The Slipperiest Solid Substance on Earth

While cutting gas cylinders in half is not a recommended laboratory procedure, DuPont chemist Roy J. Plunkett saw no other option on April 6, 1938. Plunkett, 27 years old with a PhD degree from Ohio State University, just two years past graduation, was stationed at DuPont's Jackson Laboratory in Deepwater Point, New Jersey. He had been working on synthesizing new chlorofluorocarbon compounds as refrigerants to replace the dangerous ammonia and SO_2 then in use. The procedure was to react tetrafluoroethylene (TFE) with hydrochloric acid to produce chlorofluorocarbons. To speed up the experimental process, Plunkett and his assistant Jack Rebok prepared 100 pounds of tetrafluoroethylene and stored it in small gas cylinders for easy access. To prevent a possible explosion, they stored the cylinders in dry ice.

On the morning of April 6, Rebok grabbed one of the cylinders and opened the valve to start an experiment. No gas came out. He made sure the valve was open by sticking a wire through it; he weighed the cylinder to confirm that it was not empty; he shook the cylinder and watched a few tiny flakes of a white waxy substance fall out. The only thing left to do was to cut the cylinder open.

"Gee whiz, it's gone wrong," Plunkett said as he viewed the white powdery substance that coated the walls of the cylinder. He soon realized that the TFE had polymerized spontaneously. He could have thrown the cylinder out and tried to find a different way to store gaseous TFE, but Plunkett was the type of scientist who examined his "failures" to see what he might learn.

A series of tests revealed that the new polymer combined stability at low temperature with a very high melting point of 327°C. It was chemically inert, resisting interaction with all but the most corrosive of compounds; it was a great electrical insulator; and it was slippery. More slippery, it turned out, than ice in contact with ice. In fact, the low static coefficient of friction of Teflon-on-Teflon, 0.04, made it the most slippery solid substance on earth.

Further experimentation revealed the reasons for these properties: the carbon backbone of the polymer chain was completely surrounded by fluorine atoms. The strong carbon–fluorine bond and high crystallinity made it chemically inert, with a high melting point and a very low coefficient of friction.

Plunkett applied for a patent for "tetrafluoroethylene polymers," also known as polytetrafluoroethylene (PTFE), on July 1, 1939. The patent focused on the corrosion-resistant nature of the polymers, not their slipperiness. "It is an object of the invention to provide a new composition of matter which is highly resistant to corrosive influences and to oxidation….," the patent stated. It was granted in 1941.

Plunkett was not a polymer chemist, so he was soon removed from the PTFE project and put to work on tetraethyl lead additives to boost the octane of gasoline. Others carried on the task of finding ways to synthesize large quantities of PTFE economically, but the process was slow at first. It proved to be an expensive material to make, limiting its marketability.

But the entry of the United States into World War II soon made marketing a moot issue. The Manhattan Project needed an extremely corrosion-resistant material to stand up to the uranium hexafluoride gas that was the source of the radioactive uranium used in the atomic bomb. Gaskets made of any other material were destroyed by this gas, but PTFE withstood the challenge. The military classified PTFE under the code name "K 416," and DuPont built a plant in Arlington, New Jersey, to produce all the PTFE the military could use.

By the time the public learned of the existence of Plunkett's polymer, it was 1946, and PTFE was known by the brand name Teflon. But Teflon was not yet ready for consumers. First, DuPont's chemists and engineers still had to learn how to make the product uniformly every time. Second, its high melting point made it difficult to form into shapes using traditional methods. Third, how can the world's slipperiest material be made to stick to anything?

DuPont opened the first commercial Teflon plant in Parkersburg, West Virginia, in 1948, but progress remained slow. Initial applications included coatings for metal machine parts and electrical insulation in appliances. Teflon was made to stick to metal machine parts by heating the parts to 650°C and immersing them in a high-velocity fluid stream of Teflon particles. Fluorocarbon resins were also invented to stick Teflon to various surfaces, and etching processes were used to roughen a surface prior to the application of Teflon.

By the mid-1950s, commercial bakeries were using Teflon rollers and pans for some baking applications, but DuPont was cautious about selling these products directly to the consumer. Some concerns about toxic gases being released when Teflon pans were heated by direct flame made the company proceed slowly to avoid potential consumer lawsuits.

It finally took a French engineer named Marc Grégoire and his wife Collette to push Teflon into the kitchen. They began making Teflon-coated aluminum cookware in their home in 1955 and selling it to French chefs. Business was so good that they formed the Tefal Corporation in 1956, with great success.

Encouraged by the French example, DuPont put Teflon cookware through rigorous tests for several years and won approval from the FDA for Teflon products for the home in 1960. Although further improvements would be needed to make sure the coating could not be easily scraped off of a surface, Teflon in the kitchen was here to stay.

DuPont developed variations of Teflon compounds over the years, including Teflon FEP, which added hexafluoropropylene to the polymer chain, and Teflon PFA, which added perfluoroalkylvinyl ethers; both of these had lower crystallinity than the original Teflon PTFE, and therefore could be melt-processed. They also developed Teflon AF, an amorphous compound that is soluble in fluorinated solvents and optically transparent.

Plunkett's polymer has been used for such low-tech applications as muffin pan coatings and Gore-Tex clothing to such high-tech ones as nose cones for spacecraft and artificial ligaments. Its highest-volume application is insulating coatings for electrical wiring.

Roy Plunkett worked his entire career at DuPont. He was elected to the National Inventors Hall of Fame in 1985. DuPont established the Plunkett Award for Innovation with Teflon in 2002. Plunkett died in 1994.

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FOR FURTHER READING: Stephen van Dulken, *Inventing the 20th Century: 100 Inventions That Shaped the World, from the Airplane to the Zipper* (New York University Press, New York, 2000); Ira Flatow, *They All Laughed…From Light Bulbs to Lasers: The Fascinating Stories Behind the Great Inventions That Have Changed Our Lives* (HarperCollins, New York, 1992); and John Scheirs, editor, *Modern Fluoropolymers: High Performance Polymers for Diverse Applications* (John Wiley & Sons, West Sussex, England, 1997).

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