A Chemical Manufacturers Association publication
covering health, safety and the environment

CHEMECOLOGY

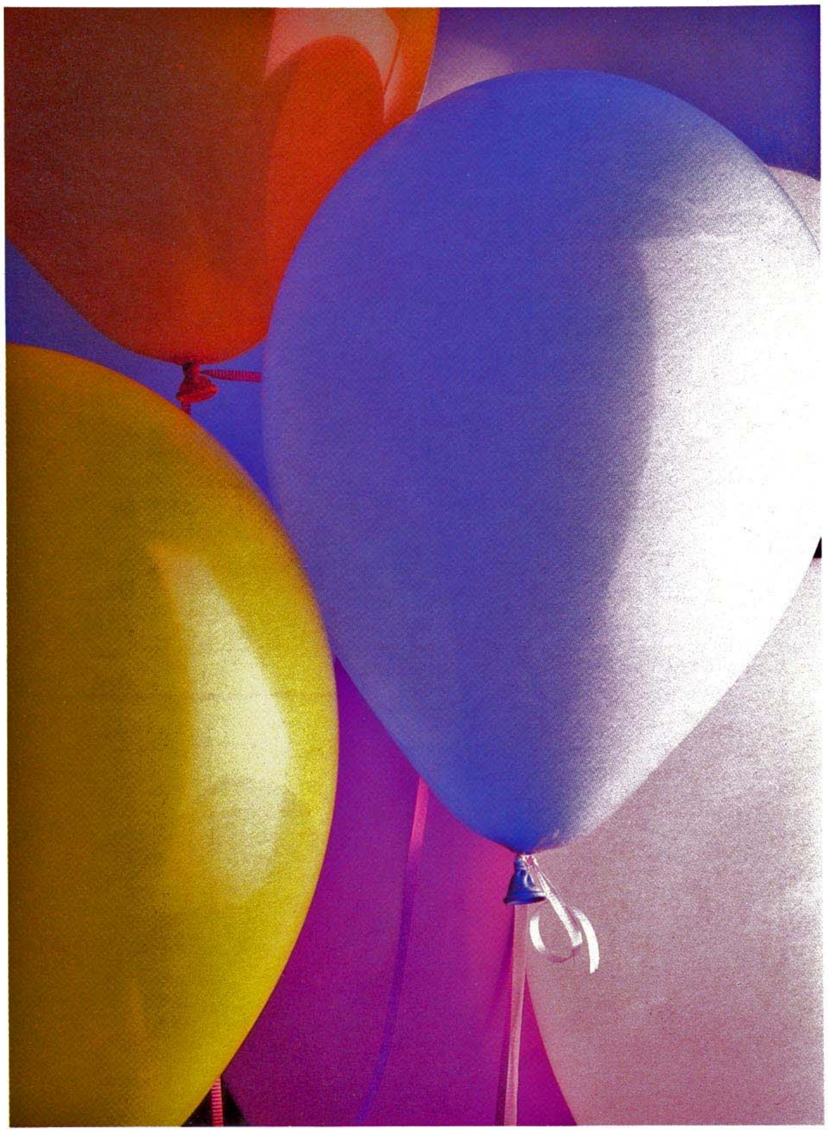
DECEMBER 1988
JANUARY 1989

VOL. 17, NO. 10

Toy Chemistry

Balls and Balloons and Things That Go 'Bang'

Chemistry Brings Toys to Life



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As a balloon is inflated the folded network of rubber molecules unfolds. As it is deflated, the molecules attempt to refold.

ON THE COVER:
Toy chemistry at work.
Photograph by John Burwell.

What gives a ball its bounce and a cap its snap? Chemistry does. What makes a balloon stretch and hold air, and what makes soap bubbles form? Again, chemistry is responsible.

Although the connection between chemistry and the playthings of children — and adults — often may not be given a second thought, the connection does exist, and not only in chemistry sets. In fact, everything from tops to tennis rackets owe something to chemistry.

According to David A. Katz, an associate professor of chemistry at Community College of Philadelphia and something of a chemistry-in-toys expert, chemistry can play a role in both the form and function of toys.

"We not only have toys that are made of chemicals," he explains, "but we have toys that utilize the properties of some of these chemicals as part of their use as playthings."

Examples of the latter include such toys as a waterproof, sandlike compound children can use to build sand castles and other things beneath the water; ink that disappears (and is re-emerging as a fuel for water pistols); and creatures that grow larger when placed in water because they are formed of a super-absorbent material. Just as dependent on chemistry for their function are such commonplace toys as balls, balloons and caps.

Katz, a 1983 winner of a CMA Catalyst Award for excellence in chemistry education, has spent a great deal of time researching these and other toys — and why they work. He says his interest in this area goes back to his childhood. As early as high school he was following the development and application of polymers, which are used extensively in toys. By 1978, he was giving informal demonstrations of inorganic and organic polymers. But Katz sees a 1982 presentation of a paper for a chemistry education meeting as a key starting point for his continuing interest in and research into "chemical" toys.

"One of the things I suggested (when asked to present a paper about the chemistry of everyday things) was a paper on the chemistry of toys," says Katz. "I'd always been interested in trying to find out more information about the chemistry of toys, and that was it. That was my first official presentation on the chemistry of toys, and it's been growing ever since."

More recently, Katz published an

article called "Chemistry in the Toy Store" for *Encyclopedia Britannica's 1988 Yearbook for Science and the Future,* and he frequently uses toys in demonstrations to interest young people in science.

'Chemical' Toys

In his article, Katz discusses a number of toys and the chemical properties that help make them work. The first one he discusses is the simple soap bubble, produced as if by magic with the wave of a wand. But the formation of a soap bubble, as Katz explains, is not magic but chemistry at work.

"Soaps are often called surfacants because they tend to act on the surface," he says. "As I try to explain to youngsters, one end is polar—it's like a little magnet—and it's attracted to certain things like water. The other end is non-polar, which is like a metal that is not attracted by a magnet.

"Because of this configuration of the soap, one end is attracted to the water and one end isn't. It kind of lines up against the surface with the non-polar end sticking out and these soap molecules get tangled together and, although they break down the surface tension on the water itself, they create their own surface tension for that soap film."

The soap and water film is somewhat elastic and somewhat attracted to itself, according to Katz. These properties enable bubbles to form. Essentially, as the soap film is blown, it elongates. But the film doesn't want to stay elongated, he says. It wants to make itself spherical. As it collapses, it collapses against itself, forming a bubble.

Katz says the larger and longer lasting bubbles are made of a solution of 10 or 12 percent soap in water. With more than a 12 percent concentration of soap, the bubbles aren't quite as big and don't last as long.

Among the other toys Katz discusses in his article are:

• *Balloons.* Balloons are made from rubber. Inside a rubber plant, conditions are slightly alkaline, according to Katz, so the natural rubber tends to flow. But in an acidic environment, the rubber tends to coagulate into a mass. The rubber molecules then stick to each other, cross linking into a network pattern. It is essentially a solid.

In the thin rubber membrane of a balloon, the network is somewhat folded, explains Katz, so when one inflates a

David A. Katz

balloon, he is actually unfolding that molecule.

"It's not quite as simple as that, because there are changes in the shape and bond rotations that are occurring, but the analogy I use when I speak with youngsters is that it's like a strand of spaghetti lying on a plate folded up, but when it is pulled, it stretches out," he says.

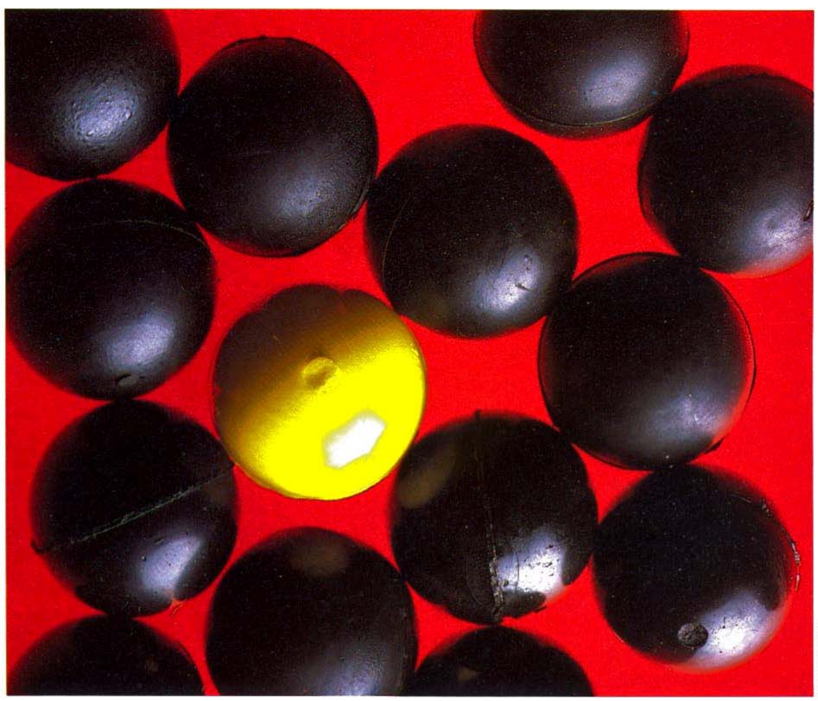
"Rubber behaves pretty much like that. When you let it go, it tries to go back to its previous shape; it tries to refold itself. This is what gives it that elasticity."

Aside from its elasticity, another property of balloon rubber is porousness, which allows air to slowly leak.

"It's not a totally solid material," Katz says. "With the small pores, there is enough space for the molecules in the air to slowly work their way through the surface. They're not big enough for them to freely move out but enough for the air molecules to squeeze in between. Generally speaking, the balloon trying to contract creates a pressure. The pressure inside the balloon tends to be higher than the pressure outside the balloon, causing the air or gas inside to try to escape.

Balloon rubber has one other interesting property. Unlike the more fluid soap bubble, which tries to heal itself when penetrated, a balloon struck by a sharp object not only punctures but tears and runs like a stocking.

"However, if you take a needle and put a little oil on it and poke it through the balloon near the end where the rubber is a little thicker, you can actually put that needle through the balloon," says Katz. "You do leave two small holes there, but you tend to stretch the rubber around the needle, rather than just tearing. The oil



John Burwell

The tough composition of Super Balls makes them extremely hard and resilient.

© Bruce Waters/UNIPHOTO

The sparks that fall from a sparkler are actually tiny bits of metal.

cuts down on the friction, so you can get the needle through the balloon."

• *Balls.* Ordinary balls bounce ordinary heights, generally corresponding to their intended use. But small, solid Super Balls and other similar products bounce higher. The reason: These balls are both harder and more resilient. According to Katz, the addition of a high concentration of sulfur gives the balls those properties.

"This makes the rubber really, really tough," he says. "It creates a lot of cross linking inside. The sulfur basically links between the different molecules, so it is harder and much more resilient. As a result, when you take this ball and drop it, there's not too much open space in there for absorption of energy. Most of the energy is given right back out in the form of its compressing and springing back, causing it to bounce."

• *Caps.* Remember cap guns and caps? Their function too, is chemistry at work. According to Katz, caps are usually made of an oxidizer such as potassium chlorate that supplies oxygen to allow a cap to burn. The material that burns is red phosphorus, also found in matches. The two substances are an explosive mixture. Manganese dioxide is added to enable the potassium to give off oxygen more rapidly and at lower temperatures, and a bit of sand is included to create the friction when the hammer of a cap gun strikes the cap. The friction creates the heat that releases the oxygen and causes the red phosphorus to burn quickly. Magnesium oxide or calcium carbonate, which are basically antacids, are also added to keep the materials stable during storage.

Why does the cap explode when struck? "It's an explosion which is essentially a very quick expansion of gases produced as a result of the burning," explains Katz. "Any gas, when heated very rapidly, expands and, as a result, you basically have a material that heats so fast it's essentially breaking the sound barrier. We get a small sonic boom."

Many toys have their origins in materials developed first for industrial use.

• *Silly Putty.* This silicone polymer is a non-Newtonian fluid, according to Katz. That is, it does not flow easily when struck. Most fluids — water for example — flow easily when hit by a force. When one dives into a pool of water, the water moves away so he can swim through it.

Silly Putty is a material with large molecules that if hit by force cannot move easily, according to Katz.

"Instead of the molecules being able to move out of each other's way quickly, they get tangled," he says. "As they start to get compressed, they seem to repel each other, so the material tends to fight back, and actually under stress cannot move easily. What we find with Silly Putty is that if you drop it, it bounces, but it bounces because it's fighting back, rather than being compressed and springing back like a rubber ball."

Katz says this property of the silicone polymer can be demonstrated by taking a large piece and stomping on it. It usually cracks.

"It tries to expand and fight back that force that is trying to compress it, and when the pressing force becomes too great, it just breaks," he says. "You can do the same thing if you're trying to stretch it. You can pull it slowly and the molecules tend to slide over one another, but if you pull it hard, it snaps."

• *Sparklers.* Sparklers used on the Fourth of July and on birthdays are a mixture of a form of gunpowder, bits of metal and wax. The gunpowder burns when the sparkler is lit. The small bits of metal — iron filings, powdered aluminum or powdered magnesium — fall from the sparkler as it burns. In other words, the metal pieces are the sparks. The wax holds it all together and keeps the metal from oxidizing during storage.

According to Katz, the sparks get their color not only from the heat — the hotter the sparkler burns, the whiter the sparks get — but from the metal types. Iron filings produce gold-colored sparks, while powdered aluminum produces white-colored sparks. Sometimes the white sparks are powdered magnesium.

The flame itself gets its color from chemicals added to the sparklers. They are the same chemicals used to produce some of the bright colors in fireworks.

"Usually they use something like strontium chloride or strontium nitrate," says Katz. "Strontium, when mixed with something flammable, imparts a red color to the flames. Barium compounds such as barium chloride or barium nitrate impart a green color. Copper chloride tends to give a blue color to the flame but not always reliably so. Some of the copper compounds give a green color."

Toy Origins

Many toys have their origins in materials developed first for industrial use. The waterproof, sandlike compound was first used to clean up oil spills and later marketed as a toy, according to Katz. "Silly Putty," he says, "was essentially a laboratory failure in trying to make a synthetic rubber based on silicon instead of carbon."

Another toy resulted from the application of an industrial product that grows when placed in water. The material is "a polymer of hydrolyzed starch-poly-acrylonitrile mixed with glycerin or ethylene glycol," according to Katz's article. It was originally made by the Department of Agriculture for use in oil wells.

"When you have an oil well that's relatively exhausted, you can put some of this down in the well and pump in some water. It soaks up the water, forming a gel, and seeps down into the crevices, forcing the oil up to the top of it. As a result, it makes it a little easier to get some of the oil out of the exhausted oil wells.

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> — **Katz**

"Someone realized that if you mix that material with a little bit of glycerin, it makes a plastic that can be easily molded and it makes these creatures that grow (in water)."

These toys came onto the market a few years ago, then disappeared, says Katz. But new interest in the materials is bringing them back in toys as well as in products like diapers.

Sometimes the use of a material in a toy precedes its use in industry. One company, according to Katz, developed a toy to spark interest in nitinol wire, which, when bent out of its original shape can be returned to form by raising the temperature of the wire.

"In some cases, the toy is used to get interest in the material," he says. "In other cases, people looking at the material say, 'hey, this is kind of fun to play with.'"

Katz says he expects to see more chemical toys in the future. "We'll see some variations of the same things. We'll see new things as they're developed," he says. "It's open to anyone's imagination who is working with a material and says, 'hey, this might make a neat toy.'"

Fun but useful: Playthings can teach valuable lessons in chemistry.

Toys Can Teach

Katz has found a way to take toys beyond "neat." He uses them in classroom demonstrations to spark interest in chemistry. Although he gives demonstrations before students of all ages, he admits to "having lots of fun" with elementary school children.

One of the toys he likes best for demonstrations is disappearing ink, a simple acid-based indicator. He uses it to teach youngsters about acids and bases.

"Essentially, what happens is you have an alcohol-water solution and a little bit of indicator. I usually use a few drops of sodium hydroxide to cause it to turn blue," he says. "Once exposed to the air, the main reaction that occurs is the carbon dioxide in the air is picked up by the sodium hydroxide, neutralizing it to form sodium carbonate and allowing the pH to drop so it's less alkaline and more acidic. So it changes color."

When Katz goes into a class full of students, almost anything can happen. He may make a cubic soap bubble using a cubic frame. Or he may put a needle through a balloon without bursting it. Or he may coagulate rubber latex into a ball before their eyes.

"I try to teach them that science can be fun and it can be interesting," he stresses. "I try to touch on some of the more positive aspects of the science. I'm hoping what I'm doing is giving people a better view of science and of how it's used for something constructive and, in some cases, entertaining." ■