Distillatio, by the sixteenth-century Flemish artist Jan van der Straet, shows an alchemy laboratory abuzz with chemical processing.

The Alchemist's Lab

Despite efforts to turn lead into gold, your average sixteenth-century alchemist was probably more scientist than magician.

by Jennifer Pinkowski

Alchemy was a protoscientific stew of chemistry, astrology, mysticism, metallurgy, physics, and religion. It had its origins in Egypt, India, and China, and has largely been associated with metallurgy and pharmacology. Its practitioners have been depicted as both cosmic clowns and demonic dabblers. But that is a modern perspective on the alchemists of medieval and Renaissance Europe. At that time alchemy was a widespread practice: archaeologists have found hundreds of artifacts from alchemical laboratories all over Europe, including England, Norway, Switzerland, France, Portugal, Germany, Austria, and Denmark (as well as Jamestown, Virginia).

On a practical level, these alchemists were often involved in brass making, gold smithing, and assessing the noble metal content of ore, jewelry, or coins. But they were also fascinated with the idea of transmutation and believed in a sort of infinite mutability of matter. They sought the philosopher's stone—the magical substance for transforming base metals into gold and indefinitely prolonging life. Roger Bacon, the thirteenth-century scholar and one of the earliest advocates of the the scientific method, described the discipline as incorporating both the ethereal and the mundane. "Theoretical alchemy theorizes about all inanimate things and about the whole generation of things from the elements," he wrote. "There is also an operative and practical alchemy, which teaches how to make precious metals and pigments, and many other things better and more plentifully than they are made by nature."

It was the operative and practical aspect of alchemy that Marcos Martinón-Torres, a Ph.D student in archaeological sciences at University College London's Institute of Archaeology, sought in his research. Over the past three years he has analyzed sixteenth-century alchemical laboratory instruments with twenty-first-century scientific equipment at the Wolfson Archaeological Science Laboratories in the institute basement. His analysis has identified the raw materials used in the production of the ceramic laboratory instruments and what made them suitable for chemical experimentation—important information for students of late medieval and Renaissance Europe looking to trace the production and trade of laboratory instruments. He's also analyzed a cryptic alchemy text and determined that it describes a reproducible metallurgical process, which indicates the author really knew his metallurgy. Martinón-Torres' analysis suggests that the average Renaissance alchemist was a religiously minded researcher working at a time when the scientific revolution was just beginning, great discoveries in astronomy and physics by scientists like Johannes Kepler and Galileo Galilei leading the way.

"Alchemy may look like magic or witchcraft to us, but in the sixteenth century, it wasn't," Martinón-Torres says. "The best we say about it is that it's a forerunner of chemistry. Alchemy and chemistry are the same thing. Many of the things we see as magic, they saw as science."

Palazzo Vecchio, Florence/Bridgeman Art Library

Bildarchiv Preussischer Kulturbesitz /Art Resource

In *The Alchemist at Work,* Pieter Brueghel the Elder (ca. 1529–69) paints a vaudevillian scene of smoldering concoctions, dubiously skilled assistants, and troublesome scamps in a messy—and likely dangerous—lab.

The artifacts Martinón-Torres studied are from Schloss Oberstockstall, a castle in Kirchberg am Wagram in Lower Austria, about 30 miles from Vienna, where in 1980 archaeologists discovered the best-preserved Renaissance laboratory ever found. Oberstockstall dates to the fourteenth century, but its laboratory was built nearly 200 years later, in 1548, by Christoph von Trenbach, the vicar of Kirchberg and canon of Passau (the region straddling the Austrian-German border). Von Trenbach, his brother, and another pair of brothers, all of them priests, were Oberstockstall's alchemists.

They were typical for their day. "Religion was present in alchemy," Martinón-Torres says. "Nature is God's creation, and getting to know God is a good thing." Alchemists believed nature tended to perfection, so "ennobling" base metals by transforming them into gold was less magic than worship. It revealed the sublime hand of God. In fact, one wall of the Oberstockstall laboratory had a slot through which the alchemists could see the chapel altar.

The laboratory was destroyed by an earthquake about 1590, its contents dumped beneath the floor of the castle's chapel sacristy, in which it was located. While remains of brick furnaces, tiles with chemical and manufacturer's marks, leather, textiles, bone, metal, ores, and slag were among the finds, the archaeologists, including Sigrid von Osten, the director of the excavations, were most intrigued by the laboratory instruments found. Specialized vessels of many different types were unearthed both in fragments and whole. Subsequent excavations have turned up about a thousand artifacts, which are housed in an alchemy museum on the castle grounds.

"When you look at these artifacts, you think you're looking over the alchemist's shoulder as he is working," says von Osten, who is now the museum curator.

The artifacts clearly match depictions of laboratory equipment found in medieval and Renaissance alchemical manuscripts, the main source of knowledge for scholars specializing in this time period. Thousands of such manuscripts exist; some are *practica,* about the practice of alchemy, which featured alchemical "recipes" for various processes, many claiming to result in endless life or wealth. Others are *theorica,* relating to the theories behind alchemy. Sometimes these two types of alchemical texts were combined.

"People viewed alchemy not only as a technology but as an applied science," says William Newman, a professor of the history of science at Indiana University who has extensively researched and written about alchemy. "They thought they had a theoretical basis for alchemy that could be drawn out into practice."

This didn't necessarily lead to clarity. As many European alchemists believed they were recovering ancient knowledge that had been lost over the centuries, many manuscripts are pointedly obscure. The authors jealously guarded the knowledge they claimed to have found, shrouding the texts in allegory and symbolism. Being able to decipher many of these texts was part of the alchemical process itself, for it proved that the practitioner was "worthy" to have such knowledge.

Even those manuscripts that aren't intentionally esoteric may not be a true representation of what the alchemists were actually doing, says archaeological scientist Ian Freestone of Cardiff University in Wales. "So often, what people write down is different from what they really think and do; the intention of the writing can be to impress the audience or in some cases to hide what one knows. The analysis of chemical remains offers us the possibility to understand the differences," he says.

Martinón-Torres thinks so, too. His research into the Oberstockstall instruments began by poring over these

The array of specialized artifacts found at the Oberstockstall castle in Lower Austria included cupels, scorifiers, crucibles, muffles, flasks, still heads, and cucurbits. Many of these types of vessels were referred to in alchemical manuscripts by the animals to which their shapes showed a likeness: the eagle, the vulture, the pelican.

symbol-heavy manuscripts. "When looking at the symbols, [I thought] it seemed that they might become noticeable in the archaeological evidence," he recalls. "Historians can hypothesize what lead is as a symbol, but we have the crucible." He was able to determine that an allegorical text was a reliable guide to metallurgy—as long as one understood the symbols. ("Metals from Metaphors," page 30.)

After studying the manuscripts, Martinón-Torres moved on to the physical analysis. In 1998, Thilo Rehren, Martinón-Torres' research supervisor at the UCL Institute of Archaeology, had done scientific analyses of some Oberstockstall artifacts (more on this later), but Martinón-Torres' focus was the artifacts' make. When he began his analysis, little was known about the production of laboratory instruments and equipment in the Renaissance.

In the windowless rooms of the archaeology laboratory, he spent months analyzing sherds from these artifacts with high-tech equipment, including optical microscopes and energy-dispersive x-ray fluorescence analysis, which gave him the bulk chemical composition of each sherd. The most powerful tool at his disposal was the scanning electron microscope with an attached energy-dispersive spectrometer (SEM-EDX), which can magnify an object 200,000 times. It creates high-resolution images of an object's appearance, composition, and contamination, as well as the shape and size of its particles.

The first thing he determined was that a good portion of the Oberstockstall artifacts were unusual. So-called "Hessian" crucibles—brightly colored, roughly surfaced triangular vessels from northern Germany—are frequently referred to in alchemical texts, and they have been found all over the world. But the crucibles at Oberstockstall, though high quality, weren't Hessian. They generally had been made of clay and graphite and often had a black, shiny surface. He traced them to Obernzell, Germany, at the time a center for the production of graphite crucibles. Subsequently he was able to identify this type of crucible in another laboratory much further away from Obernzell: Oxford, England. "Graphite crucibles don't appear in the alchemical literature until the late seventeenth century," he says. "By using archaeology we discovered something that was completely missing. We would be saying the Hessian crucibles were the ones used for everything, but that's not true."

Top: A scorifier with lead oxide slag crystals on its surface, as seen via an optical microscope. Above: Interior of a crucible as revealed by SEM-EDX. The dark sections are graphite, which made the crucible durable. Below: The Oberstockstall estate.

Comparative analysis of the graphite crucibles from Oxford, as well as Hessian crucibles discovered in London, Germany, Portugal, and Virginia, leads Martinón-Torres to suggest that, contrary to what scholars had thought, Hessian crucibles probably had a high-quality competitor—these black crucibles.

SEM-EDX can also reveal an object's properties, including hardness, reflectivity, strength, reactivity, conductivity, and melting point—qualities that would have made a vessel useful or not for an alchemist. For

Marcos Martinón-Torres (above, left, and all below)

this stage of research, Martinón-Torres focused on the Oberstockstall crucibles, scorifiers (shallow little plates that also served as lids for the crucibles), and cupels (small round cups). They were the vessels most likely used for a fire assay, a sequence of chemical operations carried out to determine what metals are present in a sample of ore or another metallurgical product.

Analysis revealed more clues to the suitability of the vessels. The crucibles were made from a highly refractory clay (able to withstand high temperatures) mixed with various amounts of sand, grog (finely ground fired clay), and crushed graphite, which further improved the resistance of the crucibles to the stresses of the fire assay. The higher the graphite content, the better the vessel was able to conduct heat and keep harsh chemicals from breaking down the crucible during particularly demanding reactions. On the other hand, the scorifiers were made of less refractory clay than the crucibles and had a wide variety of other materials, which meant that the reactions carried out in them didn't need temperatures as high. Finally, the cupels were made with bone ash, which separates noble metals from lead by absorbing the latter, leaving the gold or silver on the surface. (The cupels were the only vessels that might have been made by the Oberstockstall alchemists; a lump of bone ash was found at the site.)

From these results Martinón-Torres was able to see the typical fire assay as the

In early 2003, Marcos Martinón-Torres visited Oberstockstall to study the laboratory artifacts. He took samples back to London to analyze.

Courtesy Marcos Martinón-Torres

Metals from Metaphors

Alchemical manuscripts are notorious for their symbolic language. Just what is meant when a text says, for example, to "add to the Eagle the icy Dragon that has long had its habitation upon the rocks" or that "the twofold fiery male must be fed with a snowy swan"? Do reproducible chemical processes lie beneath the florid metaphors? And do they *work*?

Using Basilius Valentinus' influential *The Twelve Keys*, a fifteenth-century text (from which the above phrases were taken), Marcos Martinón-Torres decided to find out.

Each of the "keys" is an allegorical representation of a step in the chemical process leading to the philosopher's stone. The unhelpful text for *prima clavis*, or the first key (shown at left), reads, "Let the diadem of the king be of pure gold, and let the queen that is united to him in wedlock be chaste and immaculate…. Take a fierce gray wolf, which is found in the valleys and mountains of the world, where he roams savage with hunger. Cast to him the body of the king, and when he has devoured it, burn him entirely to ashes in a great fire…." It gets no clearer from there.

Using his knowledge of metallurgy of the time period and clues in other alchemical manuscripts (some imagery is common—lead, for example, is often depicted as Saturn), Martinón-Torres substituted the metaphors with their metallurgical equivalents, noting the crucible and cupel depicted in the lower corners of the key as well. He translated the first key as a straightforward recipe for using stibnite (the wolf) to separate silver (the queen) from gold (the king) in the crucible, and then using the lead (Saturn) to retrieve silver from the stibnite ashes in the cupel.

And it does work. For all his mysticism, Valentinus knew his metallurgy, and an alchemist familiar with the imagery would have been able to rely on the text. The first key isn't a step leading to gold via the philosopher's stone, but it does lead to gold via metallurgical separation. Martinón-Torres notes wryly, "Our analysis is a lot more explicit than the alchemists themselves."—JP

Oberstockstall alchemists would have conducted it. They would have melted an ore sample in the thermal-resistant crucible, carried out an intermediate reaction, such as concentrating the noble metals, in the scorifier, and further refined the metal in the cupel.

Interestingly, neither the suppliers of these vessels nor the alchemists who relied on them seemed to know *why* they were suitable. Appearance may have been a sign of reliability for your average alchemist, says Martinón-Torres. The Oberstockstall crucibles with a high graphite content would have been black and shiny when first made. (All crucibles, including the Hessians, turn different colors after use, depending on what they were used for.) But the crucibles with less graphite content were deliberately smoked to give them a black appearance—a sort of post-medieval marketing by the manufacturer to fit the expectations of the buyer, he suggests. "[An alchemist] might think, 'The black, smooth one is the one I want.' In this case we may have a secondary feature that leads people to choose them."

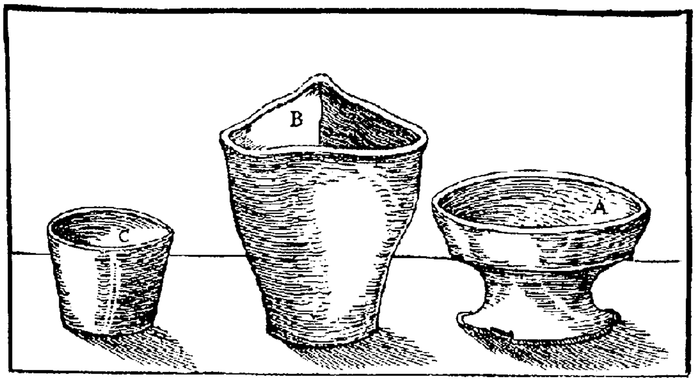
Courtesy Marcos Martinón-Torres

The idea that an object's appearance is key to its use isn't just misguided medieval thought. Martinón-Torres makes a comparison to one of modern life's favorite items: blue jeans. Initially they were desired for their rivets, which made them durable. But it was blue jeans' distinctive color that became their primary association. Nobody today asks for "riveted" jeans.

THE OBERSTOCKSTALL ALCHEMISTS may have been also experimenting with "new" metals and conducting what would now be called experimental research. In 1998 Rehren's analysis of the chemical residue on the cupels showed the frequent presence of bismuth, a heavy, brittle, leadlike metal that is frequently found with silver in ore deposits. In the sixteenth century, bismuth was considered a sort of lead—one of the seven known metals, each associated with one of the seven known planets—and may have been used instead of lead in transmutation attempts. (Bismuth would later join zinc and cobalt as elements identified by alchemists.) This would have allowed the alchemist to start one step ahead in the transmutation process—an experiment. "In the Renaissance, they thought base metals 'matured' into silver and then gold in the depths of the earth," says Rehren. "Perhaps they were picking this bismuth, this strange 'lead,' as a starting point rather than using the less advanced lead. That would have been a feasible way of experimenting for a Renaissance alchemist."

To repeatedly conduct these sorts of chemical reactions and metallurgical processes, the Oberstockstall alchemists would have needed a working, if not a theoretical, knowledge of such basic scientific concepts as the conservation of mass—which says there is no change in total mass during a chemical reaction—and constant combining proportions—which says the relative amount of each element is always the same, regardless of its preparation or source.

Bismuth, antimony, copper, silver, gold, and sulfur, as well as fahlore and other minerals, have been found on the vessels. Why they are there is the focus of Martinón-Torres' ongoing research. Under his and Rehren's supervision, another Ph.D student is analyzing the chemical residues on the vessels and will compare them to other archaeological assemblages and written sources. "Hopefully we will be able to say if someone was following a particular recipe," he says.



Courtesy Marcos Martinón-Torres (2)

A cupel, crucible, and scorifer—the three vessels most commonly used for the fire assay—from, above, a manuscript by Georg Agricola, a sixteenth-century German scholar, and, left, the Oberstockstall laboratory.

Within a hundred years of the destruction of the Oberstockstall laboratory, alchemy was already transforming into the "pure science" of chemistry, and many of its more mystical practitioners would be exposed as Barnum-esque exploiters of the gullible and greedy. But the Oberstockstall alchemists were working at a time when there was no real division between alchemy as an mystical endeavor, chemistry as a science, and metallurgy as a craft. They were multiple facets of the same explorative spirit—one that would eventually emerge as the modern science we know today, based on the three pillars of empiricism, experimentation, and inductive reasoning.

"The analysis is telling us about the possibility of these people being very systematic and discovering things they didn't expect," says Martinón-Torres. "They didn't find the philosopher's stone, but they did find modern experimental science—and that's more valuable." ■

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