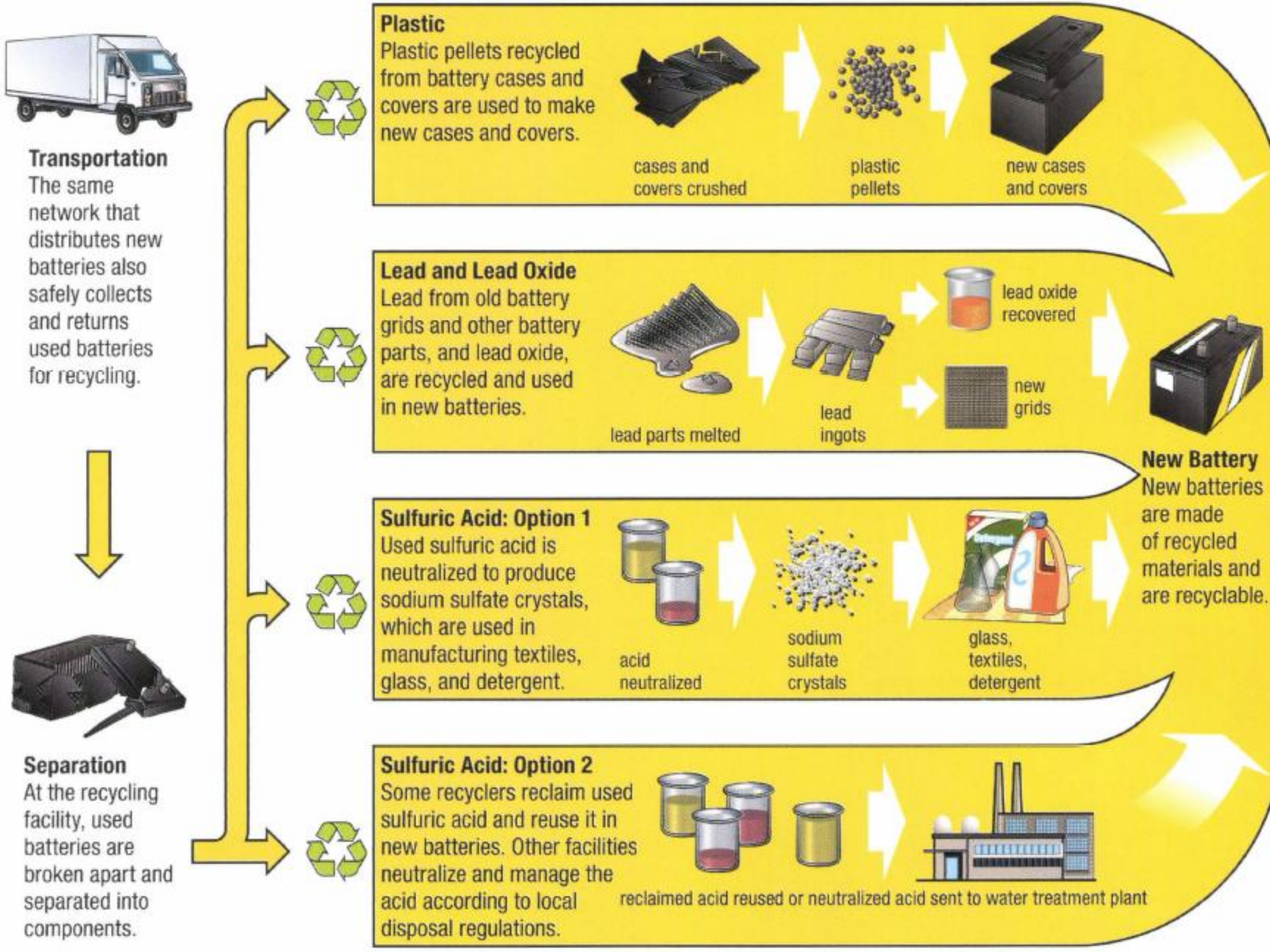
NEUTRALIZATION REACTIONS

- According to industry representatives, 97 % of discarded car batteries in Ontario are recycled. This process prevents the hazardous contents of car batteries from contaminating the environment.
- An automotive lead-acid battery consists of plates of lead and lead (IV) oxide immersed in a corrosive fluid containing concentrated sulfuric acid.
- Lead is toxic to a number of organs and systems in the body, including the heart and the nervous system.

- Every part of a discarded battery is recycled into a useful product. The plastic cases of the batteries are cleaned, ground into pellets, and reused to manufacture new battery cases.
- Lead is recovered, purified, and used to manufacture new batteries.
- The sulfuric acid drained from the batteries is treated in two ways. Some is cleaned and reused in new batteries. The remainder is neutralized with sodium carbonate (also called soda ash), Na_2CO_3:

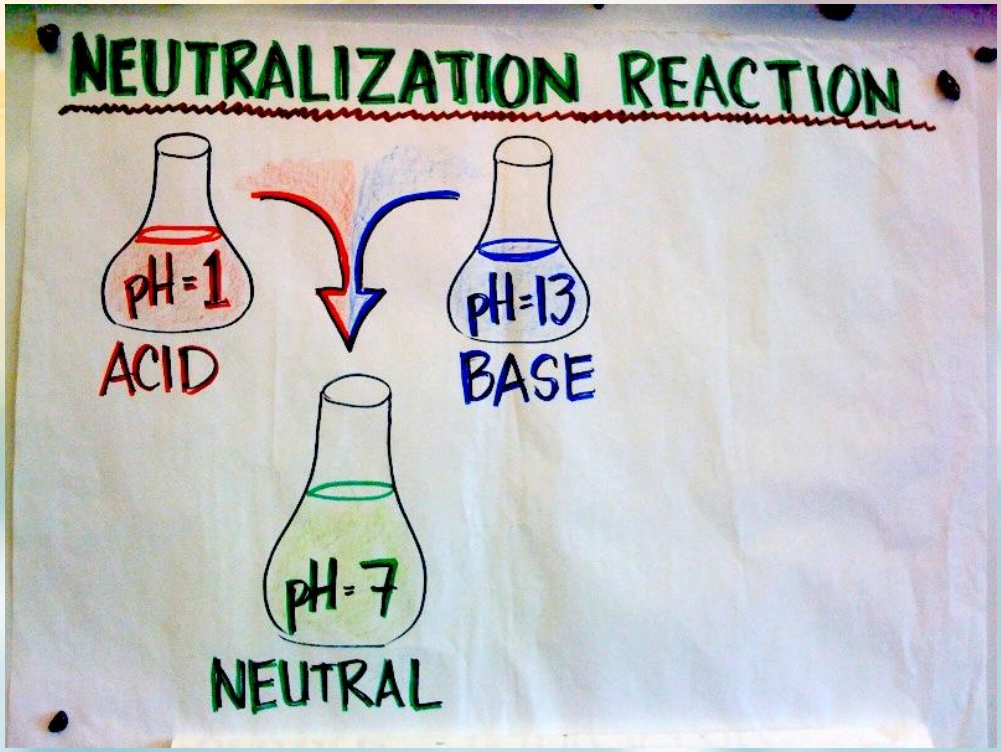
$$H_2SO_{4(aq)} + Na_2CO_{3(aq)} \longrightarrow H_2O_{(l)} + CO_{2(g)} + Na_2SO_{4(aq)}$$

- Sodium sulfate collected from this process is a key ingredient in the manufacture of glass and detergents.


Transportation
The same network that distributes new batteries also safely collects and returns used batteries for recycling.
Separation
At the recycling facility, used batteries are broken apart and separated into components.
Plastic
Plastic pellets recycled from battery cases and covers are used to make new cases and covers.
cases and covers crushed
plastic pellets
new cases and covers
Lead and Lead Oxide
Lead from old battery grids and other battery parts, and lead oxide, are recycled and used in new batteries.
lead parts melted
lead ingots
lead oxide recovered
new grids
Sulfuric Acid: Option 1
Used sulfuric acid is neutralized to produce sodium sulfate crystals, which are used in manufacturing textiles, glass, and detergent.
acid neutralized
sodium sulfate crystals
glass, textiles, detergent
Sulfuric Acid: Option 2
Some recyclers reclaim used sulfuric acid and reuse it in new batteries. Other facilities neutralize and manage the acid according to local disposal regulations.
reclaimed acid reused or neutralized acid sent to water treatment plant
New Battery
New batteries are made of recycled materials and are recyclable.

TYPES OF NEUTRALIZATION REACTIONS

- Neutralization reactions are a special case of double displacement reactions. During a neutralization reaction, an acid reacts with a base to produce a solution with a pH closer to 7 than its reactants.



NEUTRALIZATION WITH A HYDROXIDE COMPOUND

- The reaction of hydrochloric acid, $HCl_{(aq)}$, with sodium hydroxide, $NaOH_{(aq)}$, is a typical neutralization reaction. The chemical equation for this reaction is

$$HCl_{(aq)} + NaOH_{(aq)} \longrightarrow H_2O_{(l)} + NaCl_{(aq)}$$

- This type of neutralization reaction follows the general pattern:

$$\text{acid} + \text{base} \longrightarrow \text{water} + \text{ionic compound}$$

- You will discover in future chemistry courses than not all neutralization reactions follow this general equation. For most neutralization reactions, however, the hydrogen ions from an acid react with the hydroxide ions from a base to produce water. The ionic compound, which is sometimes called a "salt" is made up of the remaining ions.

NEUTRALIZATION WITH A CARBONATE COMPOUND

- Acids can also be neutralized by carbonate compounds. Calcium carbonate is the major component in limestone rock. It also makes up the shells of aquatic animals, such as clams, snails, and corals. Calcium carbonate reacts with sulfuric acid to produce carbonic acid, $H_2CO_{3(aq)}$. The chemical equation for this reaction is

$$H_2SO_{4(aq)} + CaCO_{3(s)} \longrightarrow H_2CO_{3(aq)} + CaSO_{4(aq)}$$

- However, carbonic acid immediately decomposes into water and carbon dioxide:

$$H_2CO_{3(aq)} \longrightarrow H_2O_{(l)} + CO_{2(g)}$$

- Therefore, the chemical equation for the net reaction of calcium carbonate with sulfuric acid is

$$H_2SO_{4(aq)} + CaCO_{3(s)} \longrightarrow H_2O_{(l)} + CO_{2(g)} + CaSO_{4(aq)}$$

- Carbonate compounds react similarly with other acids. In general, the reaction of acid with carbonate compound yields water, carbon dioxide, and an ionic compound:

$$\text{acid} + \text{carbonate} \longrightarrow \text{water} + \text{carbon dioxide} + \text{ionic compound}$$

NEUTRALIZATION REACTIONS IN ACTION

- Acids and bases are some of the most widely used industrial chemicals.
- Many useful household products also contain acids and bases.
- The neutralization of these compounds has important consumer and environmental applications.

NEUTRALIZING STOMACH ACIDS

- The digestive fluids in your stomach have a pH of about l.5-acidic enough to slowly "eat" through a strip of zinc metal. The source of this acidity is hydrochloric acid produced by specialized cells in the stomach lining. Hydrochloric acid aids in the digestion of proteins and suppresses the growth of unwanted bacteria. Since your digestive fluids cannot distinguish between food and stomach tissue, they could easily digest the stomach itself. Fortunately, the stomach has defences against being digested: other cells in the stomach lining produce mucus that coats the inside of the stomach, keeping the acid away from the living cells. Another defence is the ability of the cells of the stomach lining to replace themselves very quickly: at a rate of about half a million per minute.

- Stomach acid can become a problem if it leaks upward out of the stomach, through a valve-like structure and into the esophagus. Irritation of the esophagus by stomach acid is called gastroesophageal reflux, acid reflux, or "heartburn:' This condition can be caused by a number of factors, including overeating and spicy foods. A short –term fix for heartburn is to consume an antacid medication that will neutralize the excess acid in the stomach.

- The active ingredient in an antacid must be effective at neutralizing excess stomach acid and yet it must not irritate tissue on its way to the stomach. Ideally, the neutralizing compound would produce only enough hydroxide ions to react with the acid. Weakly basic substances such as magnesium hydroxide and aluminum hydroxide are used in some antacid products. Because they are only slightly soluble, neither compound produces enough hydroxide ions to irritate the mouth or throat as the tablet is chewed and swallowed.

- The chemical equation for the neutralization of hydrochloric acid with aluminum hydroxide is

$$3\ HCl_{(aq)} + Al(OH)_{3(s)} \longrightarrow AlCl_{(aq)} + 3\ H_2O_{(l)}$$

- Carbonate compounds are also safe yet effective ingredients in antacid products. Sodium hydrogen carbonate, $NaHCO_3$, and calcium carbonate, $CaCO_3$, are commonly used. The equations for the neutralization of hydrochloric acid with these compounds are

$$HCl_{(aq)} + NaHCO_{3(s)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)} + CO_{2(g)}$$

$$2\ HCl_{(aq)} + CaCO_{3(s)} \longrightarrow CaCl_{2(aq)} + H_2O_{(l)} + CO_{2(g)}$$

- Frequent consumption of sodium hydrogen carbonate is not recommended because it adds to the sodium ions we already consume by salting our food. Excess sodium ions have been linked to hypertension and stroke. Too much calcium carbonate may increase the risk of kidney stones.

REHABILITATING LAKES

- Emissions of sulfur oxide and nitrogen oxide are largely responsible for the acidification of Ontario's lakes. These oxides are acidic, and cause acid precipitation. Despite considerable progress in curbing these emissions over the last 30 years, the problem persists. Aquatic ecosystems generally can only tolerate small reductions in the pH of their water. Organisms fail to reproduce and populations crash. As pH drops below 5, only the most acid-tolerant organisms survive.

- Lakes differ in their ability to resist changes in acidity. One factor that helps offset the effects of acid precipitation is the type of rock beneath the lake. Much of the surface rock of southern Ontario is limestone (mostly calcium carbonate, $CaCO_3$). An important characteristic of limestone is that it reacts slowly with acids. Limestone in southern Ontario lakes acts as a natural antacid, helping to neutralize acidified lake water. Unfortunately, the surface geology of northern Ontario is mostly granite. Granite is a hard, impervious rock that is less reactive than limestone. As a result, the lakes in this region have little natural capacity to neutralize acid precipitation. Consequently, these northern lakes are the most prone to environmental damage from acid precipitation.

- One way to assist lakes threatened by acid precipitation is to neutralize the acidity by adding calcium oxide or lime. However, "liming" a lake only solves the acidity problem in the short term. The long-term solution is to eliminate the pollutants at their source. In later sections of this chapter, you will learn about new technologies that help industries reduce their acidic oxide emissions.

BAKING

- Substances that make bread dough rise are called leavening agents. Leavening agents produce bubbles of carbon dioxide that are trapped within the dough. As the bubbles expand, they push the elastic dough upward.
- The carbon dioxide bubbles could be produced either by baker's yeast or by a neutralization reaction involving a carbonate compound. Baking soda and baking powder are both leavening agents.
- Baking soda is pure sodium hydrogen carbonate. The leavening action of baking soda is activated when it is mixed with an acidic ingredient like fruit juice, vinegar, or buttermilk. The chemical equation for the reaction of the citric acid, $H_3C_6H_5O_{7(aq)}$, in fruit juice with baking soda is

$$H_3C_6H_5O_{7(aq)} + 3\ NaHCO_{3(s)} \longrightarrow Na_3C_6H_5O_{7(aq)} + 3\ H_2O_{(l)} + 3\ CO_{2(g)}$$

- Bubbles of carbon dioxide gas from this reaction cause the dough to rise. The warmth of the oven makes the bubbles expand. Because baking soda is unstable at high temperatures, it is generally used when a short baking time is required. That is why you will see baking soda listed as an ingredient in many cookie recipes. Baking powder, however, is a mixture of several ingredients. Two essential ingredients in most types of baking powder are baking soda and a dry acid such as tartaric acid, $H_2C_4H_4O_6$. Baking powder is activated by moisture. As solid tartaric acid dissolves and produces hydrogen ions, sodium hydrogen carbonate neutralizes its acidity. The resulting products are carbon dioxide (which makes the dough rise), water, and sodium tartrate. The chemical equation for this reaction is

$$H_2C_4H_4O_{6(aq)} + 2\ NaHCO_{3(s)} \longrightarrow Na_2C_4H_4O_{6(aq)} + 2\ H_2O_{(l)} + 2\ CO_{2(g)}$$

- Baking powders can be fast acting and slow acting, depending on the acid they contain. The acids in fast-acting baking powders (usually tartaric acid) react immediately with baking soda to produce carbon dioxide. Slow-acting baking powders contain acids that only begin to react when heated in the oven. Slow-acting baking powders are used when longer baking times are required. The recipes for cakes usually specify baking powder as the leavening agent.

CHOICE OF NEUTRALIZING REACTANT

- Neutralization reactions are important parts of many chemical processes. Some, like the recycling of car batteries, are large industrial processes in which corrosive substances must be neutralized before they can be discharged into the environment. Other reactions involve consumer products such as antacids and hair dyes. In each case, the effectiveness of the process depends on the properties of the reactants used.

- Factors when selecting an appropriate neutralizing reactant:
  - Safety
  - Reactant's Cost
  - Chemical Properties
- For example, solutions of sulfuric acid vs. ethanoic acid ($HC_2H_3O_{2(aq)}$)
- Similarly, sodium hydroxide vs. calcium hydroxide ($Ca(OH)_2$)

A VERSATILE NEUTRALIZING AGENT

- Sodium hydrogen carbonate, $NaHCO_3$, or baking soda, is unusual because it can neutralize both acids and bases. It is therefore a very versatile neutralizing compound. It is also one of the safest, since it is not corrosive at all. In fact, it is safe enough to be used in food and consumer products such as toothpaste. Acids react with sodium hydrogen carbonate following the general pattern for carbonate reactions. For example, sodium hydrogen carbonate reacts with hydrochloric acid as follows:

$$HCl_{(aq)} + NaHCO_{3(s)} \longrightarrow H_2O_{(l)} + CO_{2(g)} + NaCl_{(aq)}$$

- Sodium hydrogen carbonate reacts with bases to produce water and sodium carbonate. For example:

$$NaOH_{(aq)} + NaHCO_{3(s)} \longrightarrow H_2O_{(l)} + Na_2CO_{3(aq)}$$