the captivating chemistry of coins

By Brian Rohrig

Have you ever stood in front of a vending machine, pumping in your change, and the machine just kept spitting out one dime, until you realized that it was a Canadian dime? Why can't you use Canadian coins in American vending machines, and vice versa? And how do vending machines distinguish between real money and fake money? What are our coins made of? Are nickels made of nickel? These questions and many more will be answered as we examine the captivating chemistry of coins!

Early cash

Metallic money has been around for thousands of years, while paper money has only been popular for a few hundred years. The first coins were worth their face value of whatever precious metal they were made from. Today, all coins are deliberately made to be worth *less* than their face value, so as to prevent them from being melted down and the metals recovered and sold. All coins were originally made from gold, silver, and copper, and these elements are still referred to as the coinage metals. The drachma and denarius, which were widespread in Greek and Roman times, were composed of silver. The aureus, a gold coin, was also popular.

MIKE DIESELSKI

Alloys

Although some ancient coins were sometimes made from pure metals, today, all coins intended for circulation are made from alloys. An alloy is a homogeneous mixture of two or more elements, one of which must be a metal. There are numerous advantages to using alloys. Alloys typically are harder, more durable, and more corrosion resistant than the pure metals by themselves. Pure gold and silver, for example, are very soft, and would not hold up to the wear and tear that circulated coins experience. Even the ancients were well aware of the advantages of alloys, as bronze was a common material used to make coins. The development of bronze was so important that an entire historical era—the Bronze Age—was named in its honor. The bronze alloy used to make coins today is typically composed of 95% copper, 4% tin, and 1% zinc.

A newer coin, the Sacagawea dollar, looks like a gold coin. It is actually made from an inner core of copper surrounded by an outer layer of manganese brass (an alloy of copper, zinc, manganese, and nickel). Brass was chosen because of its gold color, since previous dollar coins were disliked by consumers because they too closely resembled other silver coins such as quarters. Brass is an extremely durable metal with excellent corrosion resistance, as evidenced by its common use in instruments and plumbing fixtures.

Even though the 1792 Mint Act mandated that all American coins be made from copper, silver, or gold, few American coins today actually contain these metals. They have become far too expensive. These precious metals have been replaced with cheaper metals, even though most coins do tend to retain the appearance of the more valuable metals.

A pretty penny

The ubiquitous penny used to be made mostly of copper but is now mostly zinc. Zinc is much less expensive than copper. Today's penny is made up of 97.5% zinc, with a paper-thin copper coating that only makes up 2.5%

Cross-section showing the structure and composition of a post-1982 penny.

of its total mass. This change came about in 1982. From 1962 to 1982, the penny was 95% copper and 5% zinc. This makeover came about because the value of the copper in a penny began to approach one cent and looked like it might rise higher. As a result, there were nationwide penny shortages due to incessant hoarding.

There are several ways to distinguish between old and new pennies. A post-1982 penny has a mass of 2.5 grams, while the pre-1982 pennies have a mass of 3.1 grams. 1982 pennies may have either mass. Since all pennies have an identical volume, a greater mass indicates a greater density. Copper is denser than zinc. (The density of Cu is 8.96 g/cm^3, while that of Zn is 7.13 g/cm^3.)

The mass of a penny tells you whether it was made before or after 1982.

Another big difference between old and new pennies is their melting point. If heated over a Bunsen burner, the new penny will be reduced to a silvery liquid blob in just a few moments. The older copper pennies can be heated over a Bunsen burner flame without melting. Zinc melts at a much lower temperature than copper. The melting point of zinc is 420°C, while that of copper is 1083°C.

Don't eat the change

Before 1982, if a small child swallowed a penny, doctors would generally advise to just let it pass, since the hydrochloric acid (HCl) in the gastric juices of the stomach will not react with copper. If you are familiar with the metal activity series, then you will know that zinc is more reactive than copper, and HCl will react with zinc.

$$2\,HCl_{(aq)} + Zn_{(s)} \rightarrow H_{2(g)} + ZnCl_{2(aq)}$$

If a newer penny is swallowed and the copper coating has worn thin or has developed even a tiny crack, the HCl in the stomach can react with the zinc within the penny. If the penny remains in the stomach long enough, it can develop some jagged edges as the stomach acid eats away at it. These jagged edges can potentially perforate the intestine as the penny passes through the digestive system. However, most of the time these swallowed pennies pass with little harm done.

Changing change

The penny is not the only coin to undergo a makeover in recent years. The Coinage Act, passed by Congress in 1965, mandated that silver be either removed or eliminated from dimes, quarters, and half dollars. Silver was completely removed from dimes and quarters in 1965 and replaced with an outer layer of a copper-nickel alloy bonded to an inner core of pure copper. In 1971, the composition of all half dollar and "silver" dollar coins were changed to that of the dime and the quarter. With coins nowadays, little is as it appears. Not only are our "copper" pennies mostly zinc, but our "silver" coins are mostly copper!

Dimes and quarters minted before 1965 were composed of an alloy of 90% silver and 10% copper, and they are considered somewhat valuable by collectors. You can easily test for the presence of silver with a simple experiment. Rub a little mustard on a silver coin and also on a nonsilver coin and let them stand overnight. In the morning, rub off the

Mustard mystery? If you suspect you have a "silver" coin, apply a generous portion of mustard to it and let it sit overnight.

In the morning, remove the mustard. If silver is indeed present, there will be a tell-tale black spot, indicating Ag_2S.

mustard. A black spot will remain on the silver coin, but not on the nonsilver coin. Mustard naturally contains sulfur compounds, and sulfur reacts with silver to form a black precipitate of silver sulfide (Ag_2S).

Coin magnetism

Ever wonder why Canadian coins cannot be used in American vending machines, and vice versa? To answer this question, test a number of American coins with a magnet. It is doubtful you will find any that are attracted. The only exception is the 1943 zinc-plated steel penny, which was manufactured during World War II to conserve copper for the war effort. There are only three elements that are ferromagnetic (strongly attracted to a magnet) at room temperature. These are iron, nickel, and cobalt. Even the nickel coin contains only 25% nickel. The rest is copper. The concentration of nickel is not great enough to make the coin ferromagnetic.


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When you place a coin in a vending machine, up to a dozen tests may be performed to verify whether a coin is genuine. Sensors within the vending machine measure the coin's weight, diameter, and rolling speed. An electrical current passes through each coin deposited to determine its rate of conductivity, thus determining its metallic content. The coin also passes through the poles of a magnet. If a coin is magnetic, it is rejected by the machine.

In Canada, the vending machines must be arrayed differently, since most Canadian coins are magnetic. However, Canadian nickels have been made mostly from copper since 1982. But Canadian dimes, quarters, and one and two dollar coins are still mostly made from nickel and therefore are strongly attracted to a magnet.


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One bus driver in Alberta, Canada, used the magnetic properties of Canadian coins to his advantage. Every day after work for 13 years, he would collect a number of coins from the coin collection unit on his bus using

Experiments With Pennies:

1. **See how many drops of water you can place on a penny, using an eyedropper. Because of the incredible surface tension of water, you can fit an astonishing number of drops on a penny before they will tumble off.**

2. **Determine which household substance is the best copper cleaner. Immerse discolored pennies in various household solutions, such as pop, juice, milk, vinegar, ketchup, lemon juice, and detergent. Leave the pennies immersed for 1 week. Remove the pennies and examine them. Which substance did the best job at cleaning the pennies? Which did the worst job?**

3. **Place several shiny pennies between the layers of a paper towel that has been soaked in vinegar. Sprinkle some salt on the pennies as well. The next day, observe what happens. The pennies will have developed a green coating of verdigris, or copper (II) acetate. See Feb. 2003 issue of *ChemMatters* for more details.**

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a long pole with a magnet attached to the end. He collected a fortune, amassing over $2.3 million. But he was eventually arrested, arousing suspicions when he purchased an $800,000 house on an annual salary of only $38,000!

An interesting experiment can be conducted with a pre-1982 Canadian nickel, a magnet, and a Bunsen burner. Place the nickel on the magnet, and holding the magnet with tongs, heat the nickel over the Bunsen burner flame. After a short while, the nickel will fall off! When heated, ferromagnetic substances lose their magnetic properties. Substances are magnetic because tiny regions within the material known as domains are all aligned in the same direction. When heated, these domains become unaligned, causing the substance to lose its magnetic attraction. After the nickel cools, the domains realign and it will once again be attracted to a magnet. The temperature at which a substance loses its magnetic properties is known as its Curie point. For nickel, the Curie point is 375 °C, easily obtainable with a Bunsen burner.

If you have some foreign coins at home, test them with a magnet. Some will be magnetic, but most will not. British pennies are magnetic, as they are made of copper-plated steel. They are even part of a popular children's toy where a magnetic pyramid is constructed.

Loonie toonies

The two-dollar Canadian coin—affectionately known as the toonie—is a fascinating amalgam of art and chemistry. It is composed of an outer ring of mostly nickel, with a gold-colored inner disk of 92% copper, 6% aluminum, and 2% nickel. The outer ring is strongly attracted to a magnet, but the inner ring is not. If this coin is heated strongly over a Bunsen burner flame and then quickly submerged in cold water, the smaller inner coin can be made to pop out!

The one-dollar Canadian coin is known as a "loonie," for the picture of the loon on its face. The "toonie" is the slang for the two-dollar Canadian coin (which alludes to both "two" by analogy with the loonie, and to "Looney Tunes," again paired with the loonie).

All metals expand when heated, but not at the same rate. The amount of expansion a material experiences when heated is known as its coefficient of linear expansion. Copper has a higher rate of expansion when heated than nickel, which also means that copper shrinks more rapidly when cooled. When plunged into cool water directly after heating, the inner coin will shrink at a greater rate than the outer ring, causing the inner coin to fall out.

When the toonie was first introduced in 1996, some defective coins would separate if given a hard blow or frozen. For many Canadians, it was great sport to see if the two parts of the toonie could be separated. Wearing the smaller inner coin as a necklace was even considered a fashion statement. This flaw in the toonie was corrected not long after its debut. It is currently against the law in Canada to deliberately separate the two parts of a toonie.

Well, hopefully some of the questions at the beginning of the story have now been answered. Whether jingling in your pocket or slung around your neck on a chain, coins provide you with yet another opportunity to discover chemistry in everyday items.

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