific, environmental, and political aspects.
• www.epa.gov/airmarkets/progsregs/arp/
• Also look up “Acid Rain Program” on wikipedia.com and read
6.1 Acids

- Acids
  - Sour taste (vinegar, lemons)
  - Dissolves marble, shells, and stone
  - Turns carbonates into CO$_2$ gas
  - Release H$^+$ ions in water, which are protons cause the one electron from H is gone
  - Actually H$^+$ is really H$_3$O$^+$ ions
  - HCl is hydrochloric acid

How does CO$_2$ become acidic?

- CO$_2$ + H$_2$O $\rightarrow$ H$_2$CO$_3$
- H$_2$CO$_3$ $\rightleftharpoons$ H$^+$ + HCO$_3$-
- The double arrow means the reaction does not go all the way, it sets up equilibrium because carbonic acid is weak, it only dissociates a small extent

How do acids make H$^+$ in water?

- When you put an acid in water, an H breaks off from the acid molecule (that covalent bond breaks) leaving an H$^+$ ion.
- HCl in water makes H$^+$ and Cl$^-$ ions.
- What ions would HBr make in water? What about HNO$_3$?

6.2 Bases

- Bases
  - Releases hydroxide ions (OH$^-$) in water
  - Taste bitter and bad
  - Slippery to touch like bleach
  - NaOH is called lye and is a base
  - Ammonia NH$_3$ is a base
    - NH$_3$ + H$_2$O $\rightleftharpoons$ NH$_4^+$ + OH$^-$
    - NH$_3$ is a weak base because the reaction does not go all the way forwards

How do Bases make OH$^-$ in water?

- When you put a base in water, an OH breaks off from the base molecule (that bond breaks) leaving an OH$^-$ ion.
- NaOH in water makes Na$^+$ and OH$^-$ ions.
- What ions would KOH make in water? What about Ba(OH)$_2$?

Strong vs Weak

- You may have heard about strong acids versus weak acids
- Watch this video
  * [http://www.mhhe.com/physsci/chemistry/animations/chang_2e/acid_ionization.swf](http://www.mhhe.com/physsci/chemistry/animations/chang_2e/acid_ionization.swf)
- Strong acids break apart or ionize completely in water while very few weak acid molecules break apart / ionize in water. So the percent ionization is very high (>90%) for strong acids but low (<10%) for weak acids.
- Strong versus weak bases are similar
6.3 Neutralization Reactions

- Acids and Bases react together to make neutral solutions
- HCl + NaOH → NaCl + H₂O
- Basically H⁺ + OH⁻ → H₂O

6.4 The pH Scale

- Goes from 0 to 14
- 7 in the middle is neutral (H⁺ = OH⁻)
- Closer to zero is acidic
- Closer to 14 is basic

Acids and Bases

**Acid** = A substance that produces hydrogen ions, H⁺, in water

**Base** = A substance that produces hydroxide ions, OH⁻, in water

**Neutral Solution** = Neither acidic nor basic; Equal concentrations of H⁺ and OH⁻

Acid in Foods

- Citric acid in citrus fruits
- Malic acid in McIntosh apples
- Lactic acid in yogurt
- Phosphoric acid in colas
- Acetic acid in vinegar

pH of natural waters

- Rain is slightly acidic
  - CO₂ naturally dissolves in rain making H₂CO₃ (carbamic acid)
  - Normal rain has a pH of 5.3
  - However we are increasing the levels of CO₂ in the atmosphere. What will that do?
- Normal seawater is around 8.2, just a bit basic

6.5 Ocean Acidification

- Called Climate Change’s nasty little sister
- Fact: CO₂ levels are higher than anytime in the past 800,000 years
- Fact: CO₂ levels are increasing at a faster rate than anytime in the past 800,000 years
- Fact: Large areas of coral have been discovered to be “bleached”
- Fact: The ocean is about 25% more acidic than it was before the industrial revolution
What is going on?

- Water can absorb CO₂ gas
  \[ \text{CO}_2(g) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_2\text{CO}_3(aq) \]
- The product is carbonic acid which increases the H⁺ ions in ocean water, thus pH decreases as H⁺ ions are what causes acidity
- Ocean pH level has decreases about 0.1 since 1800’s = 26% increase in H⁺ in seawater!
- Predicted 2050 pH level will be 0.23 lower and by 2100 will be 0.36 lower if nothing is done
- The pH of the ocean is still basic, it is just becoming less basic or more acidic
Why does it matter if the ocean becomes less basic / more acidic?

- Ocean animal shells are made of calcium carbonate, CaCO$_3$. In basic solution CaCO$_3$ will not dissolve, but as the water gets more acidic, the shells dissolve.
- So corals, echinoderms, crustaceans, pteropods, and molluscs care because it is getting harder to form their shells and requires more energy.
- Also the animals that live off the coral will be threatened.
- This will result in disruption to the entire ocean food chain.

How shells dissolve

- H$^+$ (from acid) + CO$_3^{2-}$ → HCO$_3^-$
- Acid reacts with carbonate ions making more bicarbonate ions. The calcium carbonate shells then dissolve to replace the carbonate ions.
- Scientists predict that within 40 years shells will begin to dissolve including coral reefs. One study said the Great Barrier Reef of Australia is already growing slower. Coral reefs protect coastlines and provide homes for many species.
6.6 The pH of Rain

- Normal rain is pH 5.3
- Acid rain is pH less than 5.0
- Measure pH with a pH meter
- Rain samples have been collected since 1970 all across the US and Canada
- NO\textsubscript{x} and SO\textsubscript{x} result in acid rain

What is acid rain?

- Relatively NOT Acidic
- Relatively Acidic (~5.3)

How burning coal makes acid rain

- Produces SO\textsubscript{x} and NO\textsubscript{x}
  - (SO\textsubscript{2} and SO\textsubscript{3}, NO and NO\textsubscript{2})
  - Review – Can you name these covalent compounds?
  - Sulfur dioxide, sulfur trioxide, nitrogen monoxide, nitrogen dioxide

- With water in the air they make:
  - SO\textsubscript{2} + H\textsubscript{2}O → H\textsubscript{2}SO\textsubscript{3} (sulfurous acid)
  - SO\textsubscript{3} + H\textsubscript{2}O → H\textsubscript{2}SO\textsubscript{4} (sulfuric acid)
  - 2 NO\textsubscript{2} + H\textsubscript{2}O → HNO\textsubscript{2} + HNO\textsubscript{3} (nitrous, nitric acid)
Acid Deposition

• Term referring to acid being delivered to Earth’s surface by
  – Rain, snow, fog, or hail
• We can tell what acids are in the rain by checking water sources for NO₃⁻ ions and SO₄²⁻ and SO₃²⁻ ions.
• Data shows that the Northeast has much more of these ions in their water.

6.7 SO₂ sulfur dioxide

• Produced by volcanoes
• Produced by oil and coal combustion
  – One coal plant can make 40,000 tons per year
• Bent shape
• Important in winemaking, it serves as an antibiotic and antioxidant, protecting wine from spoilage by bacteria and oxidation.
• Due largely to the EPA’s Acid Rain Program, the U.S. has witnessed a 33% decrease in emissions between 1983 and 2002.
• Inhaling sulfur dioxide is associated with increased respiratory symptoms and disease, difficulty in breathing, and premature death.

• 76% of SO₂ emissions in the US come from coal burning
• 4% come from transportation
• 7% come from smelting: Heating a metal ore, like copper or nickel, to a high temperature to purify the metal which releases SO₂.
• Note: Canada claims that half their acid deposition in the east comes from the US. We do estimate that 4 million metric tons of SO₂ do drift northward to Canada.

SO₃, Sulfur Trioxide

• SO₃ as a gas is a significant pollutant
• 2 SO₂(g) + O₂(g) → 2 SO₃(g)
• It is the primary agent in acid rain (makes sulfuric acid H₂SO₄ a strong acid)
• Its shape is trigonal planar
• It is prepared industrially on massive scales as a precursor to sulfuric acid
• In factories, SO₃ gas is mixed into flue gas (combustion exhaust) from combustion to make the ash charged before flowing through electrostatic filters. The filters will then trap the ash, making cleaner emissions possible.

Southern California

• January 1982 fog in Pasadena was pH 2.5
• Later 1982 Corona del Mar fog was pH 1.5
• But SO₂ concentration low
• Something besides SO₂ and SO₃ must contribute to acid rain!
• Does it have to do with all that traffic?
• Little sulfur in gasoline, but there is nitrogen in air that gets sucked into the gasoline engine
  – N₂(g) + O₂(g) at high temp → 2 NO(g)
• Coal plants also emit tons of NO(g)
• 35% of NO comes from coal plants, 58% comes from transportation, 5% from industry

6.8 NO nitrogen monoxide

• Also called nitric oxide
• Shape is linear
• It is also an air pollutant produced by cigarette smoke, car engines and power plants.
• The use of internal combustion engines has drastically increased the presence of nitric oxide in the environment.
• One purpose of catalytic converters in cars is to minimize NO emission by catalytic conversion to O₂ and N₂.
• Nitric oxide in the air can convert to nitric acid which causes acid rain.
• Don’t confuse with N₂O nitrous oxide, a greenhouse gas and laughing gas.
**NO₂, nitrogen dioxide**

- NO₂ is a major pollutant gas
- Bent shape
- Is a reddish brown toxic gas
- Prepared in air: \(2 \text{ NO} + \text{O}_2 \rightarrow 2 \text{ NO}_2\)
- Then \(\text{NO}_2 + \text{OH} \rightarrow \text{HNO}_3\) nitric acid
- The main sources are internal combustion engines and power plants.
- Nitrogen dioxide is also produced by atmospheric nuclear tests and is responsible for the reddish color of mushroom clouds.
- A 2005 study at UCSD suggest a link between NO₂ and SIDS.

**6.9 Nitrogen Cycle**

- \(\text{N}_2\) in air is not in a form plants can use, they need nitrates (\(\text{NO}_3^-\)) or ammonia (\(\text{NH}_3\)).
- Bacteria near bean and pea plant roots can “fix” nitrogen = removing \(\text{N}_2\) from air and convert to \(\text{NH}_3\) which plants can absorb
- Other bacteria can cause nitrification = converting \(\text{NH}_3\) into \(\text{NO}_3^-\) ions.
- Bacteria can also cause denitrification = converting nitrates back to \(\text{N}_2\) gas
- Bacteria alone often not enough – need fertilizer
  \(-\) \(\text{N}_2(g) + 3 \text{H}_2(g) \rightarrow 2 \text{NH}_3(g)\) is the Haber-Bosch process and allows industry to make ammonia

**6.10 SO₂ and NOₓ**

- Contribute to acid rain
- A little is produced naturally by volcanoes, the ocean, lightning, bacteria. But more is produced by humans.
- \(\text{NO}_x\) levels in the US are now leveling off
- \(\text{SO}_2\) emissions in the US have decreased since 1974 in part thanks to Clean Air Act 1990.
- Global \(\text{SO}_2\) levels are just now decreasing this past decade. China leads in emissions today.
- Some concern about China and India growing and emitting more \(\text{SO}_2\) and \(\text{NO}_x\) raising global levels. This is not sustainable.

**6.11-12 Acid Deposition**

- Rainwater is naturally acidic
- Natural amounts of \(\text{CO}_2\) are in air.
  \(-\) \(\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3\)
- Carbonic acid however is a weak acid
- Normal rain is about pH of 5.3
- Acid rain however has a pH of 3 – 5
- Who cares about acid rain???

**Acid Rain Can Damage Metals**

- Iron reacts with acids
  \(-\) Bridges, railroads, vehicles, fences, steel rods, ships, buildings all contain iron
  \(-\) Iron rusts faster in the presence of acid
- We spend billions of dollars to protect exposed iron by painting and coating.
- Marble also dissolves slowly in acid.
Acid Rain Deteriorates!

In 1944 At present
© NYC Parks Photo Archive/Fundamental Photographs © Kristen Brodman/Fundamental Photographs

Acid Rain Deteriorates!

Effect of NO\textsubscript{x}\ on lungs

Haze

- Caused by tiny droplets or particles suspended in the air
- Sulfuric acid can make such droplets in air which scatter sunlight and cause haze
- Breathing acidic droplets causes lung damage and drives up health care costs
- If we reduce SO\textsubscript{2} and NO\textsubscript{x} we will save billions of dollars in health care costs
- Coal plants pollute, but individuals pay the health care costs. Is this fair?

6.13 Damage to Lakes and Streams

- Humans are not the only species bearing the costs of acid rain
- Healthy lake has pH of 6.5. Below 6 damage occurs. Most dead by 5.0. All dead by 4.0.
- Luckily many midwest lakes contain limestone which neutralizes acid.
- New England is not so lucky as their lakes are becoming more acidic.

Table 6.2 Effects of Acid Rain

<table>
<thead>
<tr>
<th>Visibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>In the atmosphere, sulfur dioxide and nitrogen oxides form sulfate and nitrate aerosols that impair visibility and affect enjoyment of national parks and other scenic views.</td>
</tr>
</tbody>
</table>

Beijing LA

Table 6.2 Effects of Acid Rain

<table>
<thead>
<tr>
<th>Surface Waters</th>
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</thead>
<tbody>
<tr>
<td>Acidic surface waters decrease the survivability of animal life in lakes and streams. In more severe instances, acidity eliminates some or all types of fish and organisms.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most aquatic life disappears Many fish disappear Normal aquatic life</td>
</tr>
</tbody>
</table>

Acidity increases as pH decreases
Great Web Site – let’s check it out

- [http://www.epa.gov/acidrain/index.html](http://www.epa.gov/acidrain/index.html)

- Click on left margin for
  - Definitions
  - Effects on animals, forests, cars, buildings, health, visibility
  - How to reduce it
  - Maps

Let’s examine some household acids and bases

- **Vomit**
  - pH~1
  - Aka stomach or gastric acid
  - Acidic due to HCl
  - HCl = hydrochloric acid
  - Causes proteins to denature
  - Inhibits the growth of microorganisms in the stomach which prevents infection
  - Heartburn or acid reflux is caused by regurgitation of gastric acid
  - Acid is produced in the stomach as an aid to digestion and is not intended to be present in the esophagus

- **Citrus fruits**
  - Citric acid, C₆H₈O₇
  - Responsible for the acidic or sour taste in citrus fruits. Lemons have an especially high concentration
  - Is a natural preservative
  - First isolated in 1784 from lemons
  - Used for flavor in many soft drinks
  - Can be used as a cleaning agent

- **Vinegar**
  - Acetic acid, CH₃CO₂H
  - Produced from the fermentation of ethanol (why bad wine tastes vinegary)
  - Used in foods dating as far back as the Egyptians in 3000 BC
  - Varieties include malt, wine, balsamic, rice, palm, cane and more
  - Used as salad dressing, pickling agent, cleaning agent, eco-friendly weed killer, window cleaner, urine cleaner for pets, brass polisher, coffee stain remover and more
Colas

- Acids are added to soft drinks for that extra tangy "bite"
- Phosphoric acid, $\text{H}_3\text{PO}_4$
  - Also used as a buffer and rust remover
  - Cheap and produced in large amounts
- Citric acid (already discussed)
- The carbonation process results in carbonic acid, $\text{H}_2\text{CO}_3$
  - Also very important in the buffering of blood
  - Carbonation is when $\text{CO}_2$ is dissolved in water

What’s in Your Drink?

<table>
<thead>
<tr>
<th>Drink</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tap Water</td>
<td>7.670</td>
</tr>
<tr>
<td>Mug Root Beer</td>
<td>4.038</td>
</tr>
<tr>
<td>Diet Ritz</td>
<td>3.706</td>
</tr>
<tr>
<td>Diet Mountain Dew</td>
<td>3.365</td>
</tr>
<tr>
<td>Sprite</td>
<td>3.238</td>
</tr>
<tr>
<td>Diet Coke</td>
<td>3.299</td>
</tr>
<tr>
<td>Mountain Dew</td>
<td>3.279</td>
</tr>
<tr>
<td>7 Up</td>
<td>3.202</td>
</tr>
<tr>
<td>Diet Dr Pepper</td>
<td>3.169</td>
</tr>
<tr>
<td>Sprite Orange</td>
<td>3.019</td>
</tr>
<tr>
<td>Diet Pepsi</td>
<td>3.031</td>
</tr>
<tr>
<td>Lemon Nestea</td>
<td>2.965</td>
</tr>
<tr>
<td>Dr Pepper</td>
<td>2.899</td>
</tr>
<tr>
<td>7Up</td>
<td>2.988</td>
</tr>
<tr>
<td>Lemon Brak</td>
<td>2.868</td>
</tr>
<tr>
<td>Pepsi</td>
<td>2.530</td>
</tr>
<tr>
<td>Cola</td>
<td>2.535</td>
</tr>
<tr>
<td>Cherry Coke</td>
<td>2.522</td>
</tr>
<tr>
<td>RC Cola</td>
<td>2.387</td>
</tr>
</tbody>
</table>

pH levels of sodas

Acid Erosion of Teeth

Tap water

- Why is tap water slightly acidic and not neutral?
- $\text{CO}_2$ from the air dissolves in water
- $\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3$
- Carbonic acid is produced which lowers the pH of water

Soap

- Usually made by reacting a fat (olive oil, vegetable oils, animal fat) with lye
- Lye refers to the bases NaOH (caustic soda) or KOH (caustic potash)
- Pure lye should be stored in air tight plastic containers, not glass as it can eat away at glass
- NaOH and KOH are corrosive and will damage skin tissue
**Ammonia**

- Formula is $\text{NH}_3$
- Shape is trigonal pyramid
- Used as a cleaning product, and precursor for fertilizers and drugs
- Household ammonia is actually $\text{NH}_3$ dissolved in water, mixing it with bleach makes a toxic gas
- Highly toxic to aquatic animals thus very dangerous to the environment
- $\text{NH}_3$ was the first polyatomic molecule detected in space in 1968

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**Drain cleaner**

- Liquid drain cleaners contain sodium hypochlorite $\text{NaOCl}$ (bleach), sodium hydroxide or potassium hydroxide in concentrations up to 50 percent.
- Drain cleaners are among the most hazardous household products available to the public. Keep away from children and pets!