FROM CONDENSED-MATTER PHYSICS TO CHINESE CERAMICS

Robert Wheeler

When I got out of high school in 1946, science was in the forefront of the national consciousness because it had helped win the war. Radar and electronics fascinated me in particular. Having decided that I wanted to be an engineer, I went to Lehigh University in Bethlehem, Pennsylvania, to study what was then called engineering physics. In my junior and senior years, I spent four afternoons a week in the laboratory and one afternoon at ROTC drill. Bell Laboratories had a small facility in nearby Allentown run by the father of one of my classmates, Will Ronci. The transistor was invented at Bell in 1947. By the time we were seniors, Will and I had type A transistors to play with in the laboratory, long before any other undergraduates did.

After finishing undergraduate school, I spent two summers doing research on waves at the Woods Hole Oceanographic Institution in Massachusetts. During the academic year, I supported myself by teaching at Southern Methodist University in Dallas. Through my reading, I became interested in low-temperature physics. At that time Yale, Ohio State University, and City College of New York were the only places in the United States that had good, established graduate programs in the field. I decided to come here and work with C.T. Lane, the father of liquid helium research in this country and one of Yale's scientific greats.

Lane had made his mark by building a helium liquefier, a kind of rotary engine with pistons running up and down at a few degrees above absolute zero. Peter Kapitza, a marvelous experimentalist at Cambridge University, had solved the problem of lubricating the pistons in 1935. Anyone who works with liquid helium soon learns that using it as a refrigerant to cool solids involves very long hours in the laboratory. Once the helium is liquefied and stored in a Thermos bottle, you have to keep work-

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ing until all the liquid has evaporated. If you're lucky and the experiment is successful, you might be in the lab until five or six the next morning.

To fulfill my ROTC commitment, I went to Wright-Patterson Air Force Base for two years as a first lieutenant in the Air Force. It was a frustrating experience, because the laboratories lacked the proper apparatus for the experiments I wanted to do. Luckily, when I returned to Yale in 1954, I used a wonderful World War I-vintage spectrometer sitting in the sub-basement of Sloane Laboratory. It was ideally suited for high-resolution spectroscopy of solids at low temperatures. I started doing this work with crystals that I had learned how to grow and use while at Wright-Patterson.

The Air Force was very generous. I returned to Yale with a small research grant in my pocket—a reward for spending two years teaching them how to do things. In those days, researchers used a few liters of liquid helium that could easily be made in the laboratory. Now the laboratory at Wright-Patterson uses hundreds of liters of liquid helium every day, supplied by a big plant in New Jersey.

As a graduate student, I came to appreciate the work of the great Russian physicist Lev Landau, who demonstrated the importance of characterizing the fundamental excitations of a particular solid or condensed matter. Landau showed that very few elemental excitations are created at low temperatures. If one shines light on the system or neutrons, one probes the system. But he pointed out that use of symmetry permits one to exploit his ideas most effectively. Thus I learned how to use the mathematics of symmetry with great facility. When one raises the temperature too high, however, a great increase in the number of excitations occurs, producing a catastrophe in the form of a phase transition. This is what happens, for example, when water boils or ice melts. Since water is too complicated, I focused my research on simpler crystallographic phase transitions, when the alignment of the atoms changes in a precipitous fashion.

Around 1970, I started to think about more applied physics—in particular, how to make two-dimensional electron gases, in which all the electrons are confined to motion in a plane. So-called field-effect transistors are found in all computers today, but in the 1970s such a device was a new idea, and the physics of it was great fun. Field-effect transistors function due to the unique properties of quartz, or silicon dioxide. Quartz is nature's best electrical insulator. One can put immense electric fields across very, very thin layers of this material and make all the two-dimensional electrons behave at remote distances. This is what makes the micro switches on your computer work. In the 1970s, we were learning how to solve the problem of using silicon dioxide—how to grow it in the laboratory and how to selectively place impurities in it.

For the rest of my active research life, until the 1990s, I continued to experiment with two-dimensional electron gases, all at low temperatures. One day in 1974, I received a telephone call—I forget from whom—asking if there were any young people around who would like to go to China. I said, "Yes, I'm ready to go tomorrow." And so I joined a group of fifteen, including Jonathan Spence, Bart Giamatti, and Leon Lipson, who went to the People's Republic of China for three weeks as guests of the

Chinese government. It was on that trip that I became interested in porcelain and how it was made.

As early as the ninth century, the Chinese had found empirical solutions to the problem of making high-fired porcelain pots and glazes. It took them a long time, however, because their raw materials were all wrong. High-fired porcelain is about 20 percent aluminum oxide, or sapphire, and 80 percent silicon dioxide. If there is too much sapphire in the clay, it won't fire, even when ground up into fine particles; instead, it crumbles. Chinese clay is about 35 percent sapphire. By grinding quartz and adding it to the clay, the Chinese were able to cut the sapphire content down to about 22 percent. When fired to about 1350 degrees Centigrade, it became a hard material, impervious to water and with many other wonderful properties. The rest of the world tried desperately, but unsuccessfully, to discover their secret. Attempts to duplicate the Chinese process were not only futile but unnecessary: it turns out that both the Japanese clay from Kyushu Island and the clay at Meissen in Germany are perfect for making porcelain. One does not have to do all that extra processing to cut the percentage of sapphire. But it wasn't until the beginning of the eighteenth century that the rest of the world happened upon this new chemistry.

My interest in the porcelain-making process prompted me to start collecting Chinese porcelain. I got to know Mimi Gardner, then the curator of oriental art at the Yale Art Gallery, and subsequently its director. One evening I was having cocktails with Keith Thompson, the director of the Peabody Museum. When the conversation turned to porcelain, he said, "Oh, there's lots of that stuff in the basement of the Peabody." Mimi and I went over there and spent a couple of afternoons poking around. As a result, the Art Gallery now has a wonderful fourteenth-century blue-and-white dish that we found in the basement of the Peabody.

When I retired, I decided to redo some of my undergraduate education and take some art history classes. Prof. Creighton Gilbert put up with me for three or four courses. I also audited a seminar on the Japanese tea ceremony. Since the Art Gallery was closed for renovations, all the things that we should have had access to for the seminar were in storage. I decided to go over to the Peabody and see if I could find some of this material. After all, the tea ceremony is about handling and admiring the tea bowl, the caddy, and other things. This ritual is very, very important. If you don't have anything for the students to handle, they miss the whole point of the ceremony. Roger Colton, the manager of the Peabody's anthropology collection, allowed me to go through the storage rooms, where I picked out tea bowls, lacquer caddies, teapots, and all sorts of things. We had a wonderful afternoon with the undergraduates, examining items from the Peabody as well as from my own collection.

In the process of going through the storeroom, I noticed that the descriptions of many of the items were incomplete, and often wrong. I started systematically identifying the ceramics and lacquer ware of which I had some knowledge, and I am now going through the collection a second time, drawing upon the advice of experts in revising the labels.


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One object I found at the Peabody, a large lacquered wooden bowl, allowed me to do some semischolarly work. It was probably made by a family of artisans in Kyoto. They took a thick piece of cypress and turned it on a lathe in two pieces, a hemispherical bottom and a flattened top. The bowl is huge—385 millimeters in diameter. After being shaped, it was carefully polished. Anyone who has worked with wood knows that it likes to shrink on you in ways that you don't like. If the grain runs in a certain direction, the wood shrinks more perpendicular to the grain than parallel to the grain. For example, if I cut a piece of cypress and wait around for fifty or so years, it will have shrunk about 3 percent more perpendicular to the grain than parallel to the grain. Originally, the Peabody bowl was perfectly circular. Measuring very carefully, I determined that the diameter across the grain differed from the diameter parallel to the grain by less than one millimeter out of 385 millimeters—roughly a quarter of 1 percent. Clearly, this piece of cypress had been saved and cured for a long time.

After polishing the bowl, the artisans started applying lacquer. Lacquer resin is obtained from the lacquer tree, a kind of Asian sumac, in much the same way as sap is tapped from sugar maple trees in New England. When the clean resin is spread thinly in a warm, humid environment, it polymerizes. As the long chains of molecules in the resin become cross-linked, the lacquer coating becomes extremely hard and impervious to water. After each layer is applied, the surface is polished again. Black coloration is obtained by adding charcoal to the clear lacquer, red coloration by adding powdered cinnabar. Cinnabar is mercury sulfide, which in this case was derived from finely ground crystals originating in China. The physics of cinnabar is wonderful. It is an anisotropic crystal, meaning that if you look through an optical polarizer at one particular direction of the crystal, it transmits orange light rather than just red light. This, it turns out, is a very helpful way of identifying modern red lacquer. During the nineteenth-century Meiji period, the Japanese imported German chemists who showed them how to make mercury sulfide from elemental mercury and elemental sulfur. This process produces tiny cinnabar particles, from ten to twelve atoms in width. The resulting spatial quantization shifts the energy of the elemental excitations so that the lacquer looks more orange than the nice tomato-red associated with the natural crystal powders.

A number of layers of lacquer were applied to the bowl, but it's not clear whether the lightning design or the gold-foil family crests were applied first. For the lightning design, a needle was used to outline the pattern in the soft lacquer. That which appears gray is silver lacquer, the rest being gold. Starting from the left, one sees the silver lacquer, then a narrow gold line, then an undecorated region, a heavy wide gold line, and finally a gold region of brownish tinge. These appearances of the gold result from careful use of gold particles of various sizes in the lacquer, a technique called sprinkled gold, or *makie* in Japanese. The artisan was very good. Notice that the bowl has a sharply curved, almost hemispheric surface. As one looks from the top to the bottom,

[a] The Great Bowl
[b] The 1633 Lacquer Design
The Great Bowl Design
[c] The 1604 Tokugawa Mon
The 1633 Tokugawa Mon
[d] Tokugawa Ieyasu
[e] Mori Terumoto
[f] Mabel Loomis Todd

the lightning lines grow perceptibly narrower and closer together. The result is absolutely wonderful. One rarely sees this quality of perspective in Japanese lacquer wares.

Now let us look at the family crests, or *mon*. The one that looks like a plant—a water plantain, or *omodaka*—is associated with Mori Terumoto. He was one of the lords of a fairly large part of Japan, extending from a little west of Osaka to the Sea of Japan. It was the second largest domain at the time. The other *mon*, a trifoliate hollyhock, or *aoi*, is associated with Tokugawa Ieysau, a *daimyo* (lord) who controlled land in the eastern part of Honshu Island.

Upon the death of the great unifier Hideyoshi in 1598, Ieysau desired to assume control of the entire country. A coalition of *daimyo* from the west challenged his actions. Two great armies of about 150,000 men met in a great battle at Sekigahara in September 1600. Terumoto was called upon by the western leadership to commit his 30,000 troops. He refused and sat out the battle instead. The coalition under Ieysau was successful, whereupon the western leaders were killed. The *daimyo* who were Tokugawa allies were awarded lands in the west. Those lords, including Terumoto, who refused to support either side were labeled unreliable. After four days of discussion, it was decided to spare their lives. However, after swearing allegiance to the Tokugawa, Terumoto forfeited two-thirds of his domain. This required him to give up his castle at Hiroshima and construct a new one on the barren coast of the Sea of Japan, in the small town of Hagi. Further, all unreliable *daimyo* were required to spend alternate years in Edo, the Tokugawa castle town. Of course, their families lived in Edo all the time, hostages to the Tokugawa.

How does this history relate to the bowl? It was clearly part of a wedding dowry, with the *mon* identifying the families. I believe the wedding was between Ieysau's granddaughter, Kisa, and Terumoto's only biological son, Hidenari. There were no other marriages between these families. According to a Japanese genealogy on the Mori, the betrothal was announced on June 6, 1602, when the two children were only four and seven years old, respectively. The wedding was scheduled in Edo for April 3, 1608, at Terumoto's palace. By this time the children were ten and thirteen. However, the wedding was postponed because Kisa's father died in late 1607. After a mourning period of ninety days, Kisa left Osaka for Edo, where the marriage ceremony occurred on August 17, 1608.

I believe the Peabody bowl was part of the dowry for this wedding. I suspect that the design implied a political message from the Tokugawa to the Mori. Single jagged lines, or lightning bolts, were employed on lacquer wares in the 1590s to separate two distinct decorative patterns. Here the surface is covered with the lightning scheme. Nature's lightning had proved to be a recurring threat to the tall new castles built in that age. Notice that the Tokugawa *mon* has been modified with the insertion of double-edged swords between the hollyhock leaves. These swords are the *mon* of fierce ancient warriors. I suggest that the message was, "Behave, for we are ruthless." This pattern was new in the first decade of the seventeenth century; it later appears on dowry items for a wedding of a daughter of the third Tokugawa shogun in 1633.

My argument has flaws. I have been unable to find any other dowry items besides this bowl. We know there were originally two bowls because the lightning designs on the bottom and top of this one don't quite line up, as one would expect from such a marvelous artist. So there were two bowls, and somehow the tops and bottoms got exchanged. But there were other things in the dowry as well, and I don't know where they are. There's nothing in the Mori genealogy about the dowry items. There is some evidence that when artisans had special commissions—and this bowl was certainly a special commission—they would sometimes sign their creations. I recently found photographs of lacquer items with signatures, but the calligraphy is so small—no more than an eighth of an inch in height—that I have to go over the bowl with a microscope to be sure that I haven't missed anything.

How did the bowl get to Yale? It belonged to a woman named Mabel Loomis Todd. She was the wife of David Peck Todd, a professor of astronomy at Amherst College in the latter part of the nineteenth and early part of the twentieth century. Todd was a very good instrument maker who went all over the world trying to photograph the corona of the sun during a total eclipse. In 1887 he and his wife went to Japan for the first time, to visit the area of totality just south of Mount Fuji. Unfortunately, he failed to get any good pictures, because the sky was cloudy during the five minutes of totality.

In 1896 another total eclipse occurred in Japan. This time the Todds traveled to the very northern part of Hokkaido Island, where the remnants of the aboriginal Ainu people lived. The Japanese treated the Ainu just like the European settlers treated the American Indians, trading on terms that were very unfavorable to the natives. The Japanese soon learned that the Ainu wanted waterproof containers to store their precious items, since their houses leaked. They traded bowls and boxes made out of lacquer for furs, fish, seaweed, and hawks, which the Japanese rulers, especially the Tokugawa, used for sport.

Before her second trip to Japan, Mrs. Todd consulted with an American collector by the name of Edward Sylvester Morse, curator of Asian art at the Peabody Museum in Salem, Massachusetts (now the Peabody Essex Museum). (Later, Morse would be associated with the Boston Museum of Fine Arts, which now houses most of his ceramics collection.) He told Mrs. Todd about the Ainu and commissioned her to bring back an Ainu coat made out of salmon skins. She did and it still exists at the Peabody.

The Todds sailed from San Francisco on a boat 132 feet in length. After stopping in Hawaii, they reached Japan at the end of June, a week after a terrible tsunami had hit the country. Mrs. Todd stayed in the south while her husband went north to set up his telescopes. Joining him there at the beginning of August, she spent ten days collecting things from all over Hokkaido. In her travels to native villages on horseback, she soon gained the confidence of the Ainu. Among the things that she wanted to buy, and they were willing to sell, was this bowl. Upon returning home, Mrs. Todd wrote a book about their trip. She also photographed her lacquer purchases, so we have a photograph of the bowl. It was filthy when we found it in the basement of the Peabody; smoke had clearly preserved the design.

The other part of the story is that Mabel Todd was the first editor of Emily Dickinson's poems. She had an affair with Dickinson's brother, the treasurer of Amherst College, and the two of them kept intimate diaries. During the 1920s and 1930s, the Todds and the Dickinsons argued acrimoniously, in the press and in the courtroom, over the disposition of Emily Dickinson's poems. By the 1960s the Todds' only daughter, Millicent, was getting to be an old woman. Since she had no children, she controlled the disposition of the Todd diaries, papers, and the photographic plates taken during her father's astronomical expeditions. The latter included wonderful images of Mount Fuji made in the 1880s.

Prof. Richard Sewall at Yale, a Dickinson scholar who was much interested in the family papers, enlisted Judith Schiff to assist him in negotiations. Schiff, Yale's chief research archivist, was very knowledgeable about the luminaries who lived in the Amherst area during the late nineteenth century and prevailed upon Millicent to give everything to Yale. In 1961 all the Todds' diaries, photographic plates, and journals came to Yale, where they now occupy more than two hundred linear feet of shelf space in Manuscripts and Archives. All the three-dimensional material—more than two thousand items, including the first set of booties that Mabel Todd knitted for her daughter—went to the Peabody. When it arrived, the labels identified the oriental items as Ainu, so obviously they belonged in the Peabody and not in the Yale Art Gallery. As we were going through the storeroom, this great bowl was on a high shelf. One day Roger Colton said, "There's something up here that I think you want to see." It's very exciting to find one of the first lacquer items done at the beginning of the seventeenth century at the direction of the Tokugawa. There's nothing quite like it anywhere that I have been able to find in the literature.

My continuing search for Japanese artifacts in the Peabody's anthropology collection has yielded many surprises. For example, going through a drawer one day, I found a group of largely uninteresting scrolls. Underneath them, however, was a rather thick package containing forty nineteenth-century woodblocks by such famous artists as Utamaro, Hokusai, and Hiroshige. Purchased around 1900, some of the prints are clearly restrikes and later editions, but a few appear to be excellent examples of early states.

Identification of many items is an ongoing task. Ogawa Morihiro, the Metropolitan Museum's expert on arms and armor, spent a wonderful day in the storeroom. Of the twenty or so Japanese swords in the collection, three or four are outstanding examples of fifteenth- and sixteenth-century origin. The Peabody has five samurai suites of armor, one of which was donated by the great paleontologist O.C. Marsh, who purchased it in Denver in the 1880s. After the Meiji restoration in 1868, the samurai were no longer allowed to wear swords or armor, so some of the best of it ended up in this country or in Europe. Mr. Ogawa was very enthused and said he'd never seen anything quite like the Marsh armor. A curator from the Metropolitan has begun the process of evaluating the Peabody's lacquer ware, and we also plan to bring in an expert to look carefully at the ivory, much of it beautifully carved. So the fun continues.