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Invention and entrepreneurship: the electrolytic process and the establishment of The Pittsburgh Reduction Company

Few inventions are successfully commercialized. This is a history of one that was. On February 23, 1886, while experimenting in the woodshed of his kitchen in Oberlin, Ohio, Charles Martin Hall discovered an inexpensive way to smelt aluminum. Nearly five months later, in accordance with legal custom, he applied for a patent. For seventeen years, as the owner of a patent, he could sue others who attempted to copy his invention without his permission. This gave him, in effect, a legal monopoly right to transform his discovery into a useful commercial process. Hall's patent, U.S. No. 400,766, was not actually issued until April 2, 1889, but the claim to it had already become the principal asset of a little experimental shop known as The Pittsburgh Reduction Company, Alcoa's corporate predecessor.[1]

It was on a summer day in Pittsburgh, on July, 31, 1888, when a small group of entrepreneurs gathered at the home of Alfred Hunt to discuss their potential interest in Hall's patent claim. These budding aluminum entrepreneurs were experts in steel, all connected, one way or another, with an industry that was enjoying spectacular growth, fast becoming the linchpin of Pittsburgh's industrial development. Nonetheless, they had some spare funds and were attracted to the technical and commercial possibilities of the lighter, nonferrous metal, about which they knew very little. There is no detailed record of the meeting, but Hunt no doubt explained to them what he had found out about Hall's process. It was as yet undeveloped; it had not been proven to be technically or commercially feasible. Nevertheless, its potential was worth considering: If the process could be made to work, if a market could be found for its product, then one of earth's most common (yet theretofore inaccessible) elements could be mass produced under patents for great profit. Eight days later, a smaller group of six agreed to stake $20,000 to support a trial development of the new aluminum process.[2]

The entrepreneurs won their bet. Within months, Hall's invention was developed into commercial production. The enterprise grew rapidly, and by the mid-1890s, The Pittsburgh Reduction Company was operating a large smelting complex in Niagara Falls, New York, and a fabricating plant in New Kensington, Pennsylvania, making aluminum and aluminum shapes for an emerging national market. By the time the firm was renamed the Aluminum Company of America in 1907, it had become one of America's larger industrial enterprises with a secure patent monopoly on its main line of business. The investors who stayed with the business became rich, and Hall himself would leave an estate that, on the basis of a single discovery, made him the wealthiest inventor in the United States.

The technical and commercial background

Aluminum, or "aluminium," as it is known outside the United States, is an abundant element comprising about eight percent of the earth's crust. And yet for most of the nineteenth century, it was a precious metal few people wanted and even fewer could afford. In the midnineteenth century, the cost of aluminum exceeded $500 per pound, more than twice the value of gold or platinum.[3] After the great English chemist Sir Humphry Davy had identified "alumium" in 1807, interest in the metal was limited to the curiosity of a few scientists and to the Court of France, where in the 1850s it adorned the banquet table in the form of finely crafted eating utensils and became a fashionable substance for jewelry, more fashionable at times than either gold or silver. Aesthetically pleasing in its silvery color, incredibly light but strong, and resistant to corrosion, aluminum was envisioned by Napoleon III as an untapped resource with great military potential. The Emperor, hoping to outfit his *cuirassiers* in light helmets and armor, joined the French Academy in financing the experiments of Henri Sainte-Claire Deville, who had discovered a promising process to reduce aluminum in large quantities from the chemical compounds that imprisoned it in nature.[4]

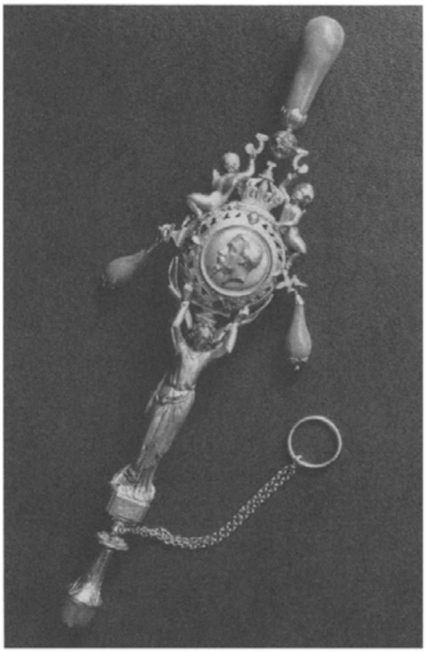

Fig. 1.1. Napoleonic baby rattle made of aluminum, circa 1850.

The seeming economic paradox of aluminum – its natural abundance and high price – arose from the technical difficulty in separating it from other elements to which it is bonded. In the earth, aluminum appears almost always as an oxide known as "alumina," which is found in nearly all common rocks. Occurring mainly in the form of silicates such as feldspars, micas, and various clays, aluminum came to be known in the nineteenth century as the "metal of clay." This was a revelation. While metals such as iron, bronze, and copper had been used by humanity since antiquity, aluminum, at least in its metallic form, had remained elusive. Uses of aluminum silicates for pottery and "alums" for vegetable dyes and medicines had been traced back to ancient Egypt and Persia. However, no one recognized aluminum as an element until 1782, when Antoine Lavoisier postulated its existence as "the oxide of a metal whose affinity for oxygen is so strong that it cannot be overcome either by carbon or any other known reducing agent."[5]

The reduction, or smelting, of pure, metallic aluminum from its oxide-bound state confounded some of the best scientific minds of the nineteenth century. Lavoisier had not acted upon his speculation, and not until some twenty-five years later did Davy succeed in isolating aluminum for barely an instant. By fusing iron with alumina in an electric arc, Davy freed the element from its oxide only to have it join immediately with the iron as an alloy.[6] Between Davy and Deville, who was the first to bring aluminum to market, at least two significant steps toward the isolation of aluminum by chemical means were taken. In 1825, Danish physicist H. C. Oersted produced the first small amount of aluminum by heating potassium amalgam with aluminum chloride, which he had first made by passing dry chlorine over a heated mixture of alumina and carbon. This process yielded potassium chloride and an aluminum amalgam, which once distilled "without contact with the atmosphere . . . forms a lump of metal which in color and luster somewhat resembles tin" showing "remarkable qualities." Friedrich Wöhler in Berlin repeated Oersted's experiments, but to no avail; however, he then substituted metallic potassium for the potassium amalgam and was able to produce metallic aluminum in the form of gray powder. By 1845, after eighteen years of painstaking research, Wöhler managed to make aluminum in large enough amounts for study when he hammered out two metal globules from particles the size of pinheads and then measured their specific gravity at somewhere between 2.50 and 2.67. In addition to its remarkable lightness (about a third of the density of copper), Wöhler confirmed some of the metal's other important qualities: it was "ductile" (easy to work when cold), "stable in air," and "can be melted with the heat of a laboratory blowpipe." Wöhler, however, could not melt his tiny particles together into a coherent mass. An oxide film that formed on the metal particles (and incidentally protected them from corroding influences) prevented their coalescence.[7]

Laboratory research in aluminum was an indulgent and expensive undertaking for curious scientists. Deville, a more entrepreneurial researcher than his predecessors, addressed the problem left by Wöhler's experiments by using sodium instead of potassium to react with aluminum chloride. Deville observed that sodium chloride formed in the reduction of the aluminum chloride acted as a flux, enabling the particles to fuse together. This was the discovery that excited the French Academy and the Emperor.[8]

Because sodium was far less expensive than potassium, Deville's process held out hope for making aluminum at a reasonable cost. Beginning with a grant from the Academy and support from the

Fig. 1.2. Henri Sainte-Claire Deville.

state, Deville conducted developmental work on his process with the aid of several French scientists at the Javel Chemical Works. In 1855, bars, or "ingots," of aluminum were exhibited at the Paris Exposition, as Deville began commercial production with Debray, Morin, and Rousseau Frères at Glacière at a selling price of 300 francs per kilo. The work at Glacière gave way to a new facility at Nanterre built specifically for the production of aluminum in 1857. At Nanterre, Deville introduced some changes in the chemistry, the most significant of which involved the introduction of fluorides, such as fluorspar and cryolite, as fluxes. Ten parts of crushed aluminum-sodium chloride were mixed with five parts fluorspar and two parts sodium in a closed reverberatory furnace. Aluminum, ninety-seven percent pure, was tapped out of the furnace in a stream and then formed in a solid body under the cover of a slag that flowed out last.

Through production economies of scale and technique, the price of aluminum was reduced to 200 francs per kilo, or $17 per pound, in 1859.[9]

Deville, whose ambition was to make aluminum for a handsome profit, tried to postulate a market niche for the metal. He thought that aluminum was best regarded as an "intermediate metal standing between the precious and base metals." The markets for such a material were predictably confined to ornamental uses, whether applied in pure form or as an alloy in combination with other metals. Still, he knew that for even such limited markets, the price would have to come down. He attacked that problem by producing the sodium used in the reduction process himself in an attempt to lower its cost.[10]

Innovative activity accelerates as expectations for future profits rise. Accordingly, Deville's improvements in the cost structure of aluminum production aroused the interest of many free-lance inventors and also brought many new commercial enterprises into the business. By 1888, several aluminum concerns in England, France, and Germany, employing a variety of methods, had made dramatic strides in reducing the price of sodium and in improving its utilization. An American, Hamilton Castner, discovered a means for producing sodium from caustic soda, bringing sodium's cost down to twenty-five cents per pound at a time when one pound of aluminum required three times that amount of sodium in the furnace. Castner's method was adopted in 1886 by a British firm, the Aluminium Company, Ltd. at Oldbury, which was the low-cost producer of both sodium and aluminum for three years. Elsewhere in England, advances were made in the reduction of cryolite. One German company formed around a patented process using aluminum fluoride as the source of aluminum and sodium as the reducing agent. The utilization of sodium reached as high as ninety-percent efficiency in this process, which also yielded aluminum of more than 99.5-percent purity.[11]

Despite these technical improvements and their corresponding reductions in costs, aluminum remained a craftsman's material, luxurious and semiprecious. Remarkable advances in sodium reduction processes helped bring the American price of the metal down to eight dollars per pound by the end of 1887. But this was still too high a price for mass consumption. The accumulated total of worldwide aluminum production since 1854 was probably under 140,000 pounds, mostly produced in the 1880s.[12] Applications ranged from jewelry and other small personal items to more functional but still

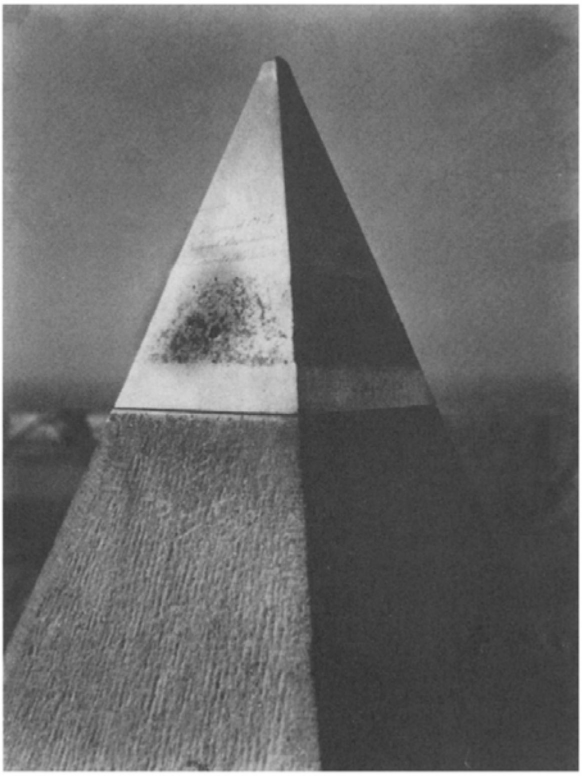

Fig. 1.3. The aluminum capitol atop the Washington Monument.

luxurious uses in navigation instruments, balances, and clocks. Napoleon had purchased a breastplate, but no aluminum products were produced in volume for military purposes or otherwise. Some artists found aluminum-copper or -silver alloys desirable for statuary: the image of Eros in Piccadilly Circus was a Deville-Process cast, and 100 ounces of aluminum found a lofty perch atop the Washington Monument, where the metal served as both ornament and lightning rod in 1884, at a cost of $225.[13]

Between 1854 (when Deville had begun his work) and 1859, the price of aluminum plunged from about $550 to about $17 per pound, making it about equal in value to silver. By 1888, as sodium reduction techniques reached their apogee, the world price of aluminum had continued to drop to about $4. The decrease had not been enough to render aluminum a "base metal," but it was sufficient for a number of small firms to bring it to market for specialized and profitable applications. A number of aluminum alloys that could be produced without making aluminum first had also come onto the market. In 1886, an American company operated by the prominent metallurgists Alfred and Eugene Cowles patented an electrothermal process for reducing mixtures of alumina, carbon, and some other heavy metal to produce light alloys with up to forty-percent aluminum content. Then, suddenly, a technological revolution occurred, displacing sodium methods of making pure aluminum by cheaper and radically different means of production, that would make the earth's commonest metal available for a mass market.

This technological revolution occurred in November 1888, when the pilot plant of The Pittsburgh Reduction Company became the first commercial enterprise to smelt aluminum by electrolysis. Just seven years later (and four years after the last of the sodium reduction works was closed), some 920,000 pounds of aluminum produced by electrolysis were sold in the United States for about fifty-four cents per pound.[14]

Invention: The electrolytic process

The advent of a fundamental technological innovation, such as the Hall Process for smelting alumium, depends on at least two prior conditions: an accumulated body of knowledge that establishes strong scientific or empirical foundation for the decisive insight, and a well-perceived commercial opportunity for the exploitation of the invention. Inventions such as Hall's also arise in a cultural climate favorable to specific kinds of scientific inquiry. In the industrializing societies of Western Europe and America in the late nineteenth century, there was a high value placed on the application of science to economic production. It is hard to imagine Hall, or anyone else for that matter, devoting himself to a problem as scientifically complex as the smelting of aluminum in the absence of the prevailing ethos of industrial progress. Given the context, it is not surprising to see that Hall was but one of several curious explorers into the chemistry of aluminum and was not the only one to find an answer to its most intriguing problem within a very short span of time.

In fact, the discovery of the modern process of smelting aluminum is one of many famous cases of simultaneous invention, in which people working independently make substantially the same discoveries based on equivalent understandings of the state of an art. Working continents apart and in complete ignorance of each other, Charles Martin Hall and a French citizen, Paul L. T. Héroult, each devised a commercially plausible way to produce aluminum electrolytically and thereby ushered in a new era in man's use of metals. That the two men arrived at the same means for making aluminum at almost the same time resulted from a concatenation of technological developments in metallurgy and in the new science of electricity.

In the late nineteenth century, metallurgy was less a modern science than a raw empirical discipline. Systematic knowledge about the nature of metals and their behavior under different conditions was the accumulated wisdom of centuries of slow, sporadic trial and error. This was true even of ferrous metals, which had been smelted since the third millennium B.C. and from which highly successful hardened products had been developed over the centuries. There existed no fundamental understanding of the properties of cast iron, wrought iron, and steel until the late eighteenth century. An oxide-bound, nonferrous metal, aluminum was, by comparison, a complete enigma.[15]

Davy's attempts to reduce aluminum proceeded from his crude understanding of molecular structures and his interest in the nascent science of electricity. He tried but failed to reduce aluminum with a current from a battery. Any chance of success with electrolytic methods awaited more intense sources of power. In the meantime, an alternative path of chemically based experiments was taken by Oersted, Wöhler, and Deville. By 1854, Robert Bunsen and Deville independently produced aluminum by electrolysis of aluminum chloride, but contemporary batteries were still inadequate for generating the power required to make the process economically feasible. Other technical problems, including the high volatility of aluminum compounds under electrolysis, defeated numerous experiments. Nevertheless, inventors persisted in the belief that electrolysis – as it has been applied to the plating of silver, gold, copper, and nickel – held the key to cheap aluminum reduction. This belief was justified when the development in the 1870s of practical dynamos made possible the continuous generation of the large amounts of electric power required to reduce aluminum at a reasonable cost.[16]

If anyone seemed destined to find a way to transform aluminum into a "common metal," it was the young Charles Martin Hall, the third son and sixth child of a Congregational missionary who had settled in Oberlin, Ohio. Little is known about his early years other

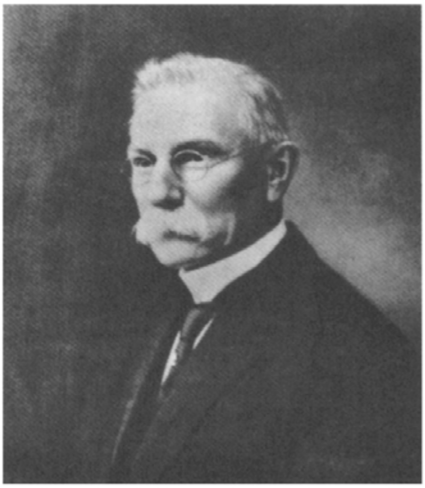

Fig. 1.4. Frank Fanning Jewett, Charles Martin Hall's chemistry professor at Oberlin.

than that he was intellectually precocious and that his imagination was seized by chemistry more than by ordinary childhood pastimes. According to his principal biographer, he became interested in books at an age when most children could not yet read, and among his readings was a well-worn chemistry textbook he found in his father's library. By the age of twelve, he was performing makeshift chemical experiments at home.[17]

Tradition has it that Hall was inspired by a remark of his Oberlin chemistry professor, Frank Fanning Jewett, to the effect that fame and fortune awaited the man who could find a cheap way to reduce aluminum. Jewett, who had been quick to recognize Hall as a gifted student, "took him into my private laboratory and gave him a place by my side – discussing his problems with him from day to day."

> Possibly [said Jewett years later] a remark of mine in the laboratory one day led him to turn his especial attention to aluminum. Speaking to my students, I said that if anyone should invent a process by which aluminum could be produced on a commercial scale, not only would he be a great benefactor to the world but would also be able to lay up for himself a great fortune. Turning to a classmate, Charles Hall said, "I'm going for that metal." And he went for it.[18]