Compounds & Elements

Electrolysis of Water

**Equipment** Hoffman apparatus, platinum electrodes, AC-DC rectifier, 100 DC "house current".

**Reagents** Dilute sulfuric acid.

**Presentation**
1. Fill tube with dilute sulfuric acid. Be certain each of the side tubes is completely filled with the solution.
2. Connect the terminals to the current. The power supply should be set anywhere between 6-12 volts, depending upon how fast you wish the electrolysis to proceed.
3. Allow reaction to occur. The hydrogen tube will fill at twice the rate of the oxygen tube.

**Hazards** Because sulfuric acid is both a strong acid and a powerful dehydrating agent, it must be handled with great care. The dilution of concentrated sulfuric acid is a highly exothermic process and releases sufficient heat to cause burns. Therefore, when preparing dilute solutions from the concentrated acid, always add the acid to the water, slowly, with stirring and cooling the receiving beaker. Hydrogen and oxygen gases will be produced in close proximity to one another. This is an explosive combination and any spark could set off this reaction.

**Discussion** There are two electrochemical reactions taking place: oxidation is occurring at the anode and reduction is occurring at the cathode.

**Cathode:**
\[ 2 \text{H}_2\text{O} (l) + 2 e^- \rightarrow \text{H}_2 (g) + 2 \text{OH}^- \]

**Anode:**
\[ 2 \text{H}_2\text{O} (l) \rightarrow \text{O}_2 (g) + 4 \text{H}^+ (aq) + 4 e^- \]

To keep the numbers of electrons balanced, the cathode reaction must take place, twice as much as the anode reaction. If the cathode reaction is multiplied by 2 and the two reactions are added together we get:

\[ 6 \text{H}_2\text{O} (l) + 4 e^- \rightarrow 2 \text{H}_2 (g) + \text{O}_2 (g) + 4 \text{H}^+ (aq) + 4 \text{OH}^- (aq) + 4 e^- \]

If we combine the H\(^+\) and OH\(^-\) to form H\(_2\)O and cancel species that appear on both sides of the arrow, we get the overall net reaction:

Net:
\[ 2 \text{H}_2\text{O} (l) \rightarrow 2 \text{H}_2 (g) + \text{O}_2 (g) \]

Since equal moles of gases at equal pressures occupy equal volumes, the fact that the volume of hydrogen is twice that of the oxygen confirms that there are twice as many moles of hydrogen as oxygen being produced.

**References:** Alyea and Dutton, p.222.

Thermodynamics

Thermite Reaction

**Equipment** Two clay flower pots whose tops are 2.5 inches in diameter and which have approximately 1 cm diameter holes in their bottoms, durable, non-combustible container filled to a depth of approximately 2.5 cm of sand. The diameter should be large enough to catch the molten iron, which will flow from the flower pots. A large ringstand with a ring that will support the flower pots. A safety shield, barbecue lighter, and tongs.

**Reagents** 40-50 grams of thermite mixture. The thermite mixture is a combination of finely powdered aluminum and iron(III) oxide (also called ferric oxide) in a mass ratio of 1:3 respectively, a 5-7.5 cm length of fireworks sparkler.

**Presentation**
1. Plug the hole in the bottom of one of the flower pots with a piece of paper or tape.
2. Fill this flower pot approximately 2/3 full with the thermite mixture. This will take 40-50 grams.
3. Push the sparkler down into the thermite mixture in the center of the pot. Push it into a depth such that it is firmly held in place, somewhere between 1/4 and 1/2 of its length is sufficient. Gently tap the bottom of the pot onto a hard surface to insure that everything is well packed.
4. Nest the filled flower pot into the empty flower pot. The inner flower pot inevitably cracks and the outer flower pot contains it.
5. Place the flower pots into the ring and adjust the ring height, so that the pots are clearly visible to the audience.
6. Make sure the sand container is correctly positioned to catch the molten iron that will flow from the pots.
7. Place the safety shield between the audience and the pots.
8. Light the top of the sparkler with the barbecue lighter and step back.

**Hazards** This reaction produces a large amount of heat flying sparks and molten iron. All combustible materials should be removed from the vicinity of the demonstration and a fire extinguisher should be readily available. Water should not be used to put out any fires or to cool the molten iron. The molten iron can decompose water into hydrogen and oxygen which can be an explosive mixture. Molten iron dropped into water can shatter with a grenade like effect. The molten iron can cause very severe burns and should only be handled with tongs after it has solidified.

**Discussion** The chemical reaction that is occurring in this demonstration is as follows:

\[ \text{Fe}_2\text{O}_3(s) + 2 \text{Al}(s) \rightarrow \text{Al}_2\text{O}_3(s) + 2 \text{Fe}(s) \]

The enthalpy change for this reaction is -849 kJ/mol of iron(III) oxide. To give some idea of what this released heat is doing, keep in mind that iron melts at 1,530 °C. The amount of thermite used in this reaction is suitable for a large lecture hall. The amount may be scaled down for smaller rooms while still providing a spectacular demonstration. After the pots have cooled, separate them and throw the inner pot away. The outer pot should be suitable to be used as the inner pot in the next demonstration. There are numerous methods listed in the literature for setting off this reaction, magnesium ribbon, sulfuric acid and potassium chlorate and sugar, potassium permanganate and glycerine. None of these methods is as convenient, safe, or reliable as the method described herein.


**Temperature Dependence of Silver Oxide Formation**

**Equipment** Bunsen burner or propane torch, lighter. If artificial tarnishing is necessary: 5 volt power supply and leads, container to hold silver object.

**Reagents** Piece of tarnished silver. We use a pitcher, but any item large enough to be visible to the audience should work. Silver oxide powder will also work, though it doesn't have the same impact as a familiar household item. If artificial tarnishing is necessary: 1 M sodium hydroxide solution of sufficient quantity to dip silver object into it

**Presentation**
1. Go through the free energy calculations and show the temperature dependence of the silver oxide formation.
2. Display the tarnished item to the audience, note the tarnished blackened appearence. If your object is not tarnished sufficiently, follow the tarnishing procedures below before the demonstration.
3. Light the torch or Bunsen burner and heat a portion of the tarnished object. The black silver oxide will be replaced by metallic silver wherever the temperature has been raised sufficiently. Apply the heat carefully so as not to melt your object.

**Electrochemical Tarnishing Procedure**
1. Make up enough 1 M sodium hydroxide solution to immerse a significant portion of your item in.
2. Mechanically polish your item until it is smooth and shiny.
3. Immerse your item in the sodium hydroxide solution.
4. Connect the pitcher to the positive lead of the power supply. Connect the negative lead to a large counter electrode (graphite works well).
5. Turn on the power supply and adjust the voltage until the item blackens, this should require less than 5 volts.
6. Allow the item to tarnish for approximately 10 minutes.
7. Turn off the power supply, disconnect the power supply leads, remove the item from the solution, and rinse thoroughly with deionized water.

**Hazards** Either the propane torch or the Bunsen burner can produce an intense and very hot flame. Severe burns can result either directly from the flame or by touching objects heated in them. Solid sodium hydroxide and concentrated solutions can cause severe burns to eyes, skin, and mucous membranes.

**Discussion** Silver metal will oxidize spontaneously upon exposure to free oxygen. This process is commonly referred to as "tarnishing". The chemical reaction describing this process is shown below. 4 Ag(s) + O_2(g) ® 2 Ag_2O(s) Silver metal is a grayish white color, silver oxide is a black color. This contrast in colors makes tarnished silver appear much different in appearence than untarnished silver. This explains why so much physical and chemical effort is spent in removing the tarnish from silver objects.

Thermodynamic Constants of Compounds of Interest [1]
The standard state enthalpy (\(\Delta H^o_{\text{rxn}}\)) and entropy (\(\Delta S^o_{\text{rxn}}\)) changes for the reaction are -62.2 kJ and -0.133 kJ/K respectively as calculated from the thermodynamic data in the above table. These values tell us that the reaction is exothermic and that the entropy of the reaction is negative. The decrease in entropy is to be expected when there are fewer moles of gaseous products than there were moles of gaseous reactants. The entropy and enthalpy terms are in conflict. The enthalpy term favors the reaction being spontaneous, but the entropy term favors the reaction being non-spontaneous. When the terms conflict in such a manner, the temperature at which the reaction occurs will determine the spontaneity. The following equation will allow the standard Gibb’s free energy (\(\Delta G^o_{\text{rxn}}\)) of the reaction to be calculated.

\[
\Delta G^o_{\text{rxn}} = \Delta H^o_{\text{rxn}} - T \Delta S^o_{\text{rxn}}
\]

Substituting the previously calculated values for the standard state enthalpy and entropy changes and the standard state temperature of 298 K into the previous equation yields:

\[
\Delta G^o_{\text{rxn}} = -62.2 \text{ kJ} - (298 \text{ K})(-0.133 \text{ kJ/K})
\]

\[
\Delta G^o_{\text{rxn}} = -22.6 \text{ kJ}
\]

Since \(\Delta G^o_{\text{rxn}} < 0\), the reaction is spontaneous at room temperature. This agrees with our experience that silver does spontaneously tarnish as it sits in air. By rearranging Eq. 1 we may determine at what temperature the reaction would be at equilibrium (\(\Delta G^o_{\text{rxn}} = 0\)). NOTE: It is not entirely accurate to use standard state thermodynamic quantities away from \(T = 298\) K, since they do have a temperature dependence to them, but this usually introduces an acceptably small error in the resulting calculations.

\[
T = \frac{\Delta H^o_{\text{rxn}}}{\Delta S^o_{\text{rxn}}}
\]

\[
T = \frac{-62.2 \text{ kJ}}{-0.133 \text{ kJ/K}}
\]

\[
T = 468 \text{ K}
\]

For \(T < 468\) K the reaction is spontaneous, for \(T = 468\) K the reaction is at equilibrium and for \(T > 468\) K the reaction would be non-spontaneous (or the reverse reaction, see reaction below, would be spontaneous). In order to remove the tarnish from our silver object all we need do is raise the temperature to above 468 K. The animated GIF below shows the temperature being raised by applying a propane torch’s flame to the side of a badly tarnished silver pitcher.

\[
2 \text{Ag}_2\text{O} (s) \rightleftharpoons 4 \text{Ag} (s) + \text{O}_2 (g)
\]


### Endothermic Reaction of Sodium Bicarbonate with Hydrochloric Acid

**Equipment** SBI, temperature probe, 400 mL beaker, magnetic stir bar, stir plate, small 3 finger clamp and ringstand.

**Reagents** 33.3 mL of 3 M hydrochloric acid, 8.4 g of NaHCO₃.

**Presentation** Logger Pro settings: Use a temperature range of 10-25 °C, collect data for 100 seconds at a rate of 2 samples per second.

1. Add the NaHCO₃ to the beaker, place the stir bar in the beaker.
2. Place the beaker on the stir plate. Some insulating material between the beaker and the stir plate is helpful.
3. Clamp the temperature probe to the ringstand, lower the probe into the beaker until it is almost touching bottom. Place the probe so that it is to the side, out of the way of the stir bar.
4. Connect SBI to the computer.
5. Start Logger Pro program and set parameters.
7. Add hydrochloric acid slowly to the beaker, so that the reaction does not overflow the beaker.

Note: Remove the temperature probe from the solution as soon as data collection is complete and rinse with DI water.

**Hazards** Hydrochloric acid can irritate the skin. Hydrochloric acid vapors are extremely irritating to the eyes and respiratory system. Therefore, it should be handled only in well-ventilated area.

**Discussion** The standard state enthalpy of the following reaction is +28.5 kJ mol⁻¹

\[
\text{NaHCO}_3 (s) + \text{H}^+ (aq) \rightleftharpoons \text{Na}^{+} (aq) + \text{CO}_2 (g) + \text{H}_2\text{O} (l)
\]

The standard state Gibb’s free energy is -41 kJ mol⁻¹. Since the reaction is spontaneous, it must be entropy driven. This intuitively makes sense because one of the reactants is a solid and one of the products is a gas, so the overall entropy has increased. A calculation reveals the entropy increase to be 230 J mol⁻¹ K⁻¹.
**Dust Explosion**

**Equipment** 25 x 20 cm can with tightly fitting cover and a bulb funnel attachment for dispersing powder, candle or gas, 8 cm funnel, watch glass, barbecue lighter.

**Reagents** 2 mL of **dry** lycopodium powder.

**Presentation**
1. Place small pile of lycopodium powder on a watch glass.
2. Try to ignite the pile with the lighter.
3. Place lycopodium powder in funnel.
4. Let the powder settle before lighting the candle or gas.
5. Place plug in hole used for lighting the gas or candle.
6. Cover the can securely.
7. Press bulb to disperse the powder.
8. Explosion shoots cover in air and flame rises to around a height of 2 meters.

**Hazards** Stand back to avoid the flying lid and flames. Lycopodium powder is very flammable. Low hazard may cause eye and/or skin irritation, may cause gastrointestinal irritation (nausea, vomits, diarrhea), if ingested may cause respiratory irritation, if inhaled possible asthmatic attack.

**Discussion** Lycopodium powder is the spore from club moss. This demonstration illustrates the increase in a reaction rate with an increase of surface area. With the lycopodium was in a pile, the exposed surface was relatively small and the rate was so slow as to be non-existent. When the powder is blown out of the funnel, the surface area is huge and the combustion reaction rate is so fast that it becomes explosive.

**References** Alyea and Dutton, p. 8(2-17).

**HCl Cannon**

**Equipment** One 250-mL Erlenmeyer flask, a # 6 stopper with 3 holes, two graphite electrodes of a diameter to fit the stopper holes and a length to reach nearly to the bottom of the flask, power supply capable of approximately 6 volts and 2 amperes, 100-mL clear plastic graduated cylinder, with end spout cut off, 2-hole stopper to fit the graduated cylinder, cork to fit the graduated cylinder, plastic tubing and glass bends to channel gases and a camera flask or some other source of intense white light. **Optional:** red and blue filters.

**Reagents** 250 mL of **6 M** HCl, 250 mL of **6 M** NaOH

**Presentation**
1. Pour the HCl solution into the flask so that the level is about 5 cm from the bottom of the stopper.
2. Place the stopper with electrodes and the gas outlet tube firmly onto the flask.
3. Place the stopper with the gas inlet and outlet tubes from the flask firmly into the graduated cylinder.
4. Place the outlet from the graduated cylinder into the NaOH solution The NaOH will react with any escaping chlorine converting it into hypochlorite.
5. Connect the output of the power supply to the electrodes and turn on the power supply.
6. Adjust the power supply to between 5 and 6 volts. This should produce a current of approximately 2 amperes. Hydrogen and chlorine gas bubbles should start forming on the surfaces of the electrodes. **The amount of chlorine formation may look small at first, but the chlorine is soluble in water and so some of it is being dissolved in the solution. The solution will become pale green colored from this process.**
7. Allow the electrolysis to continue until the contents of the graduated cylinder are distinctly green colored from the chlorine (probably 15-20 minutes depending upon the rate of electrolysis).
8. Turn off the power supply.
9. Quickly replace the stopper with the inlet and outlet tubes with a cork. **The cork should be pressed only very gently into the graduated cylinder to prevent the cylinder from rupturing upon ignition.**
10. Clamp the graduated cylinder into to a ringstand, so that the cork will travel in a high arc over the audience.
11. Wearing eye and ear protection, charge a camera flash and flash it next to the tube.
12. The filters may be placed over the light source. The red filter will not transmit light of sufficient energy to initiate the reaction. The blue filter will transmit light of sufficient energy to initiate the reaction.
Hazards Hydrochloric acid can irritate the skin. Hydrochloric acid vapors are extremely irritating to the eyes and respiratory system. Therefore, it should be handled only in well-ventilated area. Solid sodium hydroxide and concentrated solutions can cause severe burns to eyes, skin, and mucous membranes. The cork is propelled with sufficient force to cause injury if someone is hit at blank range. The cylinder may shatter if the cork is seated too firmly. The cylinder weakens with every demonstration and will usually burst after 3-4 uses. The demonstrator should wear some type of hearing protection and the audience should be cautioned to cover their ears.

Discussion

\[
\begin{align*}
\text{Cl}_2 + \text{light (500nm)} & \rightarrow 2\text{Cl}\text{•} (\text{initiation}) \\
\text{Cl}\text{•} + \text{H}_2 & \rightarrow \text{HCl} + \text{H}\text{•} (\text{propagation}) \\
\text{H}\text{•} + \text{Cl}_2 & \rightarrow \text{HCl} + \text{Cl}\text{•} (\text{propagation}) \\
2\text{Cl}\text{•} & \rightarrow \text{Cl}_2 (\text{possible termination}) \\
\text{H}\text{•} + \text{O}_2 & \rightarrow \text{HOO}\text{•} (\text{possible termination}) \\
\text{Cl}\text{•} + \text{O}_2 & \rightarrow \text{ClO}_2\text{•} (\text{possible termination}) \\
\text{radical} + \text{container wall} & (\text{possible termination})
\end{align*}
\]


**Reaction of Magnesium with Dry Ice**

**Equipment** Barbecue lighter, Screwdriver, Handheld propane torch, Gloves, Tongs, Insulating pad or towel

**Reagents** 5lb slabs of dry ice (2), 30 g of Mg turnings

**Presentation Preparation**
1. Using a flathead screwdriver, gouge a hole in the middle of one of the slabs of dry ice. The hole should be a hemisphere, roughly 3-4 cm in diameter.
2. Using a flat, polished metal surface, polish one side of each dry ice block until the two pieces fit together without a gap.
3. Store the dry ice in an insulated container until the time for the presentation of the demonstration.

**Demonstration**
1. Remove the indented piece of dry ice from the container and place it on a towel.
2. Fill the cavity with magnesium turnings.
3. Make sure that no combustible materials are near the apparatus.
4. The next steps are best done with a partner. Light the magnesium turnings. This will take 15 seconds or so, since oxygen has been depleted from the air around the turnings and the magnesium is quite cold.
5. While one person is lighting the magnesium, the other person should be ready to place the other piece of dry ice over the burning magnesium. This needs to be done quickly in order to minimize the reaction of magnesium with molecular oxygen, which is a faster and more exothermic reaction.
6. Once the other piece of dry ice is in place, step back, dim the lights and watch the dry ice glow brilliantly white!
7. Once the reaction has ceased to glow (3-5 minutes), remove the top piece of dry ice and show the white MgO. Using the tongs, the shell of the MgO ball can be cracked open to reveal a black powder which is elemental carbon.

Hazards Work in a well-ventilated area. Do not look directly at burning magnesium. The reaction will release some fine particles of magnesium and magnesium oxide into the air. This can be harmful if inhaled in large quantities. Neither a carbon dioxide nor a water fire extinguisher will put out a magnesium fire. Should a fire result, the best thing to do is to let it burn out on its own, provided it is not growing out of control. In that case call the fire department.

Discussion The white, flaky material is MgO while the black residue is mostly carbon with traces of Mg$_3$N$_2$. The reaction is broken down into elementary steps as shown below. The energies associated with each step were taken from one of two sources, steps 1-6 [3] and steps 7-9 [2].

<table>
<thead>
<tr>
<th>Elementary Step</th>
<th>Associated energy (kJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 2 [ Mg(s) → Mg(l) ]</td>
<td>2 [132]</td>
</tr>
<tr>
<td>2. 2 [ Mg(l) → Mg(g) ]</td>
<td>2 [9.037]</td>
</tr>
<tr>
<td>3. 2 [ Mg(g) → Mg$^{1+}$(g) + e ]</td>
<td>2 [737.3]</td>
</tr>
<tr>
<td>4. 2 [ Mg$^{1+}$(g) → Mg$^{2+}$(g) + e -]</td>
<td>2 [1,449.8]</td>
</tr>
<tr>
<td>5. CO$_2$(g) → C(s) + O$_2$(g)</td>
<td>392.0</td>
</tr>
<tr>
<td>6. O$_2$(g) → 2 O(g)</td>
<td>497.31</td>
</tr>
<tr>
<td>7. 2 [ O(g) + e → O$^{1-}$(g) ]</td>
<td>2 [-141]</td>
</tr>
</tbody>
</table>
The dominant thermodynamic term that gives rise to the exothermicity of the reaction is the lattice energy, step 9. Because of the stability of magnesium oxide, carbon dioxide yields its oxygen to magnesium to form this product. Magnesium will react with other oxides. The key factor is how much energy is required to decompose the oxide as illustrated in step 5. Sand (SiO₂) and water (H₂O) will both react with magnesium under the proper conditions. Unlike the alkali metals, magnesium does not react violently with water at room temperature. The reason for this difference is that a layer of insoluble magnesium oxide forms around the magnesium which separates the remainder of the magnesium from the water. With sodium and potassium, the heat of the reaction is enough to melt the remaining metal, thus increasing the accessible surface area which vigorously accelerates the reaction. The bottom line is that magnesium will take oxygen from nearly any source to form the remarkably stable compound, magnesium oxide.

References

**Sugar Dehydration Without Sulfuric Acid**

**Equipment** 60 mL syringe with nozzle cut off, scrap metal heat shield, mortar and pestle, pipette with bulb, match or butane lighter, aluminum foil and 100 mL beaker.

**Reagents** Table sugar, potassium chlorate, 95% ethanol.

**Presentation**
1. Weigh out 15 g of table sugar (sucrose) and 4 g of potassium chlorate.
2. Place the sugar and potassium chlorate in the mortar and lightly grind until you produce a fine powder and the two components are mixed thoroughly.
3. Pull the plunger back into the syringe until it reaches the 20 mL mark.
4. Pour the powder mixture into the syringe to a depth of approximately 0.5 cm, add enough ethanol to thoroughly wet the powder. Tap the syringe plunger down on a solid surface to remove air bubbles.
5. Repeat step 4 until the syringe is full.
6. Cover the open end of the syringe with the scrap metal. Invert the syringe and place the scrap metal on a firm surface. Depress the plunger to further compress the mixture.
7. Lift the syringe off of the scrap metal and extrude the mixture from the syringe. You should end up with a column approximately 2-3 cm high resting on the scrap metal. If you are not going to use the demonstration within a few minutes, you should cover it with a small beaker to minimize the ethanol evaporation.
8. Place the mixture on a surface and remove any combustible material back about two feet. Laying down some aluminum foil will make any eventual cleanup easier.
9. Remove the beaker if there is one, add another dropper full of ethanol to the mixture and light it with the match or butane lighter.

**Hazards** Potassium chlorate is a strong oxidizing agent. Caution, there are warnings that potassium chlorate should not be exposed to heat, shock or friction and that doing so may lead to fire or explosion, especially if there are oxidizable contaminants present such as sugar. This demonstration has been performed repeatedly without experiencing any such problems associated with the light grinding that is called for, but such possibilities should always be taken into account. There is a small amount of smoke and flame associated with these reactions. A room with even moderately decent ventilation will have no problem dealing with the amounts produced. The heat shield will get quite warm from the reactions and may cause burns if handled too soon upon completion of the demonstration.

**Discussion** This demonstration consists of three reactions, each succeeding reaction is dependent upon the previous reaction for its activation energy. All of the reactions are exothermic.

\[
\text{CH}_3\text{CH}_2\text{OH}(l) + 3\text{O}_2(g) \rightarrow 2\text{CO}_2(g) + 3\text{H}_2\text{O}(g) + 1236 \text{kJ}
\]

\[
\text{C}_{12}\text{H}_{22}\text{O}_{11}(s) + 8\text{KClO}_3(s) \rightarrow 12\text{CO}_2(g) + 11\text{H}_2\text{O}(g) + 8\text{KCl}(s) + 2029 \text{kJ}
\]

\[
\text{C}_{12}\text{H}_{22}\text{O}_{11}(s) \rightarrow 12\text{C}(s) + 11\text{H}_2\text{O}(g) + 429 \text{kJ}
\]
The energies that are shown for the three reactions are based upon the assumptions that the water and carbon being formed are in the gaseous and graphite forms respectively. There is evidence that these assumptions are not entirely accurate (2,3).

From reaction 2, we can see that potassium chlorate reacts with the sugar, but there is only enough potassium chlorate to react with approximately 16% of the available sugar. This allows the remaining 84% of the sugar to react according to reaction 3, driven by the energy release of reaction 2. The gases that are produced during these reactions leave the solid carbon riddled with gas pockets, producing a light, airy carbon column.

References

Gases

Relative Diffusion Rates of Gases

Equipment Specially constructed diffusion rate tube, laser pointer, ringstand, clamps, cotton swabs (2), small rubber bands (2).

Reagents Concentrated HCl and NH₃ solutions.

Presentation
1. Clamp the glass tube to the ringstand so that it is exactly horizontal.
2. Screw the two plugs, the small one holding the laser pointer and the larger one, into the appropriate threads on the glass tube.
3. Adjust the clamp or rubber bands until the laser pointer comes on and stays on.
4. Adjust the laser pointer orientation until it travels the length of the glass tube and strikes near the center of the large plug.
5. Place a small rubber band on the shaft of each swab. Adjust the position of the rubber bands so that the head of the swab rests just above the main tube, so that the heads don’t interfere in the laser beam path.
6. Place several drops of concentrated HCl on one of the cotton swabs. Place several drops of concentrated NH₃ on the second cotton swab.
7. Place one swab into each of the access tubes located near the ends of the main tube. Allow the swabs to go down to the point that the rubber band on the shaft stops the travel.
8. Dim the room lights.
9. After about 3-4 minutes, the solid ammonium chloride particles will begin to form and they will scatter the laser light. This will produce a very visible red spot in the main tube where the particles have formed.
10. You may measure the relative distances from the particle formation to the swab location. The results will conform reasonably well to Graham’s law, or you may simply point out that the particles formed closer to the HCl swab than to the ammonia swab because ammonia is lighter and travels faster.

Hazards Hydrochloric acid can irritate the skin. Hydrochloric acid vapors are extremely irritating to the eyes and respiratory system. Therefore, it should be handled only in well-ventilated area. Concentrated aqueous ammonia can cause burns and is irritating to the skin, eyes, and respiratory system. The light from laser pointers may cause eye damage if shown directly into the eye.

Discussion The reaction we are examining is the following: \( \text{NH}_3(g) + \text{HCl}(g) \rightarrow \text{NH}_4\text{Cl}(s) \) The two gases are released at opposite ends of an enclosed glass tube. When the gases meet, they form ammonium chloride. The ammonium chloride is formed as a finely divided white powder, some of which remains suspended in the air and some of which deposits on the glass surface. Graham’s law tells us that the rate of diffusion of a gas is inversely proportional to the square root of the molecular mass of the gas.

\[
\text{rate}_1 \propto \frac{1}{\sqrt{m_1}} \quad \text{and} \quad \text{rate}_2 \propto \frac{1}{\sqrt{m_2}}
\]
Given the molecular masses of HCl (36.5 g/mol) and NH₃ (17.0 g/mol), we calculate a relative rate of

\[
\frac{\text{rate}_1}{\text{rate}_2} = \sqrt{\frac{m_1}{m_2}}
\]

This says that in a given amount of time, NH₃ should travel 1.46 times as far as HCl. In practice, we see the value of about 1.27. The reason for this is that the gases are actually diffusing through a third gas (air). There are additional collisions that retard the progress of the faster gas, NH₃ to a greater degree than the slower gas, HCl. If a green laser pointer is available, the scattered light is much more dramatic than with the red laser pointers.


The Collapsing Can

Equipment Water, 1-5 gallon can fitted with a rubber stopper or valve, ringstand, large iron ring or large clamp, Bunsen burner and gloves for handling hot can. Alternatively: Aluminum soda can, tongs, and a 2-liter beaker filled with ice water, wire screen for the burner or hot plate.

Presentation
1. Add water to the can to a depth of approximately 1 cm.
2. Heat the water in the can until steam issues continually from the can. Caution, the burner flame can quickly burn a hole in the aluminum can. For a 5 gallon can, the steam should be allowed to issue for a minimum of 5 minutes.
3. Turn off the Bunsen burner and quickly stopper the can or close the valve. OR Remove the aluminum can from the heat with the tongs and quickly invert it in the beaker of ice water.
4. You may speed the cooling of the gallon cans by spraying them with cold water.

Hazards The hot can, water and especially the steam can cause severe burns.

Discussion The boiling water displaces air leaving the interior of the can filled almost entirely with water vapor at atmospheric pressure. As the can cools, the interior pressure equals the vapor pressure of water at that temperature. At 25°C the vapor pressure of water is approximately 20 mm Hg, the pressure differential is approximately 14 lbs/in² or for a rectangular can whose dimensions are 4" x 10" x 8" the total pressure exerted on the surface of the can is: \[2 \times (4 \times 10) + 2 \times (4 \times 8) + 2 \times (8 \times 10)] \times 14 = 4.2 \times 10^3 \text{ lbs} \text{ or approximately 2 tons.}

References Alyea and Dutton, p. 23(10-1).

Nitric Acid Acts Upon Copper

Equipment 1 liter round bottomed flask, cork ring, 1 hole stopper to fit round bottomed flask, 90° glass bend to fit into stopper, approximately 60 cm of Tygon tubing to fit the glass bend, 2 liter or larger clear container (beaker, flask, bucket, aquarium, etc.), 2 pre 1983 U.S. pennies or 6 grams of copper, long glass stir rod, a lightbox improves the visibility tremendously.

Reagents 50 mL of concentrated nitric acid, approximately 2 liters of tap water, 1-2 mL of 0.1% phenolphthalein solution, 6 M or stronger ammonia solution

Preparation
1. Fill the large container nearly full with tap water.
2. Add 1-2 mL of the phenolphthalein solution to the large container and stir.
3. Add ammonia solution dropwise with stirring until the solution is distinctly pink, but not any excess.
4. Insert the glass bend into the stopper and into the tubing.
5. Place the tubing into the container until it is near the bottom.
Presentation

1. Place all of the components on a lightbox if one is available.
2. Place the round bottomed flask on the cork ring, tilt it and gently allow the pennies to slide to the bottom of the flask. Place the flask upright.
3. Carefully add the 50 mL of nitric acid to the round bottomed flask.
4. Quickly place the stopper firmly into the round bottomed flask.

Hazards Nitric acid is a corrosive chemical with a number of adverse effects: Effects of Exposure: TARGET ORGANS: EYES, SKIN, MUCOUS MEMBRANES OF THE RESPIRATORY TRACT, TEETH. THIS MATERIAL IS CORROSIVE TO ANY BODY TISSUES IT CONTACTS. DENTAL EROSION IS ALSO REPORTED. ACUTE EFFECTS - IRRITATION AND/OR CORROSIVE BURNS OF SKIN, EYES, AND UPPER RESPIRATORY TRACT (URT), DELAYED PULMONARY EDEMA, PNEUMONITIS, BRONCHITIS, AND DENTAL EROSION. Nitrogen dioxide is a toxic compound, do not inhale it. INHALATION: PULMONARY TRACT IRRITATION, THROAT IRRITATION, TIGHTNESS IN CHEST, HEADACHE, NAUSEA, & GRADUAL LOSS OF STRENGTH. SKIN/EYES: CORROSIVE ACTION.

This demonstration presents several very interesting chemical and physical phenomena.

The first reaction is an oxidation reduction reaction where copper is oxidized from the zero state to a +2 state and the nitrogen is reduced from the +5 state in nitrate to the +2 state in nitrogen monoxide. It may be pointed out that other strong acids such as hydrochloric and sulfuric do not react with copper.

The red-brown gas that appears in the round bottomed flask is caused by the same compound responsible for the red-brown haze that hangs over certain cities, nitrogen dioxide. The nitrogen monoxide reacts with atmospheric oxygen to produce nitrogen dioxide as shown in the second reaction.

There is acid-base chemistry going on. The nitrogen dioxide that is produced in the round bottomed flask is bubbled through water that has been made basic via the addition of ammonia and the condition made visible by the presence of phenolphthalein. As the nitrogen dioxide bubbles through the basic solution, the pink color disappears. This shows that the solution is no longer basic, but has become acidic. The nitrogen dioxide has been converted to nitric acid and nitrous acid as shown in the third reaction. This is the same reaction by which nitrogen oxide pollutants make acid rain.

The reaction between the copper and the nitric acid is exothermic. The contents of the round-bottomed flask including the gas are at an elevated temperature.

The reaction comes to an end when the last of the copper is used up. This makes the copper the yield limiting reagent. When the reaction ceases, the bubbles of gas stop. As the contents of the round-bottomed flask cool, the gas pressure decreases in the round bottomed flask. This illustrates the pressure-temperature relationship of gases. As the pressure in the round bottomed flask decreases, the gas in the tubing is drawn back into the flask and water from the Erlenmeyer flask is also drawn through the tubing. This is a fairly slow process since the flask cools slowly.

Nitrogen dioxide is soluble in water and is continuously dissolving in the water from the large container. Since the interface between the nitrogen oxide and the water is confined to the cross sectional area of the tubing, the dissolution proceeds slowly. When the water from the large container finally is drawn all the way through the tubing and enters the round-bottomed flask, the interface become much larger and the rate of dissolution increases dramatically. Within a matter of seconds nearly the entire round-bottomed flask is filled with water from the large container.

The solution now in the round bottomed flask takes on the characteristic blue color of the Cu(H₂O)₆²⁺ (n is typically 4,) which illustrates some complex ion chemistry.

\[
3\text{Cu}^{0} + 2\text{NO}_3^{-}(aq) + 8\text{H}^{+}(aq) \rightarrow 3\text{Cu}^{2+}(aq) + 4\text{H}_2\text{O}(l) + 2\text{NO}(g) \\
2\text{NO}(g) + \text{O}_2(g) \rightarrow 2\text{NO}_2(g) \\
2\text{NO}_2(g) + \text{H}_2\text{O}(l) \rightarrow \text{H}^+(aq) + \text{NO}_3^{-}(aq) + \text{HNO}_2(aq) \\
3\text{HNO}_2(aq) \rightarrow \text{H}^{+}(aq) + \text{NO}_3^{-}(aq) + 2\text{NO}(g) + \text{H}_2\text{O}(l)
\]

The procedure used in this demonstration is loosely based upon a pamphlet authored by Lang, Showalter and Shulfer ¹. The chemistry is described in a book by Shashashiri ².

References

1. C. Marvin Lang, Donald L. Showalter, Gary J. Shulfer, "YES VIRGINIA, ... LEARNING CHEMISTRY CAN BE FUN!", University of Wisconsin-Stevens Point, 1992, p. 2-3.
Electrons and Atom

Magnetic Susceptibility

Equipment 5 kilogauss magnet, ring stand with wood or aluminum rod clamped on top, thread with loop at end affixed to rod, small test tubes with hook in each stopper for string attachment. Additionally, a digital balance with a minimum accuracy of 0.1 g and a hook below the pan may be used.

Reagents SiO₂, KNO₃, Na₂SO₄, CoCl₂, MnO₂, Fe₃O₄, NH₄VO₃, KMnO₄, K₂Cr₂O₇, Cu, Co(NH₃)₆Cl₃, Na₃FeF₆, Cr₂O₃, (NH₄)₂SO₄·FeSO₄, Iron nails, Co(NH₃)₄Cl₂Cl₂.

Presentation
1. Remove keeper from magnet. Force keeper down with thumbs, allowing the heavy disk to follow the magnet’s inner surfaces until the keeper can be removed.
2. Hang the samples on the thread. Adjust the length and height so the sample is level with the poles of the magnet. Move the magnet along the desk. The sample tube will follow the magnet or not. Describe atomic architecture of sample, note color, guess weather para- or diamagnetic, covalent or ionic bonding.
3. Alternatively, suspend the tube directly from the balance hook (out of magnetic field) and zero the balance.
4. Suspend the tube from thread so that it is in the magnetic field.
5. Note if any change in the balance reading occurs.

Hazards Remove wrist watch. The iron nails may smash against the magnet and break the test tube.

Discussion Paramagnetic materials contain unpaired electrons.

References Tutorial Video Tape III found in Learning Resources Centers in Walter Library and St. Paul Library.

Ions and Molecules

Extraction

Equipment 250 or 500-mL separatory funnel, four 100-mL beakers, overhead projector, ringstand with iron ring.

Reagents About 500 mL of water saturated with iodine and about 300 mL of chloroform or cyclohexane.

Presentation
1. Half fill the separatory funnel with the water/iodine solution. Be certain the stopcock is closed first!
2. Dispense ~20 mL of the water/iodine solution into a 100 mL beaker.
3. Place the beaker on the overhead projector, so that it may be seen that some of the light is absorbed by the solution.
4. Add 75-100 mL of chloroform or cyclohexane to the separatory funnel. Stopper the separatory funnel.
5. Hold the stopper in place and invert the separatory funnel 2-3 times fairly quickly.
6. Right the separatory funnel and loosen the stopper to vent some of the pressure that has built up.
7. Replace the stopper, and hold it as you invert several more times. The organic layer should be distinctly purple.
8. Continue to invert until the color of the chloroform layer becomes constant.
9. Drain the chloroform layer into a container.

Repeat steps 2-9 for as many times as you care to. The amounts stated here are for a series of 3 extractions.

Hazards Vapor of iodine is a severe irritant and lachrymator. Solutions of iodine irritate skin. Contacts may cause skin burns. Chloroform may irritate eyes and skin (with no serious damage). Chloroform is a suspected carcinogen and teratogen. Therefore, avoid contacts with iodine and chloroform; they should be handled with care. Excessive inhalation of cyclohexane is irritating to the upper respiratory tract. Repeated contact with the skin can cause dermatitis.

Discussion Iodine is a non-polar molecule this has a weak interaction with the hydrogen bonded water molecules. The energy associated with the iodine/ water interactions is not enough to compensate for the lost energy of the water/water interactions. This ultimately means that not much iodine will dissolve in water. If a solvent with weaker solvent/solvent interactions than water were introduced to this system, iodine would find it easier to disrupt these interactions and insert itself (dissolve) between the
solvent molecules, cyclohexane or chloroform are such solvents. They have no hydrogen bonding and are only very slightly polar. Energywise, it is more favorable for the iodine to dissolve in the non-polar solvent than in the water, so it exists preferentially (but not totally, an equilibrium will exist) in the non-polar solvent. The release of energy as the iodine switches solvents is partially responsible for the initial build up of pressure in the separatory funnel.

This same argument explains why the non-polar solvent does not dissolve in the water, so two layers are produced when the two solvents are added together.

The transfer of iodine from the water to the chloroform is an equilibrium process. This can be seen in the series of beakers of the iodine/water that were dispensed from the separatory funnel. After each extraction of iodine with chloroform, the amount of iodine remaining in the water became less and less. The series of beakers becomes less and less colored as the iodine responsible for the color is removed.

Why do the extraction in a series of small additions instead of one large addition?
Assume that the iodine distributes itself between the water and chloroform layer in a ratio of 1:9 respectively. This means that one extraction will remove 90% of the original iodine from the water, leaving 10% behind. A second extraction removes 90% of the remaining iodine from the water. In terms of the original amount of iodine that would be: 

\[
(0.10)(0.90) = 0.090 \text{ or } 9\%
\]

This leaves 0.10 - 0.090 = 0.010 or 1% of the original iodine in the water and 0.990 or 99.0% of the original iodine is in the two chloroform extractions. This is certainly better than the 90% gained from one extraction. This could go on and on depending upon your patience and how much chloroform you can lay your hands on. Three extractions would leave only 0.0010 or 0.1% of the original iodine in the water. The process of extractions reaches its ultimate practical limits in a technique known as chromatography. This a technique where the number of extractions has grown huge (100’s of thousands in some cases) and the size of the solvent fractions has shrunk to essentially a shell of a few solvent molecules surrounding a solute molecule (iodine in this case).

References
1. Alyea and Dutton, p. 223.
2. Tutorial Video Tape IX found in Learning Resources Centers in St. Paul Library. Tutorial Video Tape XIII also found in the Learning Resources Centers

**Tyndall Effect (light scattering)
(blue sky-red sunset)**

**Equipment** One 1-liter tall form beaker, long stirring rod, overhead projector, mask for overhead with a hole cut in the center (the hole's diameter should be slightly smaller than the beaker's diameter).

**Reagents** One liter of 0.025 M HCl solution, 6 mL of saturated sodium thiosulfate solution (Na₂S₂O₃).

**Presentation**
1. Place the mask on the overhead, center the hole on the projector.
2. Add the HCl solution to the beaker, place the beaker over the hole in the mask.
3. Focus the projector, so there is a bright spot on the screen.
4. Add 6 mL of the thiosulfate solution to the beaker and stir. Remove the stirring rod and observe the beaker and the spot on the screen.

**Hazards** Hydrochloric acid can irritate the skin. Hydrochloric acid vapors are extremely irritating to the eyes and respiratory system. Sodium thiosulfate may be harmful if swallowed or inhaled, may cause irritation to skin, eyes and respiratory tract.

**Discussion**
The first signs of turbidity occur in the beaker in approximately 1 to 1.5 minutes. The contents of the beaker will becomes more turbid as time goes on. The beaker will begin to glow and will glow more brightly as the turbidity increases. The spot on the screen will darken and take on a reddish-orange tint. Eventually, the spot will darken completely (in approximately 4.5 minutes). These effects result from the light being scattered by colloidal particles of sulfur. These sulfur particles are generated via the following reaction:

\[
\text{S}_2\text{O}_3^{2-} \text{(aq)} + \text{H}^+ \text{(aq)} \rightarrow \text{S}\text{(colloidal)} + \text{HSO}_3^- \text{(aq)}
\]

A little time is required to produce colloidal particles of sufficient size to noticeably scatter, so you get to see the gradual increase of the scattering effect. Scattering intensity is proportional to the fourth power of the frequency of the light being scattered. This means that blue light has a more intense scattering than red light. As the blue light is scattered, the beaker takes on a bluish glow and the spot of light reaching the screen has the blue removed from it and becomes more reddish. When
there are enough colloidal particles in the solution, no light gets through and the spot on the screen darkens to black. A similar effect can be seen in the sky. Particles in the atmosphere scatter the blue wavelength and we see a blue sky. At sunrise and sunset the sunlight travels through the maximum amount of atmosphere to reach your eye, during this journey, the greatest amounts of blue wavelengths are scattered and the light that reaches your eye is correspondingly richer in the red wavelengths. If the number of scattering particles is increased from sources such as forest fires or volcanic eruptions, you get spectacularly red sunrises and sunsets.

References


Liquids & Solids

The Franklin Flask

**Equipment** Franklin flask, boiling chip, ringstand plus iron ring, thermometer or temperature probe, stopper, burner or hotplate, thermal gloves or towel.

**Reagents** Water, crushed ice.

**Presentation**

1. Partially fill the flask with water and add a boiling chip.
3. Withdraw the flask from the heat using thermal gloves or a towel.
4. When no more steam issues from the flask, insert the stopper with the thermometer or temperature probe into the flask firmly. **Test security of stopper by inverting the flask OVER THE SINK.** If secure, invert flask on ringstand.
5. Place crushed ice in the concave bottom. Water will boil until ice is melted. Keep replenishing the ice until the water has fallen to within 15-20°C of room temperature.

**Hazards** The flask and the hot water can cause burns. Trying to seat the stopper too firmly may cause the neck of the flask to break.

**Discussion** The pressure inside the flask equals the vapor pressure of the water at any given temperature. The cold surface condenses some of the water vapor and reduces the pressure below the equilibrium vapor pressure of water. The water boils to reestablish equilibrium. The hottest water molecules enter the vapor phase. This lowers the flask's temperature via evaporative cooling.

References Alyea and Dutton, p. 60(4-4s).

Solutions and Salts

**Beer's Law**

**Equipment** Plastic well plate with six wells, dropper, small glass stir rod, overhead projector.

**Reagents** KMnO₄ solution of sufficient concentration to be completely opaque.

**Presentation**

1. Place 5 mL of DI water in wells 1-3, place 10 mL of DI water in wells 4-6. Place well tray on overhead projector.
2. Using the KMnO₄ solution, add 1 drop to well 1, 2 drops to well 2 and 4 drops to well 3. Stir the wells.
3. Using the KMnO₄ solution, add 2 drops to well 4, 4 drops to well 5 and 8 drops to well 6. Stir the wells.

**Hazards** Potassium permanganate is a strong oxidizer. Dust causes severe respiratory irritation. Either solid or solutions cause burns of skin.

**Discussion** It should be noted that the KMnO₄ concentrations in wells 1, 2, and 3 are equal to the KMnO₄ concentrations in wells 4, 5, and 6 respectively. This is not a rigorous experimental or mathematical proof, but does convey the essence of Beer's law. In wells 1-3, the only parameter that is changing is the concentration of the KMnO₄. The concentration in well 3 is twice that of well 2 which is twice that of well 1. It may be reasonably said that the amount of light absorbed or the absorbance A of the solution is proportional to the concentration C of the absorbing species.
If the wells on the two different rows are compared, it appears that the absorbance of well 4 matches that of well 2 and that 5 matches 6. The $\text{KMnO}_4$ concentration in well 4 is half the $\text{KMnO}_4$ concentration in well 2. The only difference is that the pathlength $b$ of well 4 is double that of well 2. It may be reasonably said that the absorbance of the solution is proportional to the pathlength.

Mathematically, something that is proportional to two independent quantities is proportional to their product.

We can change the proportionality to an equality by the addition of a proportionality constant. In the case of Beer’s law that proportionality constant is called the molar absorbivity $e$.

**Acids Bases and Buffer**

**Alka-Seltzer Buffer**

**Equipment** One 6 well plate, small stir rod, small rinse beaker.

**Reagents** 50-60 mL of DI water, Alka-Seltzer tablet, universal indicator and solutions of 1 M $\text{HCl}$ and 1 M $\text{NaOH}$.

**Presentation**
1. Add 20-25 drops of universal indicator to the DI water.
2. Pour equal amounts of the DI water w/ indicator into each of the six wells, approximately 10 mL.
3. Break the Alka-Seltzer tablet and choose two pieces of approximately equal mass in the 0.15-0.20 g range.
4. Add one Alka-Seltzer piece to well 3 and the other to well 6 and stir.
5. Add one drop of 1 M $\text{HCl}$ to well 1 and one drop of 1 M $\text{NaOH}$ to well 4 and stir.
6. Add $\text{HCl}$ to well 3 in 5 drop intervals with stirring until the color in well 3 matches the color in well 1. This will take approximately 25 drops.
7. Add $\text{NaOH}$ to well 6 in 5 drop intervals with stirring until the color in well 6 matches the color in well 3. This will take approximately 25 drops.

**Hazards** Hydrochloric acid can irritate the skin. Hydrochloric acid vapors are extremely irritating to the eyes and respiratory system. Therefore, it should be handled only in a well-ventilated area. Solid sodium hydroxide and concentrated solutions can cause severe burns to eyes, skin, and mucous membranes.

**Discussion** An Alka-Seltzer tablet contains 1.9 g (0.022 mole) of sodium bicarbonate and 1.0 g (0.005 mole) of citric acid. Keep in mind we are using fractions of this. When the tablet is added to water, the citric acid reacts with the bicarbonate, producing citrate and carbon dioxide gas.

$$3\text{HCO}_3^{-}(aq) + \text{H}_3\text{C}_6\text{H}_5\text{O}_7^{-}(aq) \rightarrow \text{C}_6\text{H}_5\text{O}_7^{3-}(aq) + 3\text{CO}_2(g) + 3\text{H}_2\text{O}(l)$$

The balanced reaction and the starting amounts of sodium bicarbonate show that there is an excess of the bicarbonate ion. This excess is responsible for the buffering effect of the Alka-Seltzer. The bicarbonate can react with excess acid,

$$\text{HCO}_3^{-}(aq) + \text{H}^+(aq) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(l)$$

Or the bicarbonate can react with excess base,

$$\text{HCO}_3^{-}(aq) + \text{OH}^-(aq) \rightarrow \text{CO}_3^{2-}(aq) + \text{H}_2\text{O}(l)$$


**Disappearing Color**

**Equipment** 1 L or 500 mL Florence flask, stopper.

**Reagents** 1:3 ethanol:water solution with thymolphthalein indicator.

**Presentation**
1. The solution should be a dark blue, if it is not blue, add 1 M NaOH until it is. This typically requires 1-1.5 mL per liter of solution.
2. Fill a Florence flask approximately 1/2 to 1/3 full of the solution and stopper the solution.
3. Have students unstopper the flask, whisper some command to the solution, restopper the flask and give it a gentle swirl.
4. Have the student pass the flask to the next student.
5. Repeat steps 3 and 4 until solution turns colorless.
6. Return the solution to the storage bottle for use at a later date.

Hazards: Solid sodium hydroxide and concentrated solutions can cause severe burns to eyes, skin, and mucous membranes. Ethyl alcohol is flammable.

Discussion: When this solution is exposed to a source of CO₂, the pH will decrease and change the thymolphthalein indicator to its acidic form which is colorless. The ethanol keeps the thymolphthalein in solution. The following reactions illustrate what is occurring in the flask.

\[
\begin{align*}
\text{CO}_2(g) & \rightleftharpoons \text{CO}_2(aq) \\
\text{CO}_2(aq) + \text{H}_2\text{O}(l) & \rightleftharpoons \text{H}_2\text{CO}_3(aq) \\
\text{H}_2\text{CO}_3(aq) + \text{H}_2\text{O}(l) & \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{HCO}_3^- \\
\text{In}^-\text{(aq)} + \text{H}_3\text{O}^+(aq) & \rightleftharpoons \text{HIn}^{-}\text{(aq)} + \text{H}_2\text{O}(l)
\end{align*}
\]

colorless \hspace{2cm} \text{blue}


Red Cabbage Acid Base Indicator

Equipment: Blender, knife, wire mesh, enough 250 mL beakers for every proposed sample + 3, 10-mL graduated cylinder, glass stir rods. A pH meter may be used to confirm the color observations.

Reagents: Head of red cabbage, DI water, 0.5 M solutions of HCl and NaOH, assorted household products such as milk, soap, aspirin, vinegar, etc. Avoid bleach unless you are prepared to talk about oxidation.

Presentation Procedure:
1. Cut half a head of red cabbage into 1-inch cubes, place in blender, cover cabbage with DI water, and blend thoroughly.
2. Pour the juice into a 250-mL beaker, using a wire mesh to remove the majority of any remaining solids.

Presentation:
1. Add 5 mL of cabbage juice to beakers of 0.5 M HCl and NaOH to provide color reference points.
2. Add 5 mL of the cabbage juice to each sample.
3. Liquid samples: Pour 125 mL into a 250-mL beaker, add cabbage juice and mix.
4. Solid samples: Add ~1 teaspoon of solid to a 250 mL beaker, add 125 mL of DI water, cabbage juice, and mix.
5. You may use a pH meter to determine the pH values of all of the samples.

Hazards: Hydrochloric acid can irritate the skin. Hydrochloric acid vapors are extremely irritating to the eyes and respiratory system. Therefore, it should be handled only in well-ventilated area. Solid sodium hydroxide and concentrated solutions can cause severe burns to eyes, skin, and mucous membranes.

Discussion: Red cabbage and other plants (beets, blueberries, radishes, and many more) contain a class of compounds called anthocyanins. Anthocyanins have different colors that depend upon the numbers of removable protons that remain attached
to the molecule. Anthocyanins are weak acids. When weak acids have different colors depending upon the number of protons that remain with the molecule, we call them acid-base indicators. Some of the more common acid-base indicators are phenolphthalein and litmus (neither of which are anthocyanins). If we were to represent an anthocyanin molecule and two removable protons as $H_2\text{Antho}$, the equilibria showing the loss of its protons would be:

$$H_2\text{Antho} \rightleftharpoons H^+ + \text{HAntho}^-$$
$$\text{HAntho}^- \rightleftharpoons H^+ + \text{Antho}^{2-}$$

If $H_2\text{Antho}$ were red and $\text{HAntho}^-$ were blue and $\text{Antho}^{2-}$ were yellow, we might see a red color at low pH, blue at medium pH, and yellow at high pH. As we change from low to high pH we go from a large $[H^+]$ to moderate $[H^+]$ and finally to low $[H^+]$. As the $[H^+]$ changes, we gradually convert among the three forms of the anthocyanin. The colors that would be seen would be:

<table>
<thead>
<tr>
<th>$[H^+]$</th>
<th>color</th>
</tr>
</thead>
<tbody>
<tr>
<td>very high</td>
<td>red</td>
</tr>
<tr>
<td>high</td>
<td>mixture of red and blue</td>
</tr>
<tr>
<td>moderate</td>
<td>blue</td>
</tr>
<tr>
<td>low</td>
<td>mixture of blue and yellow</td>
</tr>
<tr>
<td>very low</td>
<td>yellow</td>
</tr>
</tbody>
</table>


**Nitric Acid Acts Upon Copper**

**Equipment** 1 liter round bottomed flask, cork ring, 1 hole stopper to fit round bottomed flask, 90° glass bend to fit into stopper, approximately 60 cm of Tygon tubing to fit the glass bend, 2 liter or larger clear container (beaker, flask, bucket, aquarium, etc., 2 pre 1983 U.S. pennies or 6 grams of copper, long glass stir rod, a lightbox improves the visibility tremendously

**Reagents** 50 mL of concentrated nitric acid, approximately 2 liters of tap water, 1-2 mL of 0.1% phenolphthalein solution, 6 M or stronger ammonia solution

**Preparation**

6. Fill the large container nearly full with tap water.
7. Add 1-2 mL of the phenolphthalein solution to the large container and stir.
8. Add ammonia solution dropwise with stirring until the solution is distinctly pink, but not any excess.
9. Insert the glass bend into the stopper and into the tubing.
10. Place the tubing into the container until it is near the bottom.

**Presentation**

5. Place all of the components on a lightbox if one is available.
6. Place the round bottomed flask on the cork ring, tilt it and gently allow the pennies to slide to the bottom of the flask. Place the flask upright.
7. Carefully add the 50 mL of nitric acid to the round bottomed flask.
8. Quickly place the stopper firmly into the round bottomed flask.

**Hazards** Nitric acid is a corrosive chemical with a number of adverse effects: Effects of Exposure: TARGET ORGANS: EYES, SKIN, MUCOUS MEMBRANES OF THE RESPIRATORY TRACT, TEETH. THIS MATERIAL IS CORROSIVE TO ANY BODY TISSUES IT CONTACTS. DENTAL EROSION IS ALSO REPORTED. ACUTE EFFECTS - IRRITATION AND/OR CORROSIVE BURNS OF SKIN, EYES, AND UPPER RESPIRATORY TRACT (URT), DELAYED PULMONARY EDEMA, PNEUMONITIS, BRONCHITIS, AND DENTAL EROSION. Nitrogen dioxide is a toxic compound, do not inhale it. INHALATION: PULMONARY TRACT IRRITATION, THROAT IRRITATION, TIGHTNESS IN CHEST, HEADACHE, NAUSEA, & GRADUAL LOSS OF STRENGTH. SKIN/EYES: CORROSIVE ACTION.

**Discussion**

This demonstration presents several very interesting chemical and physical phenomena.

The first reaction is an oxidation reduction reaction where copper is oxidized from the zero state to a +2 state and the nitrogen is reduced from the +5 state in nitrate to the +2 state in nitrogen monoxide. It may be pointed out that other strong acids such as hydrochloric and sulfuric do not react with copper.
The red-brown gas that appears in the round bottomed flask is caused by the same compound responsible for the red-brown haze that hangs over certain cities, nitrogen dioxide. The nitrogen monoxide reacts with atmospheric oxygen to produce nitrogen dioxide as shown in the second reaction.

There is acid-base chemistry going on. The nitrogen dioxide that is produced in the round bottomed flask is bubbled through water that has been made basic via the addition of ammonia and the condition made visible by the presence of phenolphthalein. As the nitrogen dioxide bubbles through the basic solution, the pink color disappears. This shows that the solution is no longer basic, but has become acidic. The nitrogen dioxide has been converted to nitric acid and nitrous acid as shown in the third reaction. This is the same reaction by which nitrogen oxide pollutants make acid rain.

The reaction between the copper and the nitric acid is exothermic. The contents of the round-bottomed flask including the gas are at an elevated temperature.

The reaction comes to an end when the last of the copper is used up. This makes the copper the yield limiting reagent. When the reaction ceases, the bubbles of gas stop. As the contents of the round-bottomed flask cool, the gas pressure decreases in the round bottomed flask. This illustrates the pressure-temperature relationship of gases. As the pressure in the round bottomed flask decreases, the gas in the tubing is drawn back into the flask and water from the Erlenmeyer flask is also drawn through the tubing. This is a fairly slow process since the flask cools slowly.

Nitrogen dioxide is soluble in water and is continuously dissolving in the water from the large container. Since the interface between the nitrogen oxide and the water is confined to the cross-sectional area of the tubing, the dissolution proceeds slowly. When the water from the large container finally is drawn all the way through the tubing and enters the round-bottomed flask, the interface become much larger and the rate of dissolution increases dramatically. Within a matter of seconds nearly the entire round-bottomed flask is filled with water from the large container.

The solution now in the round bottomed flask takes on the characteristic blue color of the Cu(H₂O)ₙ²⁺ (n is typically 4,) which illustrates some complex ion chemistry.

\[
\begin{align*}
3\text{Cu}^{(s)} + 2\text{NO}_3^{-}(aq) + 8\text{H}^{+}(aq) & \rightarrow 3\text{Cu}^{2+}(aq) + 4\text{H}_2\text{O}(l) + 2\text{NO}_2(g) \\
2\text{NO}_2(g) + \text{O}_2(g) & \rightarrow 2\text{NO}_2(g) \\
2\text{NO}_2(g) + \text{H}_2\text{O}(l) & \rightarrow \text{H}^+(aq) + \text{NO}_3^{-}(aq) + \text{HNO}_2(aq) \\
3\text{HNO}_2(aq) & \rightarrow \text{H}^+(aq) + \text{NO}_3^{-}(aq) + 2\text{NO}_2(g) + \text{H}_2\text{O}(l)
\end{align*}
\]

The procedure used in this demonstration is loosely based upon a pamphlet authored by Lang, Showalter and Shulfer. The chemistry is described in a book by Shashashiri.

**References**

3. C. Marvin Lang, Donald L. Showalter, Gary J. Shulfer, "YES VIRGINIA, ... LEARNING CHEMISTRY CAN BE FUN!", University of Wisconsin-Stevens Point, 1992, p. 2-3.

**Electrochemistry**

**Electrolysis of Water**

**Equipment** Hoffman apparatus, platinum electrodes, AC-DC rectifier, 100 DC "house current".

**Reagents** Dilute sulfuric acid.

**Presentation**

1. Fill tube with dilute sulfuric acid. Be certain each of the side tubes is completely filled with the solution.
2. Connect the terminals to the current. The power supply should be set anywhere between 6-12 volts, depending upon how fast you wish the electrolysis to proceed.
3. Allow reaction to occur. The hydrogen tube will fill at twice the rate of the oxygen tube.

**Hazards** Because sulfuric acid is both a strong acid and a powerful dehydrating agent, it must be handled with great care. The dilution of concentrated sulfuric acid is a highly exothermic process and releases sufficient heat to cause burns. Therefore, when preparing dilute solutions from the concentrated acid, always add the acid to the water, slowly, with stirring and cooling.
the receiving beaker. Hydrogen and oxygen gases will be produced in close proximity to one another. This is an explosive combination and any spark could set off this reaction.

Discussion
There are two electrochemical reactions taking place: oxidation is occurring at the anode and reduction is occurring at the cathode.

\[
\text{Cathode:} \quad 2 \text{H}_2\text{O} (l) + 2 \text{e}^- \quad \overset{\text{®}}{\to} \quad \text{H}_2(g) + 2 \text{OH}^- \\
\text{Anode:} \quad 2 \text{H}_2\text{O} (l) \quad \overset{\text{®}}{\to} \quad \text{O}_2(g) + 4 \text{H}^+ (aq) + 4 \text{e}^-
\]

To keep the numbers of electrons balanced, the cathode reaction must take place, twice as much as the anode reaction. If the cathode reaction is multiplied by 2 and the two reactions are added together we get:

\[
6 \text{H}_2\text{O} (l) + 4 \text{e}^- \quad \overset{\text{®}}{\to} \quad 2 \text{H}_2(g) + \text{O}_2(g) + 4 \text{H}^+ (aq) + 4 \text{OH}^- (aq) + 4 \text{e}^-
\]

If we combine the H\(^+\) and OH\(^-\) to form H\(_2\)O and cancel species that appear on both sides of the arrow, we get the overall net reaction:

\[
\text{Net:} \quad 2 \text{H}_2\text{O} (l) \quad \overset{\text{®}}{\to} \quad 2 \text{H}_2(g) + \text{O}_2(g)
\]

Since equal moles of gases at equal pressures occupy equal volumes, the fact that the volume of hydrogen is twice that of the oxygen confirms that there are twice as many moles of hydrogen as oxygen being produced.

References Alyea and Dutton, p.222.

HCl Cannon

Equipment One 250-mL Erlenmeyer flask, a # 6 stopper with 3 holes, two graphite electrodes of a diameter to fit the stopper holes and a length to reach nearly to the bottom of the flask, power supply capable of approximately 6 volts and 2 amperes, 100-mL clear plastic graduated cylinder, with end spout cut off, 2-hole stopper to fit the graduated cylinder, cork to fit the graduated cylinder, plastic tubing and glass bends to channel gases and a camera flask or some other source of intense white light. Optional: red and blue filters.

Reagents 250 mL of 6 M HCl, 250 mL of 6 M NaOH

Presentation
1. Pour the HCl solution into the flask so that the level is about 5 cm from the bottom of the stopper.
2. Place the stopper with electrodes and the gas outlet tube firmly onto the flask.
3. Place the stopper with the gas inlet and outlet tubes from the flask firmly into the graduated cylinder.
4. Place the outlet from the graduated cylinder into the NaOH solution The NaOH will react with any escaping chlorine converting it into hypochlorite.
5. Connect the output of the power supply to the electrodes and turn on the power supply.
6. Adjust the power supply to between 5 and 6 volts. This should produce a current of approximately 2 amperes. Hydrogen and chlorine gas bubbles should start forming on the surfaces of the electrodes. The amount of chlorine formation may look small at first, but the chlorine is soluble in water and so some of it is being dissolved in the solution. The solution will become pale green colored from this process.
7. Allow the electrolysis to continue until the contents of the graduated cylinder are distinctly green colored from the chlorine (probably 15-20 minutes depending upon the rate of electrolysis).
8. Turn off the power supply.
9. Quickly replace the stopper with the inlet and outlet tubes with a cork. The cork should be pressed only very gently into the graduated cylinder to prevent the cylinder from rupturing upon ignition.
10. Clamp the graduated cylinder into to a ringstand, so that the cork will travel in a high arc over the audience.
11. Wearing eye and ear protection, charge a camera flash and flash it next to the tube.
12. The filters may be placed over the light source. The red filter will not transmit light of sufficient energy to initiate the reaction. The blue filter will transmit light of sufficient energy to initiate the reaction.

Hazards Hydrochloric acid can irritate the skin. Hydrochloric acid vapors are extremely irritating to the eyes and respiratory system. Therefore, it should be handled only in well-ventilated area. Solid sodium hydroxide and concentrated solutions can cause severe burns to eyes, skin, and mucous membranes. The cork is propelled with sufficient force to cause injury if someone is hit at blank range. The cylinder may shatter if the cork is seated too firmly. The cylinder weakens with every demonstration and will usually burst after 3-4 uses. The demonstrator should wear some type of hearing protection and the audience should be cautioned to cover their ears.
Discussion

\[ \text{Cl}_2 + \text{light} (500\text{nm}) \rightarrow 2\text{Cl}^\cdot (\text{initiation}) \]
\[ \text{Cl}^\cdot + \text{H}_2 \rightarrow \text{HCl} + \text{H}^\cdot (\text{propagation}) \]
\[ \text{H}^\cdot + \text{Cl}_2 \rightarrow \text{HCl} + \text{Cl}^\cdot (\text{propagation}) \]
\[ 2\text{Cl}^\cdot \rightarrow \text{Cl}_2 (\text{possible termination}) \]
\[ \text{H}^\cdot + \text{O}_2 \rightarrow \text{HOO}^\cdot (\text{possible termination}) \]
\[ \text{Cl}^\cdot + \text{O}_2 \rightarrow \text{ClO}_2^\cdot (\text{possible termination}) \]
radical + container wall (possible termination)

References

**Fuel Cells and Electrolysis**

**Equipment** Solar Module, PEM-Electrolyser with storage cylinders, 2 overflow pipes for storage cylinders, PEM Fuel Cell, Load Measurement Box, 2 red cables, 2 black cables, 4 silicone tubes, 3 tubing stoppers, stopwatch, lamp with 100 Watt bulb (maximum), alignment diagram. For a complete picture of the apparatus, see Fig. 1.

**Reagents** Distilled or deionized water

**Presentation** This kit can perform several functions:

A. The solar module converts light into current
1. Place the solar module on the alignment diagram so that it is directly over the shaded region of the circle, facing the lamp.
2. Place the lamp on the alignment diagram so that the edge of the bulb is over the edge of the bulb diagram.
3. Turn on the lamp.
4. To measure the current or voltage of the power generated, connect the solar module to the appropriate inputs on the load measurement box using banana clips (optional).

B. The current splits water into hydrogen and oxygen in the electrolyser
1. Connect the overflow pipes to the gas storage cylinders.
2. Fill the O2 and H2 gas storage cylinders to the 0 mL mark with distilled water.
3. Connect the solar module to the electrolyser with the banana clips.

C. The hydrogen and oxygen are fed into the fuel cell, where they are converted directly into electrical current.
1. Connect the electrolyser to the appropriate fuel cell gas inlets using the two long silicone tubes (the gas inlets of the fuel cell are located above the outlets).
2. Connect the short silicone tubes to the gas outlets of the fuel cell (located directly below the gas inlets). Both of these tubes should be plugged on the other end.
3. Before running the fuel cell, one should collect 5-10 mL of H2 in the hydrogen storage cylinder.
4. To initiate a current, unplug the hydrogen outlet tube briefly to allow hydrogen to get to the fuel cell. This can be monitored by watching the bubbles in the silicone tube.

D. The current drives the electric motor or the bulb.
1. Connect the fuel cell to the current input of the load measurement box using banana clips.
2. An additional set of banana clips can be used to measure the voltage produced by the fuel cell.
3. Ohm's Law can be demonstrated by varying the resistance and comparing the current and voltage.
4. Turn the load to "lamp" to see the lamp light up. It is very faint but take note of the efficiency of the process. A 100 watt bulb can barely light a 12 mW bulb after the power has been converted through these various processes.
5. Turn the load to "motor" to see the motor spin. This is much more visible.
6. The fuel cell will run as long as the 100 W lamp remains on to produce hydrogen or there is hydrogen remaining in the storage tube. To stop the fuel cell, simply remove its hydrogen supply.

**Hazards** Since hydrogen gas is produced in the demonstration, open flames and sparks should be kept away. The lamp generates a lot of heat and could overheat the system if it is placed too close to the solar module. The lamp and solar module should be handled carefully as they could result in skin burns.

**Discussion**
The chemical reactions involved in these processes are the decomposition, via electrolysis, and reformation, via fuel cell, of water:

\[
\begin{align*}
2 \text{H}_2\text{O}(l) & \rightarrow 2 \text{H}_2(g) + \text{O}_2(g) \\
2 \text{H}_2(g) + \text{O}_2(g) & \rightarrow 2 \text{H}_2\text{O}(l)
\end{align*}
\]

The fuel cell works like a battery - the difference is that the fuel cell is constantly supplied with new fuel (H\textsubscript{2}). At the anode, hydrogen gas is lysed and ionized to protons and electrons (see Fig. 2). These protons pass through the polymer electrolyte membrane (nafion, see Fig 2) until they find oxygen and ultimately form water. This is the cathode reaction.

**Fuel Cell based on Polymer Electrolyte Membrane Assembly**

![Fuel Cell diagram](image)

Anode: \text{H}_2(g) \rightarrow 4 \text{H}^+ + 4 \text{e}^-

Cathode: \text{O}_2(g) + 4 \text{H}^+ + 4 \text{e}^- \rightarrow 2 \text{H}_2\text{O}(l)

Overall: \text{H}_2(g) + \text{O}_2(g) \rightarrow 2 \text{H}_2\text{O}(l)

*Electron flow from anode (neg.) to cathode (pos.)*

Max. theoretical V: 1.23 V \hspace{1cm} Max. practical V: 0.6-0.9 V

**Figure 2** The electrons produced at the anode are unable to pass through the polymer electrolyte. Instead they get pushed out of the cell into a circuit that ultimately connects to the cathode. The current of this circuit can be used to power a motor or a light bulb. The catalysts used in hydrogen fuel cells are usually a mixture of platinum and ruthenium. Platinum provides a surface to which \text{H}_2(g) can bind. This binding weakens the H-H bond so that lysing and ionization can easily occur (see Fig. 2). A similar process happens at the cathode, facilitating the joining of oxygen, electrons, and protons to form water. The expense of the platinum catalyst is one reason why fuel cells are not yet universal in automobiles. Another drawback is that these catalysts are poisoned over time and eventually lose their activity. The poisoning is the result of sulfur, carbon monoxide, and other contaminants coating the catalytic surface. The solar module's maximum voltage is 2.4V while its maximum generated current is 200 mA. The electrolyser runs on 1.5 V and a current of up to 500 mA. It can produce H2 at a maximum rate of 3.5 mL/min. The fuel cell runs on 0.7 V and can produce a current of 1000 mA. The fuel cell kit comes with multiple manuals for various experiments to explore different aspects of the processes. Calculations can be made to verify Ohm's law, Avogadro's number, and the stoichiometry of water. Feel free to search through them for the experiment best suited for your situation.

**References**

2. Operating Instructions: Solar Hydrogen Technology Science Kit

**Copper-Zinc Galvanic Cell**

**Equipment** Two 250-mL tall form beakers, strip of zinc, strip of copper, two clamps to hold metal strips, salt bridge filled with 3% agar and 1 M KCl or KNO\textsubscript{3}, voltmeter or computer interface.

**Reagents** 250 mL of 1.0 M \textsubscript{Cu}SO\textsubscript{4} and 250 mL of 1.0 M ZnSO\textsubscript{4}.

**Presentation**

1. Pour one of the solutions into a beaker and the other solution into the other beaker.
2. Clamp the copper strip into the beaker containing the \textsubscript{Cu}SO\textsubscript{4} solution and do the equivalent with the zinc strip.
3. Connect the two beakers with the salt bridge. It is critical that the salt bridge reach beneath the surface of both solutions and that there are no air bubbles anywhere throughout the bridge.
4. Connect one lead from the voltmeter to each of the metal strips. You should get a reading near 1.10 V.
Note: In order to preserve the salt bridge, after completing the demonstration, remove the salt bridge from the beakers, rinse with DI water and return it to its storage container.

Hazards Copper Compounds can be toxic if taken internally, and dust from copper compounds can irritate mucous membranes.

Discussion The standard reduction potentials for the two half-cells are given below.

<table>
<thead>
<tr>
<th>Half Cell RXN</th>
<th>$E^\circ$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Cu}^{2+}(aq) + 2 \text{e}^- \rightleftharpoons \text{Cu}^0(s)$</td>
<td>+0.34</td>
</tr>
<tr>
<td>$\text{Zn}^{2+}(aq) + 2 \text{e}^- \rightleftharpoons \text{Zn}^0(s)$</td>
<td>-0.76</td>
</tr>
</tbody>
</table>

The reaction with the more positive $E^\circ$ proceeds as it is written (\textit{It is the cathodic reaction and the copper strip is the cathode}). The reaction with the less positive (more negative) $E^\circ$ will be forced to proceed in the opposite direction as it is written (\textit{It is the anodic reaction and the zinc strip is the anode}). Changing the direction of a reaction changes the sign of $E^\circ$ for the reaction. Add the two reaction according to the way they will be reacting and sum the appropriate $E^\circ$ value to produce the overall cell reaction and the cell potential.

\[
\text{Cu}^{2+}(aq) + Zn^0(s) \rightleftharpoons \text{Cu}^0(s) + Zn^{2+}(aq) + 1.10
\]

Physically, this says that the copper strip will get heavier as copper ions are reduced and deposited on its surface and the zinc strip will be getting lighter as zinc atoms are oxidized and leave the surface and enter the solution. As can be seen in the photo, our experimental cell is 20 mV lower than the predicted 1.10 V. There are a number of factors that can account for this. The most likely factors are that the solutions are not at 1 molar concentration and that there are potential drops due to resistance to electrical conductivity in the salt bridge and the solutions.


**Plating Copper onto Iron**

**Equipment** Piece of iron (strip, rod, etc.), 250-mL beaker.

**Reagents** Just about any Cu$^{2+}$ containing solution at a concentration of 0.1-1.0 M.

**Presentation**
1. Pour 50-150 mL of the Cu$^{2+}$ solution into the beaker.
2. Dip the piece of iron into the Cu$^{2+}$ solution. The copper will begin plating the iron immediately and within seconds the copper coating will be quite visible.

**Hazards** Solutions of Cu$^{2+}$ irritate eyes and may irritate skin.

**Discussion** The standard reduction potentials for the two half-cells are given below.
The reaction with the more positive $E^\circ$ proceeds as it is written (*It is the cathodic reaction*). The reaction with the less positive (more negative) $E^\circ$ will be forced to proceed in the opposite direction as it is written (*It is the anodic reaction*). Changing the direction of a reaction changes the sign of $E^\circ$ for the reaction. Add the two reaction according to the way they will be reacting and sum the appropriate $E^\circ$ values to produce the overall cell reaction and the cell potential.

\[ \text{Cu}^{2+}_{(aq)} + 2 \text{e}^- \rightleftharpoons \text{Cu}^0_{(s)} \quad +0.34 \]

\[ \text{Fe}^{2+}_{(aq)} + 2 \text{e}^- \rightleftharpoons \text{Fe}^0_{(s)} \quad -0.44 \]

Physically, this says that the Cu$^{2+}$ concentration will decrease as copper ions are reduced and deposited on the surface of the iron and the iron strip will be getting lighter as iron atoms are oxidized and leave the surface and enter the solution. If allowed to continue, the solution would lose the blue color from the Cu$^{2+}$ and become a pale green from the Fe$^{2+}$.

**Tearing an Aluminum Can in Half**

**Equipment** You will need an aluminum can, and a container large enough to sit the can in.

**Reagents** Approximately 400-500 mL of 1 M CuCl$_2$.

**Presentation**
1. Rinse the aluminum can.
2. Score the inside of the can about half way up completely around the circumference of the can. This removes the plastic lining and exposes the bare aluminum.
3. Place the can in the protective container.
4. Pour enough Cu$^{2+}$ solution into the can so that the solution level is above the score mark.
5. Wait approximately 1-3 minutes.
6. Pour the solution out of the can.
7. Grip each end of the can and simultaneously twist and pull. The can will tear apart easily along the score.

You can play a trick by using a scored can and an unscored can and choosing two volunteers from the audience (one clearly stronger than the other). After finishing step 6, give the unscored can to the stronger volunteer. The weaker volunteer will tear apart their can with ease.

**Hazards** Solutions of CuCl$_2$ irritate eyes and may irritate skin.

**Discussion** The standard reduction potentials for the two half-cells are given below.
The reaction with the more positive E° proceeds as it is written (It is the cathodic reaction.). The reaction with the less positive (more negative) E° will be forced to proceed in the opposite direction as it is written (It is the anodic reaction.). Changing the direction of a reaction changes the sign of E° for the reaction. Add the two reaction according to the way they will be reacting and sum the appropriate E° value to produce the overall cell reaction and the cell potential.

\[
\begin{align*}
3\text{Cu}^{2+}(aq) + 2e^- & \rightleftharpoons \text{Cu}^0(s) & +0.34 \\
2\text{Al}^0(s) & \rightleftharpoons \text{Al}^{3+}(aq) + 2e^- & +1.66 \\
\hline
3\text{Cu}^{2+}(aq) + 2\text{Al}^0(s) & \rightleftharpoons 3\text{Cu}^0(s) + 2\text{Al}^{3+}(aq) & +2.00
\end{align*}
\]

This reaction can only take place once the aluminum metal is exposed from behind the protective plastic coating.


**Iron Corrosion**

**Equipment** Petri dish, iron wire or nail.

**Reagents** Agar, potassium chloride, potassium ferricyanide (K₃Fe(CN)₆), phenolphthalein solution, 6 M HNO₃.

**Presentation Solution preparation:** This makes 60 mL of solution, which is sufficient to make up two petri dishes. The solution will be 1% w/w agar, 0.3 M KCl.

1. Add 0.6 g of agar, 1.3 g KCl, 2-3 mL of 0.1 M K₃Fe(CN)₆, 20 drops of 0.01% phenolphthalein solution and 60 mL of DI water to a 150-mL beaker.
2. Heat gently with stirring until everything is dissolved.
3. Pour the solution into the petri dishes until the level is approximately half full.
4. Place a lid on the petri dish and allow it to cool. As long as the dishes remain covered and the solution doesn’t dry out, these may be stored until needed.

**Demonstration:**

1. Clean an iron nail or piece of wire by briefly dipping it in 6 M HNO₃.
2. After cleaning, cut a length of wire ~ 5 cm in length. Be sure to cut both ends freshly.
3. Push the iron down into the agar solution, approximately in the center of the dish.
4. Observe what the iron and agar solution look like. This may be done using an overhead projector for larger classes.
5. The colors develop over time. Typically they are quite distinct after 9 minutes. Examine the iron and agar solution after the colors have developed.

**Hazards** Contacts with solid potassium chloride or with its solutions may lead to an allergic skin reaction, dust may cause throat irritation. Concentrated nitric acid is both a strong acid and a powerful oxidizing agent. Contact with combustible materials can cause fires. Contact with the skin can result in severe burns. The vapor irritates the respiratory system, eyes, and other mucous membranes, and therefore, concentrated nitric acid should be handled only in a well-ventilated area. Potassium
ferricyanide may cause eye and skin irritation, causes digestive and respiratory tract irritation. It may be harmful if swallowed or absorbed through the skin.

**Discussion** The piece of iron appears uniform on the large scale, but at the atomic level it is quite irregular. Regions of the iron which have been subjected to intense stress, like the stamped head and point of the nail, or the sheared ends of the wire, contain atoms that have a higher energy than there unstressed neighbors. These regions lose electrons or undergo oxidation slightly more readily than the unstressed regions. The reaction is shown below.

\[
\text{Fe(s)} \rightleftharpoons \text{Fe}^{2+} \text{(aq)} + 2 \text{e}^{-}
\]

These electrons are readily taken up during the reduction of water, according to the reaction below.

\[
2 \text{H}_2\text{O(l)} + 2 \text{e}^{-} \rightleftharpoons 2 \text{OH}^{-} \text{(aq)} + \text{H}_2 \text{(g)}
\]

alternatively

\[
2 \text{H}_2\text{O(l)} + 4 \text{e}^{-} \rightarrow 4 \text{OH}^{-} \text{(aq)}
\]

If we can keep water and oxygen away from our iron surfaces, we can minimize the amount of corrosion that can occur, since oxidation cannot occur without reduction. This is why we paint and wax our cars. The colors are created from two additional reactions as shown below. Phenolphthalein is a weak acid and will be denoted as HPh.

\[
\text{HPh} \text{(aq)} + \text{OH}^{-} \text{(aq)} \rightleftharpoons \text{Ph}^{-} \text{(aq)} + \text{H}_2\text{O(l)}
\]

colorless pink

Wherever there are significant quantities of OH⁻ the region will turn pink.

\[
\text{H}_2\text{O(l)} + \text{K}^+ \text{(aq)} + \text{Fe}^{2+} \text{(aq)} + \text{Fe(CN)}_6^{3-} \text{(aq)} \rightarrow \text{KFe[Fe(CN)]}_6 \cdot \text{H}_2\text{O(s)}
\]

pale yellow blue

This last compound is called variously Turnbull’s blue or Prussian blue. It is somewhat unusual in that it is a mixed valence compound containing iron in both the +2 and +3 oxidation states. The agar solution will turn blue in any region with a supply of Fe²⁺.


**Nitric Acid Acts Upon Copper**

**Equipment** 1 liter round bottomed flask, cork ring, 1 hole stopper to fit round bottomed flask, 90° glass bend to fit into stopper, approximately 60 cm of Tygon tubing to fit the glass bend, 2 liter or larger clear container (beaker, flask, bucket, aquarium, etc., 2 pre 1983 U.S. pennies or 6 grams of copper, long glass stir rod, a lightbox improves the visibility tremendously

**Reagents** 50 mL of concentrated nitric acid, approximately 2 liters of tap water, 1-2 mL of 0.1% phenolphthalein solution, 6 M or stronger ammonia solution

**Preparation**

11. Fill the large container nearly full with tap water.
12. Add 1-2 mL of the phenolphthalein solution to the large container and stir.
13. Add ammonia solution dropwise with stirring until the solution is distinctly pink, but not any excess.
14. Insert the glass bend into the stopper and into the tubing.
15. Place the tubing into the container until it is near the bottom.

**Presentation**

9. Place all of the components on a lightbox if one is available.
10. Place the round bottomed flask on the cork ring, tilt it and gently allow the pennies to slide to the bottom of the flask. Place the flask upright.
11. Carefully add the 50 mL of nitric acid to the round bottomed flask.
12. Quickly place the stopper firmly into the round bottomed flask.

**Hazards** Nitric acid is a corrosive chemical with a number of adverse effects: Effects of Exposure: TARGET ORGANS: EYES, SKIN, MUCOUS MEMBRANES OF THE RESPIRATORY TRACT, TEETH. THIS MATERIAL IS CORROSIVE TO ANY BODY TISSUES IT CONTACTS. DENTAL EROSION IS ALSO REPORTED. ACUTE EFFECTS - IRRITATION AND/OR CORROSIVE BURNS OF SKIN, EYES, AND UPPER RESPIRATORY TRACT (URT), DELAYED PULMONARY EDEMA, PNEUMONITIS, BRONCHITIS, AND DENTAL EROSION. Nitrogen dioxide is a toxic compound, do not inhale it. INHALATION: PULMONARY TRACT IRRITATION, THROAT
Discussion
This demonstration presents several very interesting chemical and physical phenomena.

The first reaction is an oxidation reduction reaction where copper is oxidized from the zero state to a +2 state and the nitrogen is reduced from the +5 state in nitrate to the +2 state in nitrogen monoxide. It may be pointed out that other strong acids such as hydrochloric and sulfuric do not react with copper.

The red-brown gas that appears in the round bottomed flask is caused by the same compound responsible for the red-brown haze that hangs over certain cities, nitrogen dioxide. The nitrogen monoxide reacts with atmospheric oxygen to produce nitrogen dioxide as shown in the second reaction.

There is acid-base chemistry going on. The nitrogen dioxide that is produced in the round bottomed flask is bubbled through water that has been made basic via the addition of ammonia and the condition made visible by the presence of phenolphthalein. As the nitrogen dioxide bubbles through the basic solution, the pink color disappears. This shows that the solution is no longer basic, but has become acidic. The nitrogen dioxide has been converted to nitric acid and nitrous acid as shown in the third reaction. This is the same reaction by which nitrogen oxide pollutants make acid rain.

The reaction between the copper and the nitric acid is exothermic. The contents of the round-bottomed flask including the gas are at an elevated temperature.

The reaction comes to an end when the last of the copper is used up. This makes the copper the yield limiting reagent. When the reaction ceases, the bubbles of gas stop. As the contents of the round-bottomed flask cool, the gas pressure decreases in the round bottomed flask. This illustrates the pressure-temperature relationship of gases. As the pressure in the round bottomed flask decreases, the gas in the tubing is drawn back into the flask and water from the Erlenmeyer flask is also drawn through the tubing. This is a fairly slow process since the flask cools slowly.

Nitrogen dioxide is soluble in water and is continuously dissolving in the water from the large container. Since the interface between the nitrogen oxide and the water is confined to the cross sectional area of the tubing, the dissolution proceeds slowly. When the water from the large container finally is drawn all the way through the tubing and enters the round-bottomed flask, the interface become much larger and the rate of dissolution increases dramatically. Within a matter of seconds nearly the entire round-bottomed flask is filled with water from the large container.

The solution now in the round bottomed flask takes on the characteristic blue color of the $\text{Cu(H}_2\text{O)}_n^{2+}$ (n is typically 4,) which illustrates some complex ion chemistry.

$$3\text{Cu(s)} + 2\text{NO}_3^-(aq) + 8\text{H}^+(aq) \rightarrow 3\text{Cu}^{2+}(aq) + 4\text{H}_2\text{O(l)} + 2\text{NO}_2(g)$$

$$2\text{NO}_2(g) + \text{O}_2(g) \rightarrow 2\text{NO}_2(g)$$

$$2\text{NO}_2(g) + \text{H}_2\text{O(l)} \rightarrow \text{H}^+(aq) + \text{NO}_3^-(aq) + \text{HNO}_2(aq)$$

$$3\text{HNO}_2(aq) \rightarrow \text{H}^+(aq) + \text{NO}_3^-(aq) + 2\text{NO}_(g) + \text{H}_2\text{O(l)}$$

The procedure used in this demonstration is loosely based upon a pamphlet authored by Lang, Showalter and Shulfer. The chemistry is described in a book by Shakhashiri.

References
1. C. Marvin Lang, Donald L. Showalter, Gary J. Shulfer, "YES VIRGINIA, ... LEARNING CHEMISTRY CAN BE FUN!", University of Wisconsin-Stevens Point, 1992, p. 2-3.

Kinetics
Catalysis
Catalytic Oxidation of Ammonia
Equipmen 250-mL Erlenmyer flask, rubber stopper for flask, barbecue lighter, rod to support wire across the top of the flask, coiled platinum wire. The coil should be approximately 7 mm in diameter and loose enough that the adjacent coils do not touch.

Reagents 25-75 mL of concentrated aqueous ammonia solution.

Presentation
1. Pour the ammonia solution into the flask and stopper it.
2. Attach wire to its support.
3. Adjust the length so that the end of the platinum is 1-3 cm above the surface of the ammonia solution.
4. Unstopper the flask.
5. Heat the end of the platinum wire until it begins to glow red.
6. Quickly, put the wire down into the flask.
7. The wire will glow brightly.
8. The wire may be removed from the flask and it will cease to glow.
9. If the wire is returned to the flask before it gets too cool, it will again glow brightly. This may be repeated many times.

Hazards Concentrated aqueous ammonia can cause burns and is irritating to the skin, eyes, and respiratory tract. Nitrogen dioxide is an extremely toxic gas. It is irritating to the respiratory tract.

Discussion Ammonia is catalytically oxidized at the platinum surface according to the following reaction.

\[
5 \text{NH}_3 (g) + 5 \text{O}_2 (g) \rightarrow 4 \text{NO}_2 (g) + 6 \text{H}_2\text{O} (g)
\]

The reaction is exothermic and as written releases 920 kJ of energy. A second reaction proceeds automatically from the first reaction.

\[
2 \text{NO}_2 (g) \rightarrow \text{2NO}_2 (g)
\]

The second reaction is also exothermic and as written releases 112 kJ of energy. These two reactions taken together make up two thirds of the Ostwald process for the synthesis of nitric acid. If the NO\textsubscript{2} were put into contact with liquid water, nitric acid and NO\textsubscript{2} would be produced. The initial heating of the wire with the lighter provides the activation energy for the reaction. Once the reaction begins, the released energy will provide more than enough activation energy for subsequent reactions to occur. An interesting variation of this demonstration is to substitute a thin copper wire, approximately 0.2 mm in diameter for the platinum wire (2). The heat from the reaction is sufficient to melt the copper wire. The molten copper will spatter and make a spectacular effect. Additionally, some of the copper will oxidize and turn the ammonia solution blue by forming a complex ion between the Cu\textsuperscript{2+} ion and the ammonia \([\text{Cu(NH}_3)_4]^{2+}\). This variation does not work as consistently well as the platinum version does.

References

Platinum Catalyzed Reaction of Hydrogen and Oxygen

Equipment Disposable glass pipet, rubber hose 3-6 feet long to fit pipet and regulator, ringstand, iron ring, wire mesh.

Reagents Tank of hydrogen gas with regulator and 0.5% platinized 1/8 inch alumina pellets

Presentation
1. Pound a small indentation into the center of the wire mesh large enough to contain 2-3 of the alumina petals. The rounded end of a ball peen hammer works well for this. Without the indentation, the hydrogen stream will blow the pellets off of the screen.
2. Attach the iron ring to the ringstand. The height is not critical. Place the wire mesh on the ring and place 2-3 pellets in the indentation.
3. Attach the rubber hose to the pipet and the regulator outlet.
4. Open the hydrogen cylinder and adjust the outlet pressure to approximately 10 psi.
5. Dim the lights.
6. Hold the pipet approximately 6-10 cm from the pellets and allow the hydrogen stream to flow over the pellets. **Note:** Hold the pipet too close and all of the oxygen will be displaced from around the pellets, hold the pipet too far away and the hydrogen concentration will be too dilute around the pellets, either way there will be no reaction.

7. The pellets will begin to glow red hot if the exothermic reaction between hydrogen and oxygen begins to occur. You may use the glow to judge how to adjust the hydrogen stream. Adjust your position for maximum glow. When this is achieved, the hydrogen stream will ignite shortly thereafter.

8. Display the flame to the audience. Closing the outlet valve on the regulator will cause the flame to go out. Repeat if desired.

9. Close the cylinder valve.

**Hazards** Hydrogen is an explosive gas, use in a well ventilated room and do not allow quantities of unreacted hydrogen to build up. The flame produced in this demonstration is very hot and can be up to 25 cm long. Do not allow the flame to come near anyone or any combustibles.

**Discussion** The combination of hydrogen and oxygen to form water is an exothermic process. Despite this fact, hydrogen and oxygen will not react automatically when mixed together. The reason for this is the rather large activation energy needed to begin the reaction. The mechanism is very complex (2-4). However we do know that it is a free radical mechanism and that one of the initiation steps is:

\[ \text{H}_2 (g) \overset{\text{\Delta}}{\rightarrow} 2 \text{H}^\cdot (g) \]

Breaking the bond between the two hydrogen atoms requires 432 kJ/mole. This energy is typically initially provided by a spark or a flame. After the reaction begins, the energy produced from it will provide the necessary energy to continue breaking apart the hydrogen molecules. A catalyst provides an alternative mechanism that has a lower activation energy, this allows the reaction to proceed without the requirement of the initial addition of energy via a flame or spark. Hydrogen molecules will adsorb to the platinum surface. The energy of the interaction between the hydrogen atoms and the platinum surface contributes to the breaking of the bond between the hydrogen atoms. The separate hydrogen atoms are then free to react at the surface or leave the surface and participate in the water forming steps.

**References**
1. Developed in house.

**Genie in a Bottle**

**Equipment** 2 liter soda bottle (or other container - beaker, flask, etc), goggles, spatula, mortar and pestle

**Reagents** 30% hydrogen peroxide, manganese dioxide, it's catalytic effect is greatest if it is freshly ground within 24 hours of use.

**Presentation**
1. Pour 50-100 mL of 30% hydrogen peroxide into 2 liter bottle (enough to cover the “dimples”) or container.
2. Add a pea-sized amount of manganese dioxide to bottle or container.
3. Gaseous oxygen will be emitted from the bottle. The reaction is exothermic; the soda bottle will get hot and shrink slightly.

**Hazards** 30% hydrogen peroxide is a strong oxidizing agent; contact with eyes and skin should be avoided. In case of contact, flush with water for at least 15 minutes. Get medical attention if eyes are affected. Also avoid contact of hydrogen peroxide and combustible materials. 30% hydrogen peroxide must be stored in its original container.

**Discussion** Oxygen is a colorless, odorless gas at room temperature and atmospheric pressure. The discovery of oxygen is typically attributed to Joseph Priestly. However, it was Lavoisier who first realized this gas was a unique component of air. Here oxygen is formed from the decomposition of hydrogen peroxide. Hydrogen peroxide is not a very stable compound and its decomposition can be induced by many means. Light will decompose it, which is why it is sold in brown bottles in drugstores. The surface of manganese dioxide provides a particularly favorable environment to catalyze the decomposition, though the mechanism is somewhat poorly understood.

\[ 2 \text{H}_2\text{O}_2 (aq) \overset{\text{MnO}_2}{\rightarrow} \text{O}_2 (g) + 2 \text{H}_2\text{O}(l) \]
The "genie in the bottle" effect is finely divided water droplets propelled from the bottle by the oxygen formed via the decomposition of hydrogen peroxide.


**Catalytic Decomposition of Hydrogen Peroxide by Iodide**

*"Elephant's Toothpaste"*

**Equipment** Large graduated cylinder (500 mL) or 2 liter soda bottle, goggles, plastic tray or sheet

**Reagents** 30% hydrogen peroxide, dishwashing detergent, saturated solution of potassium iodide -OR- solid potassium iodide

**Presentation**
1. Place graduated cylinder or soda bottle in a plastic tray or on a large sheet of plastic.
2. Pour ~50 mL of 30% hydrogen peroxide into the cylinder or bottle.
3. Add a squirt of dishwashing detergent; agitate slightly.
4. Add ~10 mL of potassium iodide solution OR 1/4 spoonful of solid potassium iodide. (Note: The reaction is much faster with the KI solution.) Step back quickly after adding the potassium iodide.

**Hazards** 30% hydrogen peroxide is a strong oxidizing agent; contact with eyes and skin should be avoided. In case of contact, flush with water for at least 15 minutes. Get medical attention if eyes are affected. Also avoid contact of hydrogen peroxide and combustible materials. 30% hydrogen peroxide must be stored in its original container.

**Discussion** Oxygen is a colorless, odorless gas at room temperature and atmospheric pressure. It is formed here by the catalytic decomposition of hydrogen peroxide by the iodide ion.

\[
\text{H}_2\text{O}_2(\text{aq}) + \text{I}^- (\text{aq}) \rightarrow \text{OI}^- (\text{aq}) + \text{H}_2\text{O}(l)
\]

**Step 1** \[
\text{H}_2\text{O}_2(\text{aq}) + \text{O}^- (\text{aq}) \rightarrow \text{I}^- (\text{aq}) + \text{H}_2\text{O}(l) + \text{O}_2(g)
\]

**Step 2** \[
2 \text{H}_2\text{O}_2(\text{aq}) \rightarrow 2 \text{H}_2\text{O}(l) + \text{O}_2(g)
\]

**Overall**
The first step is the rate limiting step of the reaction. The oxygen that is produced causes the dishwashing detergent to foam; the foam will shoot out of the container! Note that the iodide does not appear in the overall reaction. The overall reaction is exothermic; the heat produced is enough to slightly shrink the plastic of the two liter bottle.

For an interesting twist, put a small amount of food coloring (~5-10 drops) in a strip along the wall of the soda bottle or graduated cylinder (more dramatic if done with graduated cylinder. The resulting foam will have a stronger resemblance to toothpaste.


**Equilibrium**

**Equilibrium Between NO₂ and N₂O₄**

**Equipment** One or two sealed borosilicate glass tube(s) filled with nitrogen dioxide gas, two tall form 1 liter beakers, hot plate, tap water, ice.

**Reagents** None

**Presentation**
1. Fill one of the beakers with tap water and place on hot plate, heat until boiling.
2. Fill the second beaker with a mixture of ice and tap water.
3. Display the sealed tube(s) containing nitrogen dioxide. A white background makes them much more visible.
4. If you have two tubes, place one in each beaker. There will be significant changes in how dark the brown color is in each tube (cold tube gets lighter, hot tube gets darker).
5. If you are working with a single tube, note the color at room temperature and then place the tube in either of the prepared baths. Note the new color of the tube.
6. Remove the tube from the bath that it is in and place it in the other bath. Note the new color of tube.

Hazards The borosilicate tubes can easily withstand the temperature extremes of these two baths, care should be taken so as not to damage the tubes and allow the nitrogen dioxide to escape. Nitrogen dioxide is an extremely toxic gas. It is irritating to the respiratory tract.

Discussion
The equilibrium illustrated in this demonstration is between nitrogen dioxide (NO₂) and dinitrogen tetroxide (N₂O₄). The chemical equation is shown below.

\[
2 \text{NO}_2(g) \rightleftharpoons \text{N}_2\text{O}_4(g)
\]

Physical Constants of Compounds of Interest [2]

<table>
<thead>
<tr>
<th>Compound</th>
<th>Physical state</th>
<th>melting point (°C)</th>
<th>boiling point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO₂</td>
<td>brown gas in equil. with N₂O₄</td>
<td>undefined</td>
<td>see N₂O₄</td>
</tr>
<tr>
<td>N₂O₄</td>
<td>colorless liquid in equil. with NO₂</td>
<td>-9.3</td>
<td>21.15</td>
</tr>
<tr>
<td>N₂O₃</td>
<td>blue liquid or solid</td>
<td>-101.1</td>
<td>decomposes ~3</td>
</tr>
<tr>
<td>HNO₃</td>
<td>colorless liquid</td>
<td>-41.6</td>
<td>83</td>
</tr>
</tbody>
</table>

Nitrogen dioxide is a dark reddish brown gas and dinitrogen tetroxide is a colorless gas. When the equilibrium is shifted to the left, as written, the amount of nitrogen dioxide increases, the amount of dinitrogen tetroxide decreases and the color of the tube darkens. When the equilibrium is shifted to the right, as written, the amount of nitrogen dioxide decreases, the amount of dinitrogen tetroxide increases and the color of the tube lightens. There are two fairly easy ways to shift the equilibrium, the first makes use of the exothermicity of the reaction. As written, the reaction releases 58 kJ of energy (\(\Delta H^\circ = -58 \text{ kJ}\)). Since energy is released, adding more energy via heating shifts the equilibrium to the left and removing energy via cooling will shift the equilibrium to the right. The second method utilizes changes in pressure to shift the equilibrium. This will be covered in another demonstration.

If the tubes contained pure NO₂, all that would be seen in this demonstration would be varying shades of brown, but if the last image is examined closely, a blue/green liquid can be seen in the bottom of the cold tube. This comes about because there is at least a trace of water in the tubes and this leads to the following reaction.

\[
2 \text{N}_2\text{O}_4(l) + \text{H}_2\text{O}(l) \rightleftharpoons 2 \text{N}_2\text{O}_3(l) + 2 \text{HNO}_3(l)
\]

From the table we see that N₂O₃ is a blue liquid under these conditions. Pure HNO₃ is colorless, but if it is contaminated with NO₂ it becomes yellow. The yellow and blue components of this reaction produce the blue/green liquid that is seen. It has not been shown in this demonstration, but if the tube is cooled below the melting point of N₂O₄, the liquid will lose its green component and become totally blue. The reason for this is as follows. In the solid phase, the mixture of NO₂ and N₂O₄ becomes exclusively N₂O₄. This means there is no longer any NO₂ to color the HNO₃ yellow. Without the yellow component the liquid becomes completely blue. Placing the tube in some powdered dry ice is a convenient way to see this phenomenon.

References
2. Electronic version, CRC Handbook of Chemistry and Physics, 81st ed.

Organic Reactions
Relative Reactivities of Primary, Secondary and Tertiary Alcohols

I. Lucas Test

Equipment Three small screw top vials, pipettes w/ bulbs, overhead projector.

Reagents 1-butanol, 2-butanol, 2-methyl-2-propanol, Lucas reagent (16 g anhydrous zinc chloride dissolved in 10 mL concentrated hydrochloric acid).

Presentation
1. Add 5 drops of an alcohol to a vial.
2. Repeat step one with the other two alcohols and separate vials.
3. Add three squeezes of the Lucas reagent to the primary alcohol vial, screw the lid on, shake vigorously, and lay the vial on its side on the center of the overhead projector.

4. Repeat step 2 for the secondary alcohol and then the tertiary alcohol.

**Hazards** Vapors of these three alcohols are mildly irritating to eyes, nose, throat, and are toxic upon inhalation. Liquid contact with eyes is irritating and may produce burns. Repeated contact with skin may dry (defat) and crack skin. Hydrochloric acid can irritate the skin. Hydrochloric acid vapors are extremely irritating to the eyes and respiratory system. Therefore, it should be handled only in well-ventilated area.

**Discussion** The tertiary alcohol will react immediately to produce an insoluble alkyl halide. This makes the contents of the vial cloudy and the vial will appear black on the screen. The secondary alcohol reacts more slowly to produce the corresponding alkyl halide. The time varies from approximately 1-3 minutes depending upon the temperature. The screen image will initially appear clear, but will gradually darken to black. The primary alcohol will not react, so its screen image is clear and remains so.


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**II. Chromic Acid Test**

**Equipment** Three 50 mL beakers w/ stir rods, pipettes w/ bulbs, overhead projector.

**Reagents** 1-butanol, 2-butanol, 2-methyl-2-propanol, chromic acid (1 g chromium (VI) oxide dissolved in 1 mL of concentrated sulfuric acid and this diluted with 3 mL of DI water).

**Presentation**
1. Add enough of the three alcohols to separate beakers to cover the bottoms.
2. Place the beakers on the overhead projector.
3. Add ~2 drops of the chromic acid solution (enough to give the mixture a definite yellow color) to a beaker and stir the contents.
4. Repeat step three for the other two beakers.

**Hazards** Vapors of these three alcohols are mildly irritating to eyes, nose, throat, and are toxic upon inhalation. Liquid contact with eyes is irritating and may produce burns. Repeated contact with skin may dry (defat) and crack skin. Because sulfuric acid is both a strong acid and a powerful dehydrating agent, it must be handled with great care. The dilution of concentrated sulfuric acid is a highly exothermic process and releases sufficient heat to cause burns. Therefore, when preparing dilute solutions from the concentrated acid, always add the acid to the water, slowly, with stirring and cooling the receiving beaker. Both chromic oxide (VI) and chromic acid are powerful oxidizing agents and suspected human carcinogens. Contact with solid chromic anhydride may result in severe burns of eyes with possible permanent vision loss. Skin contact with solid chromic anhydride or with concentrated solutions of chromic acid causes burns with potential for major skin damage.

**Discussion** Primary and secondary alcohols will be oxidized to carboxylic acids and ketones respectively. The tertiary alcohol will not react. When the alcohol is oxidized, the $\text{Cr}^{6+}$ (yellow/orange) is reduced to $\text{Cr}^{3+}$ (blue/green). Therefore the appearance of a blue green color is indicative of a primary or secondary alcohol. The beakers that have reactions take place may become opaque from a variety of precipitates. The colors can still be viewed from the side.


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**Breathalyzer**

**Equipment** Evaporating dish, glass wool, disposable pipets, 2 mm diameter glass rod approximately 10-15 cm long, hotplate, small spatula, small funnel and short length of rubber tubing (~2 cm). If this is to be viewed in a large classroom, a video camera is almost essential.

**Reagents** Concentrated sulfuric acid, saturated potassium dichromate solution, 20% sodium silicate solution, ethanol

**Preparation**
1. Add 5 mL of 20% sodium silicate solution to an evaporating dish. These amounts will provide enough treated silica gel to make 6 trials.
2. Add saturated potassium dichromate solution dropwise until you get an intense yellow color.
3. Add concentrated sulfuric acid dropwise until the solution gels and turns orange.
4. Gently warm the evaporating dish to dry out the silica gel.
5. Stir and scrape the gel until it is fairly dry and about the consistency of coarse sand.
6. Add concentrated sulfuric acid dropwise to return a little moisture to the silica gel. **Note:** Too dry and the reaction will not occur, too wet and you cannot fill the pipet.
7. Push a loose plug of glass wool into the constricted end of a disposable pipet.
8. Attach a small funnel to the large end of the pipet with a short length of rubber tubing.
9. Add the silica gel to the pipet, tap lightly to loosely pack the gel. **Note:** You want a loose packing without large channels or voids, but not so tight that the gas won’t easily pass through the pipet.
10. Place a loose glass wool plug on top of the gel to hold it in place.
11. Seal the ends of the pipet until ready for use. The pipet may be stored indefinitely so long as the pipet is kept sealed so that no moisture is transferred and no contamination prematurely reduces the dichromate.

**Presentation**

1. Clamp the pipet horizontally to a ringstand and remove the seals from the ends of the pipet.
2. Take a clean one hole rubber stopper size 6-8 and place a balloon lip over the large end of the stopper.
3. Add approximately 2-5 drops of ethanol to the balloon through the stopper hole. The more drops that are added, the faster and more complete the reaction will be.
4. Inflate the balloon, pinch the neck of the balloon and carefully insert the large end of the pipet into the hole of the stopper just far enough so that the stopper will remain connected to the pipet.
5. Release the balloon neck, so that the air and ethanol vapor can pass through the pipet.
6. If you don’t want to perform these steps in class, you can perform steps 2-4 before class and clamp the neck of the balloon shut. Release the clamp when you are ready to perform the demonstration.

**Hazards Sulfuric acid:** This substance is a severe eye irritant and could cause permanent damage to your eyes and blindness. This substance is corrosive. Contact with the skin could cause permanent injury (including scarring) to the affected area. Ingestion may cause severe irritation or ulceration of the digestive tract, which may result in nausea, vomiting, diarrhea, and in severe cases, collapse, shock and death. This substance is extremely irritating if inhaled. Inhalation of the aerosol or mist of this material may cause serious adverse effects including acute lung damage and death.

**Potassium dichromate:** Causes eye burns. May cause chemical conjunctivitis and corneal damage. May be fatal if absorbed through the skin. Causes skin burns. May cause skin sensitization, an allergic reaction, which becomes evident upon re-exposure to this material. Chrome ulcers, penetrating lesions of the skin, occur chiefly on the hand and forearm where there has been a break in the epidermis. May be fatal if swallowed. May cause severe and permanent damage to the digestive tract. Causes gastrointestinal tract burns. May cause asthmatic attacks due to allergic sensitization of the respiratory tract. May cause ulceration and perforation of the nasal septum if inhaled in excessive quantities. Causes chemical burns to the respiratory tract. Aspiration may lead to pulmonary edema.

**Sodium silicate:** May result in irritation to eyes, skin, lungs and gastrointestinal tract. **Ethanol:** Vapors may be irritating to the eyes, nose and throat. Inhalation may cause headache, nausea, vomiting, dizziness, drowsiness, irritation to the respiratory tract and loss of consciousness. The vapors are highly flammable, keep away from open flames.

**Discussion**

This demonstration illustrates the oxidation of ethanol by dichromate (orange) under acidic conditions to produce acetaldehyde, see first reaction below. The dichromate then oxidizes the acetaldehyde under acidic conditions to acetic acid, see second reaction below. As the dichromate is oxidizing the various reactants, it is in turn being reduced to Cr\(^{3+}\), which is green. The animation shows a pipet filled with a bright orange mixture of silica gel impregnated with potassium dichromate and sulfuric acid. As the reaction proceeds, the color changes to green caused by the presence of Cr\(^{3+}\) in the form of the sparingly soluble chromium (III) sulfate salt. This particular animation utilized 2 drops of ethanol added to the balloon and the reaction takes place over a period of 5 minutes. Adding more drops would have caused the changes to occur in a much shorter period of time. If a person is close enough to this demonstration, the odors of acetaldehyde and acetic acid may be detected exiting the pipet. Also the tube gets slightly warm. This is probably a combination of the exothermicity of the chemical reactions and the produced water diluting the concentrated sulfuric acid held in the silica gel.

This reaction will work on any primary alcohol. The reactions would be the same with appropriate substitutions of the initial alcohol and the resulting aldehyde and carboxylic acid. This reaction will convert a secondary alcohol to a ketone and the reaction will not proceed as the dichromate is incapable of oxidizing the resulting ketone. No reaction will occur for a tertiary alcohol. These reactions or lack of reaction are used in organic chemistry to identify the particular type of alcohol as a preliminary step in its identification. This type of alcohol detection was once commonly used by law enforcement agencies. It has been replaced with other detection methods utilizing infrared spectroscopy, chromatography and amperometric
react with approximately 16% of the available sugar. This allows the remaining 84% of the sugar to react according to reactions 1 and 2. From reaction 2, we can see that potassium chlorate reacts with the sugar, but there is only enough potassium chlorate to react with approximately 16% of the available sugar. This allows the remaining 84% of the sugar to react according to reaction 2.

The initial idea for this demonstration was found in an internet article, several modifications were made to achieve more reproducible results. The chemistry mentioned here was taken from an organic laboratory manual, and was expanded upon.

References

Sugar Dehydration Without Sulfuric Acid

Equipment 60 mL syringe with nozzle cut off, scrap metal heat shield, mortar and pestle, pipette with bulb, match or butane lighter, aluminum foil and 100 mL beaker.

Reagents Table sugar, potassium chlorate, 95% ethanol.

Presentation
10. Weigh out 15 g of table sugar (sucrose) and 4 g of potassium chlorate.
11. Place the sugar and potassium chlorate in the mortar and lightly grind until you produce a fine powder and the two components are mixed thoroughly.
12. Pull the plunger back into the syringe until it reaches the 20 mL mark.
13. Pour the powder mixture into the syringe to a depth of approximately 0.5 cm, add enough ethanol to thoroughly wet the powder. Tap the syringe plunger down on a solid surface to remove air bubbles.
14. Repeat step 4 until the syringe is full.
15. Cover the open end of the syringe with the scrap metal. Invert the syringe and place the scrap metal on a firm surface. Depress the plunger to further compress the mixture.
16. Lift the syringe off of the scrap metal and extrude the mixture from the syringe. You should end up with a column approximately 2-3 cm high resting on the scrap metal. If you are not going to use the demonstration within a few minutes, you should cover it with a small beaker to minimize the ethanol evaporation.
17. Place the mixture on a surface and remove any combustible material back about two feet. Laying down some aluminum foil will make any eventual cleanup easier.
18. Remove the beaker if there is one, add another dropper full of ethanol to the mixture and light it with the match or butane lighter.

Hazards Potassium chlorate is a strong oxidizing agent. Caution, there are warnings that potassium chlorate should not be exposed to heat, shock or friction and that doing so may lead to fire or explosion, especially if there are oxidizable contaminants present such as sugar. This demonstration has been performed repeatedly without experiencing any such problems associated with the light grinding that is called for, but such possibilities should always be taken into account. There is a small amount of smoke and flame associated with these reactions. A room with even moderately decent ventilation will have no problem dealing with the amounts produced. The heat shield will get quite warm from the reactions and may cause burns if handled too soon upon completion of the demonstration.

Discussion This demonstration consists of three reactions, each succeeding reaction is dependent upon the previous reaction for its activation energy. All of the reactions are exothermic.

\[
\begin{align*}
3\text{CH}_3\text{CH}_2\text{OH}(l) + 3\text{O}_2(g) &\rightarrow 2\text{CO}_2(g) + 3\text{H}_2\text{O}(g) + 1236 \text{ kJ} \\
\text{C}_{12}\text{H}_{22}\text{O}_{11}(s) + 8\text{KClO}_3(s) &\rightarrow 12\text{CO}_2(g) + 11\text{H}_2\text{O}(g) + 8\text{KCl}(s) + 2029 \text{ kJ} \\
\text{C}_{12}\text{H}_{22}\text{O}_{11}(s) &\rightarrow 12\text{C}(s) + 11\text{H}_2\text{O}(g) + 429 \text{ kJ}
\end{align*}
\]

The energies that are shown for the three reactions are based upon the assumptions that the water and carbon being formed are in the gaseous and graphite forms respectively. There is evidence that these assumptions are not entirely accurate (2,3). From reaction 2, we can see that potassium chlorate reacts with the sugar, but there is only enough potassium chlorate to react with approximately 16% of the available sugar. This allows the remaining 84% of the sugar to react according to reaction 2.
3, driven by the energy release of reaction 2. The gases that are produced during these reactions leave the solid carbon riddled with gas pockets, producing a light, airy carbon column.

References

**Diels-Alder Reaction**

**Equipment** video camera, 13 X 100 mm test tubes (3)

**Reagents** 0.05 M solution of anthracene in toluene (178 mg / 20 mL), 0.05 M solution of furan in toluene (72.7 mg / 20 mL), 0.01 M solution 4-phenyl-1,2,3-triazolin-3,5-dione (N-PTD) in toluene (35 mg / 20 mL)

**Presentation**
1. Add 1 mL of N-PTD solution to each of the three test tubes. The first tube is only used to show the color of the N-PTD before reaction with a diene.
2. To the second test tube add 15 drops of anthracene solution.
3. To the third test tube add 15 drops of furan solution.
4. Draw the solutions in test tubes 2 and 3 into a pipet in order to mix the contents.

**Discussion** The Diels-Alder reaction was discovered in 1928 by German chemists Otto Diels and Kurt Alder, who received the Nobel Prize in chemistry in 1950 for their work towards understanding this 4+2 cycloaddition. The Diels-Alder reaction continues to be a widely used reaction in modern organic synthesis because in one step two carbon-carbon bonds are made in a stereoselective way. In the Diels-Alder reaction, an alkene or an alkyne react with a conjugated diene to form an unsaturated six-membered ring. For this demonstration, a colorless diene (furan (1) or anthracene (2)) is reacted with a red dieneophile (4-phenyl-1,2,3-triazolin-3,5-dione (N-PTD) (3)) and a colorless adduct is formed.

![Diels-Alder Reaction Diagram](Diels-Alder reaction diagram)

References [http://www.uni-regensburg.de/Fakultaeten/nat_Fak_IV/Organische_Chemie/Didaktik/Keusch/p2_cyclo_add-e.htm](http://www.uni-regensburg.de/Fakultaeten/nat_Fak_IV/Organische_Chemie/Didaktik/Keusch/p2_cyclo_add-e.htm) (as seen on June 20, 2003)

**Production and Combustion of Acetylene**

**Equipment** Carbide miner's lamp, butane lighter.

**Reagents** Calcium carbide, water
Preparation
1. Add approximately 10 grams of solid calcium carbide to the bottom chamber of the lamp.
2. Securely screw the two parts of the lamp together.
3. Fill the upper chamber of the lamp with water.

Presentation
1. Turn the water drop control lever located on the top of the lamp approximately 3 clicks in a clockwise direction.
2. Wait approximately 10 seconds to allow the acetylene concentration to build up and to flush the oxygen out of the lamp.
3. Light the butane lighter and bring it near the gas outlet nozzle located in the center of the reflector. The acetylene should ignite and a flame will project from the nozzle.
4. Adjust the water drop lever clockwise to make the flame larger or counter-clockwise to make the flame smaller. Dimming the room light will show just how powerful a source of illumination this lamp can be.
5. To turn the lamp off, return the water drop lever to its original position. The flame will become smaller and eventually go out as the supply of acetylene is exhausted.

Hazards Calcium carbide produces flammable acetylene upon contact with water. The calcium carbide may contain a contaminant resulting in the release of the toxic gas phosphine on contact with water. Inhilation: Cough, Laboured breathing, Shortness of breath, Sore throat. Skin: Redness, Skin burns, Pain. Eyes: Redness, Pain, Blurred vision, Severe deep burns. Ingestion: Laboured breathing. Shock or collapse (further see Inhalation).

Discussion
The reaction between calcium carbide and water to form acetylene is shown below:

\[ \text{CaC}_2 (s) + 2\text{H}_2\text{O} (l) \rightarrow \text{Ca(OH)}_2 (aq) + \text{C}_2\text{H}_2 (g) \]

The combustion of acetylene is illustrated by the following reaction.

\[ 2 \text{C}_2\text{H}_2 (g) + 5 \text{O}_2 (g) \rightarrow 4 \text{CO}_2 (g) + 2 \text{H}_2\text{O} (g) \]

The resulting flame is a very luminous yellow.

References Developed in house.

Extraction of DNA

Equipment Blender, beaker (100 mL), strainer, test tubes (up to 10 large tubes and stoppers if tubes are to be passed around class), stir sticks and test tube rack

Reagents DNA source (split peas work best), salt, water, liquid detergent, meat tenderizer, alcohol (70% isopropyl alcohol or 95% ethyl alcohol work well)

Presentation
1. Measure ~100 mL (1/2 cup) DNA source (split peas), pinch of salt (~1 mL or 1/8 tsp), and ~200 mL of water (double the amount of the DNA source) into blender. Blend on high for 15-20 sec.
2. Pour the "pea soup" through a strainer into a beaker. How much "soup" do you have? Add a volume of detergent equal to 1/6 of the "pea soup" volume. Mix slightly and let sit for 5-10 minutes. (This is very important - do not move on to Step 3 without waiting.)
3. Pour soapy "pea soup" in to test tubes; fill each ~1/3 full. Add a pinch of meat tenderizer to each test tube. Mix VERY gently (or you will break up the DNA). 4. Tilt the test tube at an angle of ~45°. Pour the alcohol gently down the side of each test tube until tube are about 2/3 full. Two layers should form. The DNA will rise into the top layer (alcohol layer). The DNA can be removed with a stir stick (sometimes).

Discussion To extract DNA, you must remove it from the cells of the DNA source such as the split peas. Blending the peas with some salt and water breaks the cells apart. However, the DNA is still safely contained in the cell because of the cell and nuclear membranes. These cell membranes are made up of lipids (like grease), which have a polar head and a non-polar tail. The detergent also consists of polar heads and non-polar tails. The molecules in detergent are able to pull apart the cell and nuclear membranes which leave the DNA in the "pea soup". The DNA in the "pea soup" is still covered and protected by the proteins from the cell. The meat tenderizer (or pineapple juice or contact lens solution) contain enzymes which are able to cut apart these proteins to leave the DNA alone. Alcohol is less dense than water and therefore floats above the "pea soup". The proteins, lipids, and DNA all need to decide which solution they prefer. The proteins and lipids prefer the water and the DNA prefers the
alcohol. The DNA therefore moves into the alcohol layer. The DNA formed tends to be stringy and clumped together. You can try to remove it from the test tubes with a stir stick but it is often difficult to do so.

**Some interesting DNA facts:** Each cell of your body contains six feet of DNA! Our bodies contain about 100 trillion cells - that means we have more than a billion miles of DNA within our bodies! To fit this into your cells, the DNA is packed efficiently by twisting tightly and clumping together.

**Some demo tips:** This demonstration works for a variety of DNA sources, detergents, and tenderizers. If you do not see DNA forming, it may be due to the type of DNA source (see discussion below) or the timing in the procedure. It is very important to wait the 5-10 minutes in Step 2 or the cell and nuclear membranes will remain intact, not allowing the DNA to be extracted. If you do not see any DNA immediately, wait 30-60 minutes. . . . the DNA will usually extract into the alcohol layer with time. Different DNA sources will yield DNA at different rates. Frozen peas do not make a good substitute for split peas due to the large amount of water contained in the peas. Extracting DNA from onions works well, but the color of the solution is not as nice. Red cabbage is not a good DNA source as the solution is too dark and the DNA is extracted rather slowly. Try to experiment with other sources of DNA!

**Polymers**

**Nylon Rope Trick**

**Equipment** Ringstand with roller, 4 ounce jar with lid, glass rod with hooked end.

**Reagents** Solution “A” (0.5 M hexamethylenediamine (H₂N(CH₂)₆NH₂, also called 1,6-diaminohexane) and 0.5 M sodium hydroxide in water), Solution “B” (0.2 M sebacoyl chloride (ClO(C(CH₂)₆COCl) in hexane).

**Presentation Preparation**

1. Make solution “A” by placing a bottle of hexamethylenediamine in warm water to melt it (m.p. 39-40°C). Dispense 6.0 g of the hexamethylenediamine into a bottle. Add 2.0 g of sodium hydroxide and add 100 mL of DI water to the bottle. Cap the bottle tightly and shake to dissolve and mix.
2. Make solution “B” by dispensing 2.0 g (1.6 mL) of sebacoyl chloride into a bottle, add 100 mL of hexane to the bottle. Cap the bottle tightly and shake to mix.

**Demonstration**

1. Add 25-50 mL of solution "A" to the jar.
2. Place the glass rod in the center of the jar with the hook down.
3. Carefully pour the same volume of solution "B" as solution "A" down the glass rod, so as not to disturb the interface between the two solutions.
4. After solution "B" has been added, pull the glass rod out of the jar. The hook will snag the nylon that has formed at the interface of the two solutions.
5. Wrap the strand of nylon around the roller and wind the nylon strand onto the roller with a steady pace.
6. When you are done winding the nylon, close the jar to minimize the hexane fumes.

**Hazards** Sebacoyl chloride is corrosive and reacts with water, so it causes severe burns to every area of contact. It is harmful if swallowed, inhaled or absorbed through skin. 1,6-diaminohexane is corrosive. It causes burns to any area of contact. It is harmful if swallowed, inhaled or absorbed through skin. 1,6-diaminohexane is extremely destructive to the upper respiratory tract, eyes and skin. It is combustible either as liquid or as vapor. Solid sodium hydroxide and its concentrated solutions can cause severe burns to eyes, skin, and mucous membranes. Overexposure to vapors of hexane is irritating to the respiratory tract. Contact with liquid is irritating to skin and to eyes.

**Discussion** The word "nylon" is used to represent synthetic polyamides. The various nylons are described by a numbering system that indicates the number of carbon atoms in the monomer chains. Nylons from diamines and dibasic acids are designated by two numbers, the first representing the diamine and the second the dibasic acid [2]. The nylon formed in this demonstration would be 6-10 nylon.

\[
\text{n H}_2\text{N(CH}_2\text{)}_6\text{NH}_2 + \text{n ClOC(CH}_2\text{)}_6\text{COCI} \rightarrow [-\text{NH(CH}_2\text{)}_6\text{NH-CO(CH}_2\text{)}_6\text{CO-}]_n + 2\text{n HCl}
\]

**References**

**Light HCl Cannon**

**Equipment** One 250-mL Erlenmeyer flask, a # 6 stopper with 3 holes, two graphite electrodes of a diameter to fit the stopper holes and a length to reach nearly to the bottom of the flask, power supply capable of approximately 6 volts and 2 amperes, 100-mL clear plastic graduated cylinder, with end spout cut off, 2-hole stopper to fit the graduated cylinder, cork to fit the graduated cylinder, plastic tubing and glass bends to channel gases and a camera flask or some other source of intense white light. **Optional:** red and blue filters.

**Reagents** 250 mL of 6 M HCl, 250 mL of 6 M NaOH.

**Presentation**

1. Pour the HCl solution into the flask so that the level is about 5 cm from the bottom of the stopper.
2. Place the stopper with electrodes and the gas outlet tube firmly onto the flask.
3. Place the stopper with the gas inlet and outlet tubes from the flask firmly into the graduated cylinder.
4. Place the outlet from the graduated cylinder into the NaOH solution. The NaOH will react with any escaping chlorine converting it into hypochlorite.
5. Connect the output of the power supply to the electrodes and turn on the power supply.
6. Adjust the power supply to between 5 and 6 volts. This should produce a current of approximately 2 amperes. Hydrogen and chlorine gas bubbles should start forming on the surfaces of the electrodes. The amount of chlorine formation may look small at first, but the chlorine is soluble in water and so some of it is being dissolved in the solution. The solution will become pale green colored from this process.
7. Allow the electrolysis to continue until the contents of the graduated cylinder are distinctly green colored from the chlorine (probably 15-20 minutes depending upon the rate of electrolysis).
8. Turn off the power supply.
9. Quickly replace the stopper with the inlet and outlet tubes with a cork. **The cork should be pressed only very gently into the graduated cylinder to prevent the cylinder from rupturing upon ignition.**
10. Clamp the graduated cylinder into to a ringstand, so that the cork will travel in a high arc over the audience.
11. Wearing eye and ear protection, charge a camera flash and flash it next to the tube.
12. The filters may be placed over the light source. The red filter will not transmit light of sufficient energy to initiate the reaction. The blue filter will transmit light of sufficient energy to initiate the reaction.

**Hazards** Hydrochloric acid can irritate the skin. Hydrochloric acid vapors are extremely irritating to the eyes and respiratory system. Therefore, it should be handled only in well-ventilated area. Solid sodium hydroxide and concentrated solutions can cause severe burns to eyes, skin, and mucous membranes. The cork is propelled with sufficient force to cause injury if someone is hit at blank range. The cylinder may shatter if the cork is seated too firmly. The cylinder weakens with every demonstration and will usually burst after 3-4 uses. The demonstrator should wear some type of hearing protection and the audience should be cautioned to cover their ears.

**Discussion**

\[
\begin{align*}
\text{Cl}_2 + \text{light (500 nm)} & \rightarrow 2\text{Cl}^* \quad \text{(initiation)} \\
\text{Cl}^* + \text{H}_2 & \rightarrow \text{HCl} + \text{H}^* \quad \text{(propagation)} \\
\text{H}^* + \text{Cl}_2 & \rightarrow \text{HCl} + \text{Cl}^* \quad \text{(propagation)} \\
2\text{Cl}^* & \rightarrow \text{Cl}_2 \quad \text{(possible termination)} \\
\text{H}^* + \text{O}_2 & \rightarrow \text{HO}^* \quad \text{(possible termination)} \\
\text{Cl}^* + \text{O}_2 & \rightarrow \text{ClO}_2^* \quad \text{(possible termination)} \\
\text{radical} + \text{container wall} & \rightarrow \text{possible termination}
\end{align*}
\]


**Beer’s Law**

**Equipment** Plastic well plate with six wells, dropper, small glass stir rod, overhead projector.

**Reagents** KMnO₄ solution of sufficient concentration to be completely opaque.

**Presentation**

1. Place 5 mL of DI water in wells 1-3, place 10 mL of DI water in wells 4-6. Place well tray on overhead projector.
2. Using the KMnO₄ solution, add 1 drop to well 1, 2 drops to well 2 and 4 drops to well 3. Stir the wells.
3. Using the KMnO₄ solution, add 2 drops to well 4, 4 drops to well 5 and 8 drops to well 6. Stir the wells.

**Hazards** Potassium permanganate is a strong oxidizer. Dust causes severe respiratory irritation. Either solid or solutions cause burns of skin.

**Discussion**
It should be noted that the KMnO₄ concentrations in wells 1, 2, and 3 are equal to the KMnO₄ concentrations in wells 4, 5, and 6 respectively. This is not a rigorous experimental or mathematical proof, but does convey the essence of Beer's law. In wells 1-3, the only parameter that is changing is the concentration of the KMnO₄. The concentration in well 3 is twice that of well 2 which is twice that of well 1. It may be reasonably said that the amount of light absorbed or the absorbance A of the solution is proportional to the concentration C of the absorbing species.

\[ A \propto C \]

If the wells on the two different rows are compared, it appears that the absorbance of well 4 matches that of well 2 and that 5 matches 6. The KMnO₄ concentration in well 4 is half the KMnO₄ concentration in well 2. The only difference is that the pathlength b of well 4 is double that of well 2. It may be reasonably said that the absorbance of the solution is proportional to the pathlength.

\[ A \propto b \]

Mathematically, something that is proportional to two independent quantities is proportional to their product.

\[ A \propto bC \]

We can change the proportionality to an equality by the addition of a proportionality constant. In the case of Beer's law that proportionality constant is called the molar absorbtivity e.

\[ A = ebC \]

**Laboratory Techniques**

### Separation of Food Dyes Via Column Chromatography

**Equipment** 10-mL syringes with luer lock tip (6) (*The demonstration may be performed with only one syringe, but it is much more time consuming.*), 6-well microplate, and an overhead projector

**Reagents** Sep-Pak® C18 cartridge, grape flavored Kool-Aid® or grape soda, 70% isopropyl alcohol solution (minimum 20 mL), 25% isopropyl alcohol solution (minimum 10 mL), 5% isopropyl alcohol solution (minimum 10 mL), deionized water

**Presentation Preparation**
1. Use grape soda as it comes or make a 0.3 g Kool-Aid per 100 mL DI water solution (minimum 20 mL).
2. Label the syringes as follows: "grape #1", "grape", "DI water", "70% isopropyl alcohol", "25% isopropyl alcohol #3", "5% isopropyl alcohol #2".
3. Fill each of the syringes with 10 mL of the appropriate solution.
4. Pretreat the column by inserting the "70% isopropyl alcohol" syringe firmly into the end of the column and pushing the solution through the column. **Note: Always connect to the long end of the column.**
5. Do the same thing with the "DI water" syringe.
6. After the demonstration, repeat steps 4 and 5 and the column may be reused indefinitely.

**Demonstration**
1. Place the microplate on the overhead projector.
2. Inject the contents of the "grape" syringe into one of the wells, note the purple color.
3. Insert the "grape #1" syringe firmly into the end of the column and inject the contents into an empty well, note that the eluent is colorless. You may also note that the column now has a purple color.
4. Insert the "5% isopropyl alcohol #2" syringe firmly into the end of the column and inject the contents into an empty well, note that the eluent has a red color. You may also note that the column now has a blue color.
5. Insert the "25% isopropyl alcohol #3" syringe firmly into the end of the column and inject the contents into an empty well, note that the eluent has a blue color. You may also note that the column is now colorless or nearly so.

**Hazards** Isopropyl alcohol is flammable and should be kept away from ignition sources, also EXPOSURE TO HIGH VAPOUR CONCENTRATIONS MAY CAUSE EYE IRRITATION. EXPOSURE TO HIGH VAPOUR CONCENTRATIONS MAY CAUSE RESPIRATORY TRACT IRRITATION, HEADACHE, DIZZINESS, NAUSEA, INCOORDINATION, DROWSINESS AND LOSS OF
CONSCIOUSNESS. ALTHOUGH INGESTION IS UNLIKELY, LIQUID WOULD IRRITATE UPPER DIGESTIVE TRACT IF SWALLOWED. INGESTION OF THIS PRODUCT MAY CAUSE HEADACHE, DIZZINESS, FATIGUE AND CENTRAL NERVOUS SYSTEM DEPRESSION.

Discussion The ingredients listed on the Kool-Aid package are: citric acid, clacium phosphate, salt, maltodextrin, modified corn starch, artificial flavo, ascorbic acid, FD&C red 40 and FD&C blue 1. The last two ingredients are the interesting components for this demonstration. This combination of red and blue dyes gives the grape drink its characteristic purple color.

These are relatively non-polar molecules, even allowing for some charge separation from the partial ionization of the sodium ions. Red 40 is a somewhat more polar molecule than is blue 1. This can be explained by the sizes of the molecules. Each molecule will have a similar amount of charge from ionization, but since blue 1 is a larger molecule the resulting charge will be spread out over a larger molecule. The contents of the Sep-Pak column (stationary phase) are very non-polar. If the dye molecules are dissolved in a relatively polar solvent (mobile phase) such as water and the resulting solution is forced through the column, The dye molecules will preferentially associate with the stationary phase. This results in a colorless liquid (eluent) exiting the column and the column takes on the purple color from the dyes. If we decrease the polarity of the mobile phase, it should be possible to cause the dye molecules to leave the stationary phase and thus remove them from the column. A 5% isopropyl alcohol and 95% water mobile phase will remove the red 40 dye from the stationary phase and the resulting eluent will be red from the dye and the column will appear blue from blue 1 that remains on the column. A slightly less polar mobile phase consisting of 25% isopropyl alcohol and 75% water will remove the blue 1 dye from the stationary phase and the resulting eluent will be blue from the dye and the column will appear white or colorless. There may be some slight blue color if all of the dye has not been removed. The more polar molecule, red 40 is removed with the more polar mobile phase and the less polar molecule blue 1, is removed with the less polar mobile phase.

References

Extraction

Equipment 250 or 500-mL separatory funnel, four 100-mL beakers, overhead projector, ringstand with iron ring.

Reagents About 500 mL of water saturated with iodine and about 300 mL of chloroform or cyclohexane.

Presentation
1. Half fill the separatory funnel with the water/iodine solution. Be certain the stopcock is closed first!
2. Dispense ~20 mL of the water/iodine solution into a 100 mL beaker.
3. Place the beaker on the overhead projector, so that it may be seen that some of the light is absorbed by the solution.
4. Add 75-100 mL of chloroform or cyclohexane to the separatory funnel. Stopper the separatory funnel.
5. Hold the stopper in place and invert the separatory funnel 2-3 times fairly quickly.
6. Right the separatory funnel and loosen the stopper to vent some of the pressure that has built up.
7. Replace the stopper, and hold it as you invert several more times. The organic layer should be distinctly purple.
8. Continue to invert until the color of the chloroform layer becomes constant.
9. Drain the chloroform layer into a container.
10. Repeat steps 2-9 for as many times as you care to. The amounts stated here are for a series of 3 extractions.

Hazards Vapor of iodine is a severe irritant and lachrymator. Solutions of iodine irritate skin. Contacts may cause skin burns. Chloroform may irritate eyes and skin (with no serious damage). Chloroform is a suspected carcinogen and teratogen. Therefore, avoid contacts with iodine and chloroform; they should be handled with care. Excessive inhalation of cyclohexane is irritating to the upper respiratory tract. Repeated contact with the skin can cause dermatitis.

Discussion
Iodine is a non-polar molecule this has a weak interaction with the hydrogen bonded water molecules. The energy associated with the iodine/water interactions is not enough to compensate for the lost energy of the water/water interactions. This ultimately means that not much iodine will dissolve in water. If a solvent with weaker solvent/solvent interactions than water were introduced to this system, iodine would find it easier to disrupt these interactions and insert itself (dissolve) between the solvent molecules, cyclohexane or chloroform are such solvents. They have no hydrogen bonding and are only very slightly polar. Energywise, it is more favorable for the iodine to dissolve in the non-polar solvent than in the water, so it exists preferentially (but not totally, an equilibrium will exist) in the non-polar solvent. The release of energy as the iodine switches solvents is partially responsible for the initial build up of pressure in the separatory funnel.

This same argument explains why the non-polar solvent does not dissolve in the water, so two layers are produced when the two solvents are added together.

The transfer of iodine from the water to the chloroform is an equilibrium process. This can be seen in the series of beakers of the iodine/water that were dispensed from the separatory funnel. After each extraction of iodine with chloroform, the amount of iodine remaining in the water became less and less. The series of beakers becomes less and less colored as the iodine responsible for the color is removed.

Why do the extraction in a series of small additions instead of one large addition?  
Assume that the iodine distributes itself between the water and chloroform layer in a ratio of 1:9 respectively. This means that one extraction will remove 90% of the original iodine from the water, leaving 10% behind. A second extraction removes 90% of the remaining iodine from the water. In terms of the original amount of iodine that would be:

\[(0.10)(0.90) = 0.090 \text{ or } 9\%\]

This leaves 0.10 - 0.090 = 0.010 or 1% of the original iodine in the water and 0.990 or 99.0% of the original iodine is in the two chloroform extractions. This is certainly better than the 90% gained from one extraction. This could go on and on depending upon your patience and how much chloroform you can lay your hands on. Three extractions would leave only 0.0010 or 0.1% of the original iodine in the water. The process of extractions reaches its ultimate practical limits in a technique known as chromatography. This a technique where the number of extractions has grown huge (100's of thousands in some cases) and the size of the solvent fractions has shrunk to essentially a shell of a few solvent molecules surrounding a solute molecule (iodine in this case).

References
1. Alyea and Dutton, p. 223.
2. Tutorial Video Tape IX found in Learning Resources Centers in St. Paul Library. Tutorial Video Tape XIII also found in the Learning Resources Centers.

Biochemistry

Extraction of DNA

Equipment  Blender, beaker (100 mL), strainer, test tubes (up to 10 large tubes and stoppers if tubes are to be passed around class), stir sticks and test tube rack

Reagents  DNA source (split peas work best), salt, water, liquid detergent, meat tenderizer, alcohol (70% isopropyl alcohol or 95% ethyl alcohol work well)

Presentation
1. Measure ~100 mL (1/2 cup) DNA source (split peas), pinch of salt (~1 mL or 1/8 tsp), and ~200 mL of water (double the amount of the DNA source) into blender. Blend on high for 15-20 sec.
2. Pour the “pea soup” through a strainer into a beaker. How much “soup” do you have? Add a volume of detergent equal to 1/6 of the “pea soup” volume. Mix slightly and let sit for 5-10 minutes. (This is very important - do not move on to Step 3 without waiting.)
3. Pour soapy “pea soup” in to test tubes; fill each ~1/3 full. Add a pinch of meat tenderizer to each test tube. Mix very gently (or you will break up the DNA). 4. Tilt the test tube at an angle of ~ 45°. Pour the alcohol gently down the side of each test tube until tube are about 2/3 full. Two layers should form. The DNA will rise into the top layer (alcohol layer). The DNA can be removed with a stir stick (sometimes).

Discussion  To extract DNA, you must remove it from the cells of the DNA source such as the split peas. Blending the peas with some salt and water breaks the cells apart. However, the DNA is still safely contained in the cell because of the cell and nuclear membranes. These cell membranes are made up of lipids (like grease), which have a polar head and a non-polar tail. The detergent also consists of polar heads and non-polar tails. The molecules in detergent are able to pull apart the cell and nuclear...
membranes which leave the DNA in the "pea soup". The DNA in the "pea soup" is still covered and protected by the proteins from the cell. The meat tenderizer (or pineapple juice or contact lens solution) contain enzymes which are able to cut apart these proteins to leave the DNA alone. Alcohol is less dense than water and therefore floats above the "pea soup". The proteins, lipids, and DNA all need to decide which solution they prefer. The proteins and lipids prefer the water and the DNA prefers the alcohol. The DNA therefore moves into the alcohol layer. The DNA formed tends to be stringy and clumped together. You can try to remove it from the test tubes with a stir stick but it is often difficult to do so.

Some interesting DNA facts: Each cell of your body contains six feet of DNA! Our bodies contain about 100 trillion cells - that means we have more than a billion miles of DNA within our bodies! To fit this into your cells, the DNA is packed efficiently by twisting tightly and clumping together.

Some demo tips: This demonstration works for a variety of DNA sources, detergents, and tenderizers. If you do not see DNA forming, it may be due to the type of DNA source (see discussion below) or the timing in the procedure. It is very important to wait the 5-10 minutes in Step 2 or the cell and nuclear membranes will remain intact, not allowing the DNA to be extracted. If you do not see any DNA immediately, wait 30-60 minutes... the DNA will usually extract into the alcohol layer with time. Different DNA sources will yield DNA at different rates. Frozen peas do not make a good substitute for split peas due to the large amount of water contained in the peas. Extracting DNA from onions works well, but the color of the solution is not as nice. Red cabbage is not a good DNA source as the solution is too dark and the DNA is extracted rather slowly. Try to experiment with other sources of DNA!