Cash, Chemistry, and Counterfeit,

Name: _____

Directions: ***Before reading the article,*** in the first column, write "A" or "D," indicating your Agreement or Disagreement with each statement. Complete the activity in the box.
As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	Text	Statement
		1. The oldest surviving paper banknote is from Mexico.
		2. Isaac Newton and Benjamin Franklin worked to devise various ways to prevent counterfeiting.
		3. At the time of the Civil War, it is estimated that almost half of the paper money in circulation in the U.S. was counterfeit.
		4. Originally photographs were black and white, so paper money was made green to avoid counterfeiting.
		5. Counterfeit detecting pens can only tell if the paper contains starch.
		6. It is easy to fake a watermark.
		7. All U.S. currency has a blue line that can be seen under a black light.
		8. U.S. currency is made from 100% cotton.
		9. The "20" printed on new $20 bills will change colors when the bill is tilted at different angles.
		10. Plastic currency is more difficult to counterfeit.

Questions for Further Learning

Write your answers on another piece of paper if needed.

Suppose the government, due to advancements in digital currency and transactions such as credit and debit cards, Venmo, etc., decides they can no longer justify allocating time and money to prevent circulation of counterfeit paper money. You have been selected to lead the task force that will devise a plan to phase out the use of paper currency in the country. Explain in detail the plan you would implement to accomplish your mission. Consider the following when constructing your plan:

- What percentage of transactions are completed using cash?
- How would you ensure all the paper currency is collected and properly stored or destroyed?
- How would you account for people who do not have bank accounts or means to use digital currency?
- What are the dangers associated with eliminating paper currency?
- Would eliminating paper currency solve the majority of financial fraud in the U.S.? Why or why not?
- Now that currency counterfeit detection has been eliminated, what new problems could arise from a cashless society?

CASH, CHEMISTRY, AND COUNTERFEIT

By Brian Rohrig

If you earn cash from babysitting, mowing lawns, or other jobs, you might have noticed that not all bills' designs and colors are the same. That's because money has changed a lot over the years; today U.S. currency is more complex and colorful than ever before. These changes have primarily come about for one reason—to beat counterfeiting.

From currency's inception, people have tried to trick others into accepting fake money. The Aztecs, a 14th- to 16th-century culture that thrived in what is now central Mexico, used cacao beans for currency, and even these were counterfeited. People would fill empty cacao pods with clay and try to pass them off for the real thing. The oldest surviving paper banknote, dating back to 14th-century China, displays a warning that (translated into English) reads "the counterfeiter shall summarily be decapitated"—leaving little doubt about how counterfeiting was viewed in that era.

Today, producing fake money remains a serious crime. But thanks to ingenuity on the part of scientists, designers, and printers who work on banknotes, genuine cash now features several attributes to ensure that producing counterfeits doesn't pay off.

Fighting forgeries

To stay ahead of counterfeiters, governments have relied on the brightest minds to fight the illegal practice. In early 18th-century England, Isaac Newton spent 30 years putting his considerable intellect to work in devising ways to foil counterfeiters.

Benjamin Franklin, the father of paper money in the United States (thus his visage on the $100 bill), devised numerous ways to thwart counterfeiters. He designed intricate patterns on his bills that were difficult to copy. On one banknote, he deliberately misspelled the word "Pennsylvania," assuming that any counterfeiter worth his salt would spell it correctly, falling for the ruse.

Despite these efforts, fake currency at certain points in history was rampant. The invention of photography in the 1830s invigorated counterfeiters' efforts. By the time the Civil War began, it was estimated that up to half of the paper money in circulation in the United States was counterfeit. In 1865, the U.S. Department of the Treasury created the Secret Service to crack down on the practice.

GETTY IMAGES

So, during the Civil War, the special green color now associated with U.S. currency made its debut: It couldn't be replicated using the black-and-white film of the day. This innovation gave rise to the term "greenbacks" for U.S. banknotes.

Simple solutions

These days, governments rely on a range of low- to high-tech tactics to fight counterfeiting.

One well-known line of defense entails testing a paper bill's material with a counterfeit-detector pen. Ordinary paper contains starch, while currency paper is made of starch-free ingredients cotton and linen. The ink in counterfeit detector pens contains triiodide ions (I_3^-) that react with starch to produce a dark purple-black color.

So, if you mark a bill printed on regular paper with one of these pens, a black mark would reveal the bill as counterfeit. However, these pens' usefulness is limited. The absence of a black mark simply indicates the absence of starch—it does not confirm a bill's authenticity.

Another simple method to test whether a bill might be real entails feeling its texture. Real bills feel rough due to the raised ink and the texture of their cotton-linen composition.

One trick that counterfeiters have used to ensure their fakes have the right texture involves removing the ink from a $1 bill, making it blank, and then printing the design of a $20 bill on the note. In response, government chemists have put a lot of time and energy into formulating inks that are difficult to remove. But, interestingly, the inks never dry—if you rub a dollar bill firmly on a piece of white paper, you can see this feature for yourself! Usually, ink used in counterfeit money is water-soluble and won't rub off.

Embedding colorful fibers and impressing watermarks in paper money are other relatively easy and long-standing methods for deterring would-be counterfeiters. As early as 1928, the Crane Company, the sole supplier of U.S. currency paper, began inserting tiny, hard-to-replicate red and blue silk fibers throughout the paper. Watermarking involves impressing designs into paper. The designs are less dense than the rest of the paper, and transmit more light. Despite being a centuries-old technique, watermarking is still tough to fake.

Modern money

When deterring counterfeiters, however, it's best to keep innovating. As soon as official currency-printers come up with new forgery-suppressing tactics, counterfeiters adapt. Luckily, new technologies help governments stay ahead of the game.

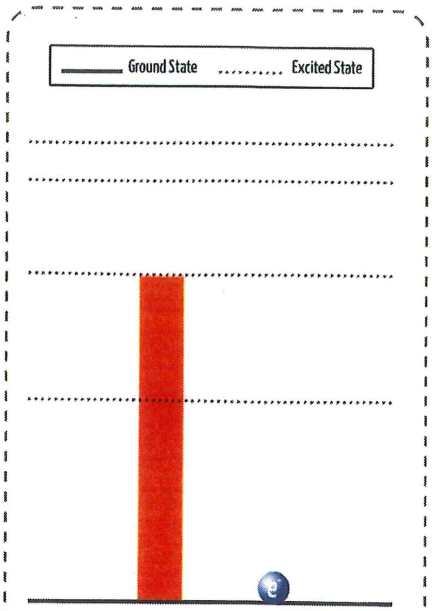


PHOTO: GETTY IMAGES, GRAPHIC: KELSEY CASSELBURY

https://teachchemistry.org/exciting-electrons

To see how UV-sensitive features in currency work, try out this online simulation created by the American Association of Chemistry Teachers. It demonstrates what happens as an electron is excited and then returns to its ground state. Drag and drop the bars next to the electron, and click the "Excite!" button (not pictured).

One recent innovation is the addition of **ultraviolet (UV)** features. On every U.S. banknote, beginning with the $5 bill, thin polyester threads are woven through the bill. Under a black light, these threads **fluoresce,** and each denomination fluoresces a different color. The strip on a $5 bill is blue, while it turns pink on a $100 bill. Nearly every country has a variety of UV features on their money. If you have access to some foreign currency, place it under a black light to reveal vivid designs.

These UV-sensitive features are the result of special fluorescent pigments in the ink. Fluorescence is the property of absorbing one type of electromagnetic radiation and emitting another. When a black light shines on a fluorescent pigment, UV light is absorbed, which excites an electron to a higher energy level. When the electron then returns to the ground state, it emits a photon with a lower energy and longer wavelength than the photon that was absorbed. The wavelength of the released photon typically lies within the visible light portion of the electromagnetic spectrum.

Another relatively new method to deter counterfeiters involves color-changing features.

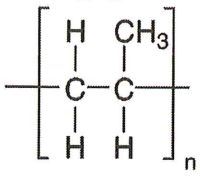
Cotton Currency

Perhaps the biggest innovation in our currency involves the substrate upon which it is printed.

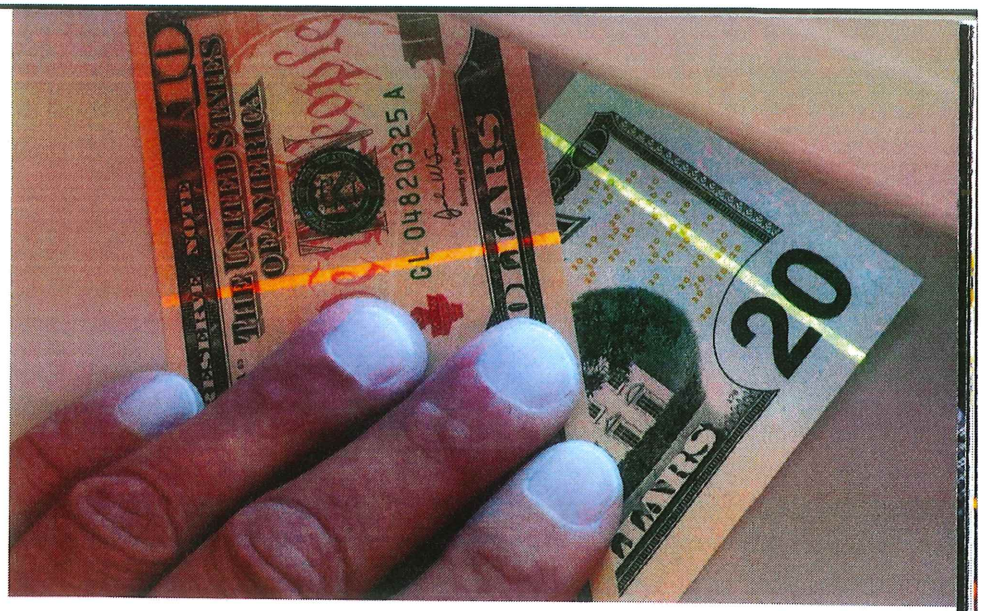
Today's "paper" money is not really made of paper. It is printed on a cotton-linen fabric, which can hold up better than normal paper. According to the U.S. Bureau of Engraving and Printing, which produces our currency, a dollar bill can be folded 4,000 times before it tears. The current content specification for U.S. bills is 75% cotton and 25% linen.

Other countries use different formulations; Euro banknotes, for example, are made of 100% cotton, giving them a softer feel.

Polypropylene



Polypropylene is a polymer made of repeating units of propylene (C_3H_6).



Polyester threads woven into U.S. currency fluoresce under a black light.

PHOTO: GETTY IMAGES, GRAPHICS: RACHEL PRICER

You can find an example of this on the $20 bill. Look for the copper-colored "20" in the lower right-hand corner of $20s that have been printed since 2003. Tilting the angle at which you view the number will change its color to green. The effect is not an optical illusion; the ink is actually changing colors!

The technical term for this color-shifting ink is optically variable ink, which changes colors based on the angle at which light strikes it. It is made by suspending tiny multilayered particles throughout the ink. Each thin layer within these particles reflects light in different ways. The reflected light that reaches our eyes is a combination of different **wavelengths** that interfere with one another both **constructively** and **destructively.** When the angle at which light strikes these particles changes, the wavelengths of reflected light also changes. Photocopying this ink yields a single color and cannot replicate the effects of color-changing ink.

Paper or plastic

In the never-ending race to stay ahead of counterfeiters, some countries have resorted to transitioning their paper currency to plastic. These thin bills, usually made with **polypropylene** $(C_3H_6)_n$, look like paper but feel slick and smooth. Plastic allows for all sorts of nifty security features, such as detailed holograms and see-through windows.

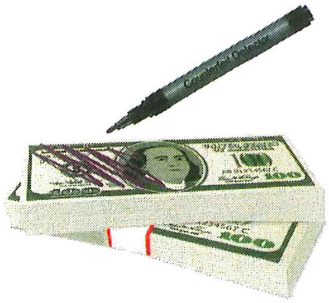
In 1988, Australia became the first country to introduce plastic currency, and since then several other countries, including Britain, Russia, Mexico, and Canada, have followed suit. Since their transition to plastic banknotes, Canadian authorities have reported that the incidence of counterfeiting dropped by nearly 75%.

Despite such benefits, much of the world still uses natural materials for their banknotes.

But with the rise of digital currency such as Bitcoin and other types of online payment services such as Apple Pay and Venmo, could printed money finally be in danger of becoming obsolete? Cold, hard cash has faced threats before from credit cards, checks, and direct deposit, yet physical money has held strong. One significant reason for this reliance on physical money is that about 6.5% of households in the United States do not have bank accounts, leaving them largely reliant on cash, according to a 2017 national survey conducted by the U.S. Federal Deposit Insurance Corporation.

Given that advances have made our paper currency more counterfeit-proof than ever before, the smart money says it will be around for many years to come.

Inside the Iodine-Starch Test



Starch is a carbohydrate, consisting of two types of polysaccharides: amylose and amylopectin.

The color change observed when an iodine solution reacts with starch is caused by a **charge-transfer complex** between triiodide ions (I_3^-) and amylose. Charge-transfer complexes form when an electronic charge is transferred between two or more molecules, or parts of molecules.

Triiodide ions form in an aqueous solution according to this equation:

$$I_2 + I^- \rightarrow I_3^-$$

In the iodine-starch test, triiodide acts as a **charge acceptor,** and amylose acts as a **charge donor.**

Electrons in such charge-transfer complexes are easily excited by light to higher energy levels. Light is absorbed in the process, and its complementary color, in this case dark purple, is observed by the human eye.

Brian Rohrig is a chemistry teacher from Columbus, Ohio.

REFERENCES

Venere, E. The Money Makers. *ChemMatters*, Feb 2003, pp 14–16.

U.S. Department of the Treasury, Bureau of Engraving and Printing, U.S. Currency: https://www.moneyfactory.gov/uscurrency.html [accessed Aug 2019].