Shall We Change?

ROALD HOFFMANN

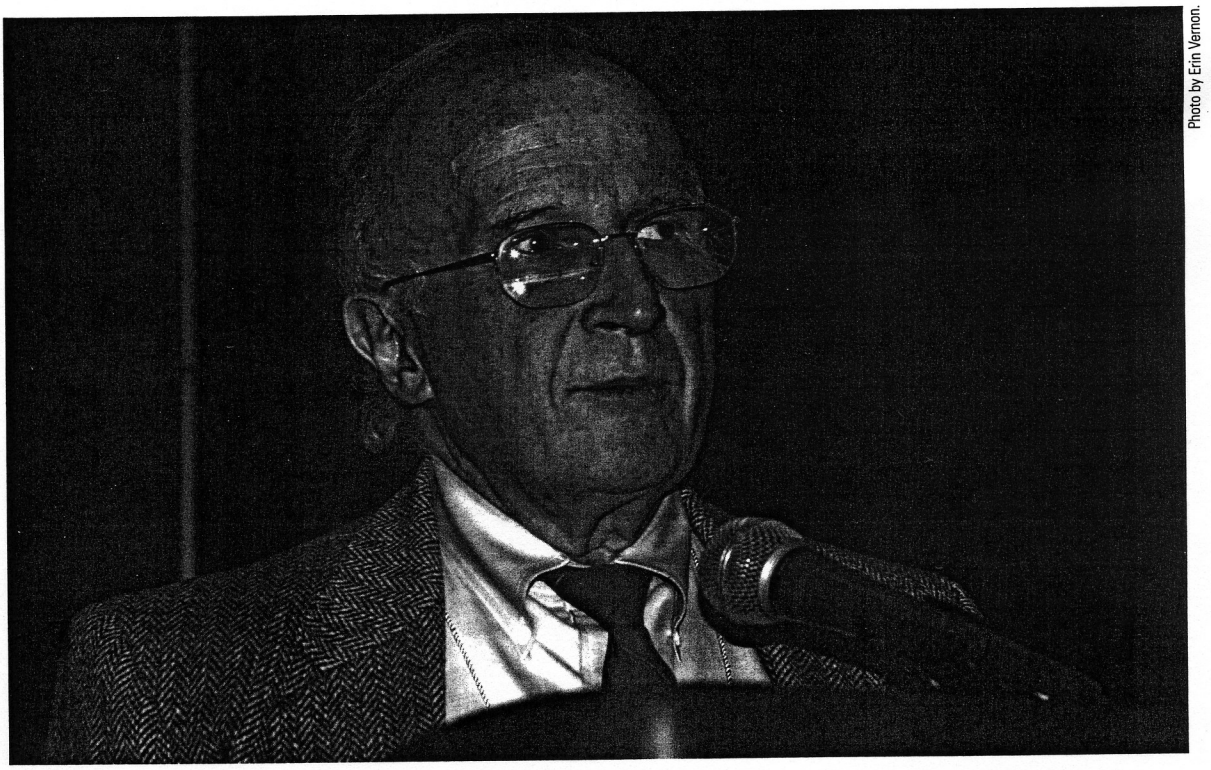

Photo by Erin Vernon.

Roald Hoffman

Shall we, should we? Transformation, of one substance into another, is chemistry. Which is why a philosophy of desired change, alchemy, in search of a metaphor, chose (and was co-opted by) chemistry, Change, by fire, is at the heart of ceramics. But, in chemistry or ceramics, we are of two minds about change. I want to explore this ambivalence, as well as the nexus between chemistry and ceramics.

A Science with Transformation at Its Core

Chemistry first. If you were to ask 400 years ago what chemistry is, you would likely get as an answer that chemistry is the art and craft—there was no science yet as such—of substances and their transformations. You could ask the question, for people were always transforming matter, before there were professional chemists. In Figure 1 you see the Gate of Ishtar (from Babylon, around 600 B.C., now in Berlin). The glaze coloring the bricks is nature transformed (so are the bricks, of course), acopper-mineral-based glaze close to Egyptian blue frits. In Figure 2 you see wall paintings from the tomb of Rekhmire, a mere 3500 years old, showing the practice of various metallurgical crafts.

That definition, of essential transformation, is still valid today. In order to show you what chemistry is, I would ideally need to do a demonstration of a chemical reaction, the heart of chemistry. Here's a poor substitute—three stages of a chemical reaction (Figure 3).

In the first, you see two substances, actually two elements. One is a beautiful reddish-brown liquid in a beaker, bromine, and next to it a substance that was not available 400 years ago, aluminum. In the

next figure, the aluminum is placed into the bromine. There is a burst of flame, smoke, and foul odors —absolutely everything that you expected of chemistry happens, right? In the process one substance is transformed into another one, an aluminum bromide.

Change —sometimes violent, often slow and peaceful as in the making of ceramics—is still the heart of chemistry. There are interesting consequences in the public conception of chemistry. So in every comic book series, from Donald Duck to Spiderman, there are chemical explosions, if not villain chemists. Mind you, that image is not all bad, because even to this day the drama of chemical change attracts young people to our science.

The inherently transforming nature of chemistry led to its curious meeting with alchemy. There arose, in a certain time, in most every culture, a philosophy of transformation—of sick people into healthy people, of a base metal into a noble metal. Perhaps also, as Jung thought, of the person doing the transformation into someone different. When such philosophies needed a metaphor to get into people's minds with, they chose chemistry. Because chemistry was the obvious way to show to people change and transformation. Figure 4 shows a typical alchemical illustration – there's a wedding, a union of a king and queen in the background; in the foreground there are chemical experiments. In the sixties, I went to some off-beat weddings in California, but I never saw any chemistry done at them. Obviously something is happening here on the symbolic plane.

Many of my colleagues would like to keep the protochemistry of alchemical invention (they did make the mineral acids after all, and gave us the forms of our laboratory glassware), to ignore the philosophy that underlay it, and laugh a little bit nervously about the charlatanry involved. This is not the view that I take; I see alchemy as a single entity, a unique cultural experiment, a philosophy that invoked chemistry as a metaphor of change. And, in the nicely complicated way that things go, chemistry then co-opted alchemy.

Mircea Eliade, a historian of religion, has written a remarkable book, *The Forge and the Crucible*, which traces the relationship between religion, metallurgy, and alchemy. In his beautiful concluding chapter, Eliade makes the haunting observation that the goal of the alchemist was to hasten the "natural" evolution of metals from base to noble, and to secure a similar transformation of the body, from sick to healthy, from mortal to eternal. The alchemists failed, in the end, and

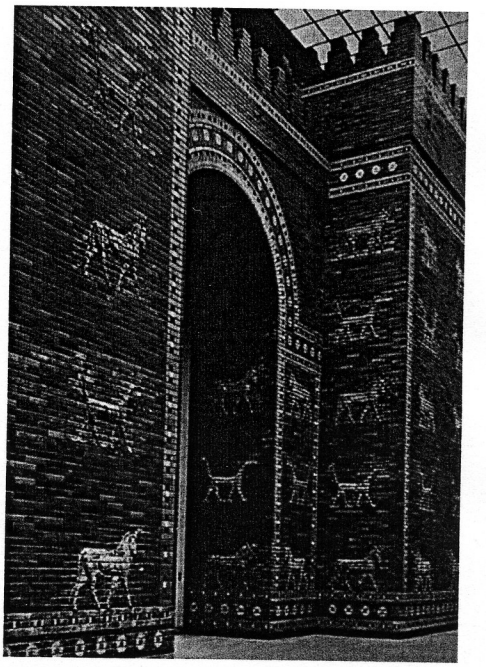

Figure 1. The Gate of Ishtar, from Babylon, now in the Pergamon Museum, Berlin.

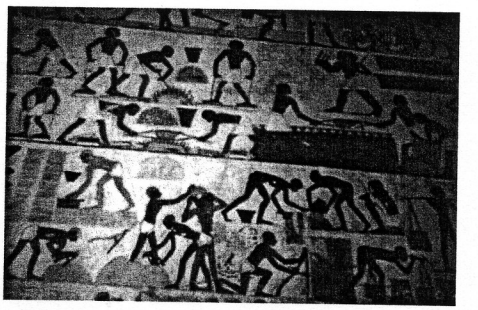

Figure 2. Wall paintings from the tomb of Rekhmire at Thebes.

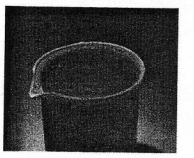

Figure 3. The reaction of aluminum with bromine.

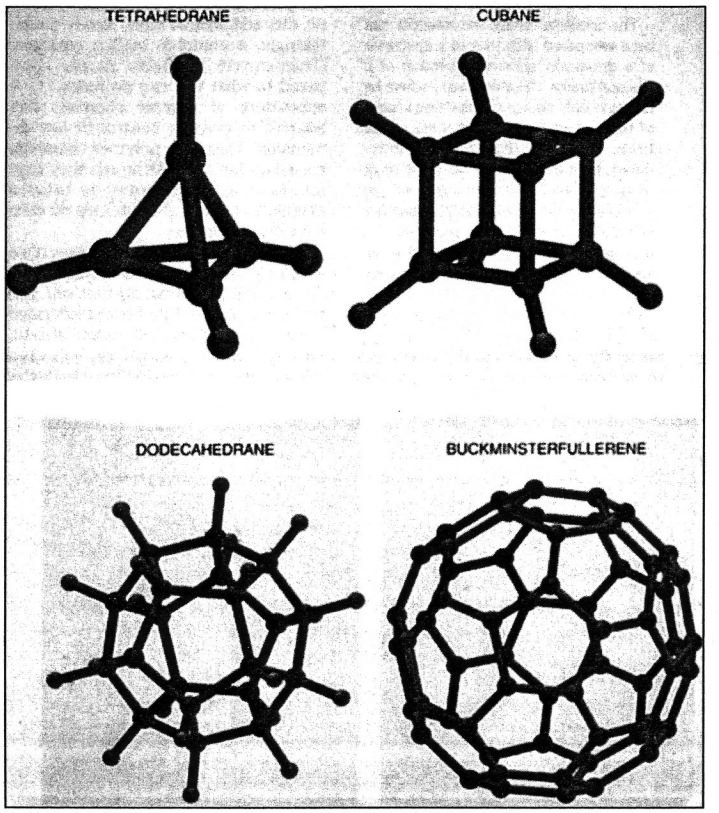

Figure 5. Models of tetrahedrane, cubane, dodecahedrane, and buckminsterfullerene.

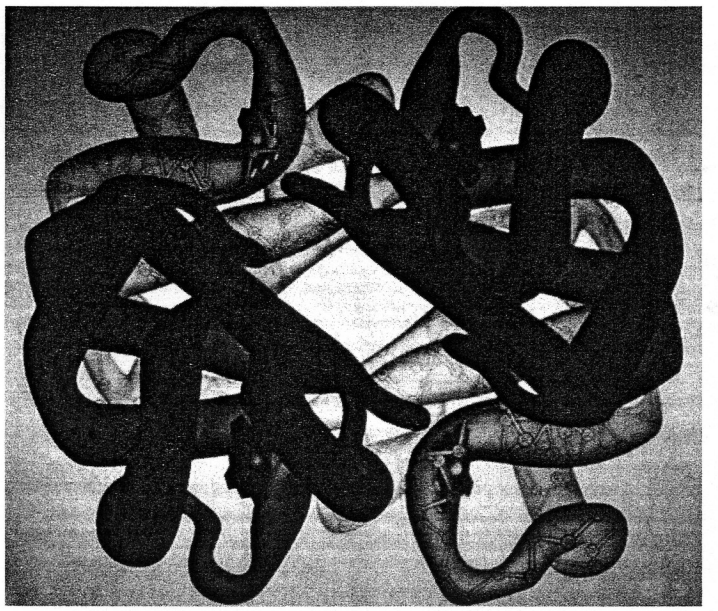

Figure 6. A molecular model of hemoglobin.

were replaced by modern chemists and physicians, who, screaming all the way that they had nothing to do with alchemy, have achieved, through catalysts, composites, and pharmaceuticals, a very large part of the alchemist's original goal. To turn mud into gold.

And chemistry having in so many ways meliorated the human condition, has found itself (I think) in need of the language of alchemy to get the spiritual value of its essential transformations across to people.

The innards of the beast

What I have recounted is one cross-section through chemistry, the first of three that I wish to show you. On to the second...

With the passage of time, within the last 200 years, we've learned to look inside the innards of the beast, so to speak. Inside these substances which we transform, or which transform of their own will, there are persistent groups of atoms which we call molecules. In a marvelous achievement of human intellect, driven by curiosity and spirit, we've learnt to know these molecules without seeing them directly; we didn't wait till there were wonderful microscopes to show us their structure. And now there is another definition of chemistry, as the art, craft, business and now science of molecules and their transformations.

Some of these molecules, beautifully simple and simply beautiful, and devilishly hard to make, are shown in Figure 5.

Curiously the one which is most simple to make (now) was the one last discovered—this is the lovely football-shaped molecule of buckminsterfullerene.

The moment I show you these lovely creations I hesitate. Why? Just because they've such a clear and direct way into our soul. And that bothers me, for I know, and

chemists and artists know, that there is infinitely more to beauty than simplicity. To make the point, let me show you the most beautiful molecule I know (figure 6).

What is this molecule, which in the simplified representation looks like a clump of pasta congealed from primordial soup, or like a tapeworm quadrille? This molecule has nothing in the world to do with simplicity, and yet it—in all of its wonderful complexity —happens to be the biochemical molecule that we know about more than any other biochemical molecule in the world. It is hemoglobin, the oxygen carrier in our blood.

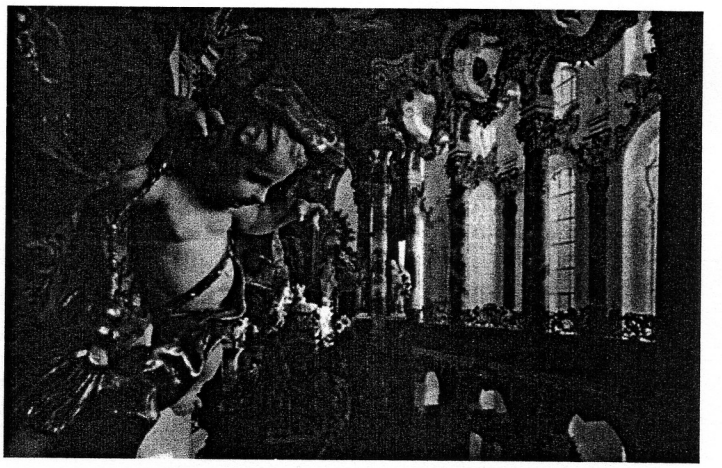

Figure 8. The Wieskirche in Bavaria.

Where beauty resides

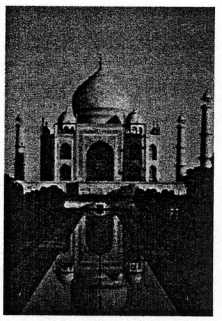

Figure 7. Taj Mahal, in Agra, India.

The simple and the complex contend for our souls not only in chemistry. Move 12 orders of magnitude upscale, to another realm of human construction, namely monumental architecture. Clearly there are periods where the simple reigns -- I could have shown you the Parthenon, or Andrea Palladio's villas, but I've chosen a high point of the Islamic architecture, the Taj Mahal in Agra, India (figure 7).

Clearly the aesthetic in this marvelous building is of the symmetrical, the simple. Contrast with this structure the interior of a typical rococo Bavarian church, the Wieskirche (figure 8) . You see its natural setting. Is nature ever symmetrical? Inside we see the human aesthetic at work. There is nary a straight line in the interior, it is all curlicues, and a reaching for complexity.

I could have just as well chosen Bernard Palissy's perfervid platters. The Wieskirche and Palissy are clearly closer in spirit to hemoglobin than buckminsterfullerene. And both are beautiful.

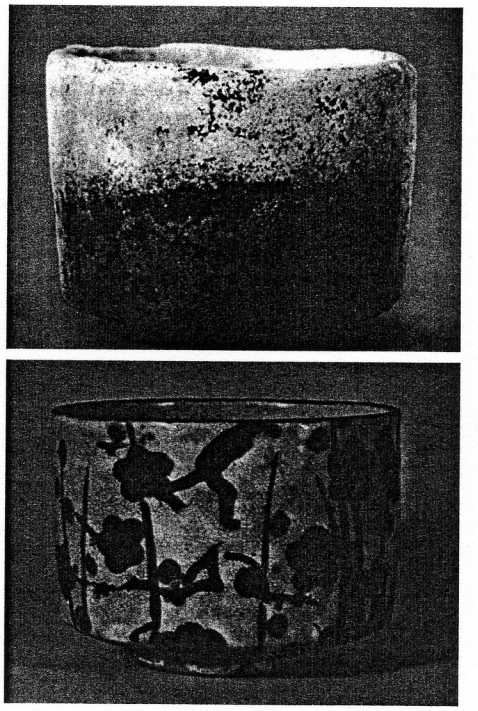

Figure 9. Koetsu and Kenzan bowls

The struggle between the simple and the complex, or between the minimalist and the decorative, has of course been played out in

functional and art ceramics as well. Take a look (figure 9) at the contrast between two 17th century Japanese ceramics—a classical bowl by Koetsu, and Ogata Kenzan's slightly later vessel, an early product of the aesthetic of the tea ceremony.

Beauty resides clearly not just in simple things, but at the tense edge where simplicity and complexity, where symmetry and asymmetry, where chaos and order contend with each other.

Common Fire and the Comforts of Chance

Let me turn to a special chemistry-ceramic tie. It's not that of the chemistry of the transformation of raw clay into a fired ceramic. That is a magic that can be studied. We've learned a lot about reducing and oxidizing atmospheres. And there is no way in which I have any more insight into glazes and slips than you do. Their chemistry is complex, which is good, for then there are many opportunities for an aleatory playground to develop. Yes, this can cause terrible frustration when nothing comes out. And also allows the ceramic object to approach closer than any other human creation the life-enhancing lack of sameness of things in nature, the subtle uniqueness of a clump of mushrooms, the grain of wood.

I want to talk about shared ground. One piece of that ground is that of the essence of transformation by fire. Fire makes things change. It makes some things hard. And it makes things flow, both. It makes things seem to disappear, and to appear.

Fire, and the memory of fire. As I've written in a poem about why I did not need to visit a concentration camp:

I do not
need to see the kiln
to know this pot
has been through fire.

No wonder that among the elements chemistry came to focus on fire. If chemistry was substances and their transformations, then surely fire was the essential principle. This led to the interesting, fecund, yet wrong theory of chemistry based on phlogiston, the essence of fire.

It is energy that causes the changes, as we've now learned. And heat remains the proximate cause of change. But, and this is something interesting for the ceramic arts to ponder, in chemistry other sources of energy have come to play increasing roles in causing transformation. (There are no open flames in today's chemistry lab.) One is light; another is electricity. All forms of energy are interconvertible, but transformations wrought by electroplating a metal, or photosynthesis, or by corrosion, essentially an electrochemical phenomenon, or by light-induced polymerization —just have a different feel to them.

One could say that the means of transformation used to form the vessel are less important than artistic considerations, say form and color. That ultimately art is impressed by a human being on matter, on any way of changing things, by choices. That please or shock. Which makes us see that it is the effect on the emotions, at times poorly expressible in words, that makes for art. Not the physics and chemistry of getting there.

I actually think that both—the way and the choice—matter. There will be an art of photocurable plastic sculpture. Your dentist is practicing it now.

I do not want to press for an overreaching similarity of chemistry and ceramics, even as the transformative essence in both draws them close. So let me look for some splits and sunders.

The role of chance in ceramics—of

the way the slip is applied, the way the fire sweeps through the wood kiln, the way the pots are stacked— is one. Louise Spence has said,"Pottery has taught me to give up control and allow things to happen." One must come to terms with the favorite pot cracking, the desired light glaze in a whole firing turning a murky dark green. I think people do.

Science (and chemistry is no different), pushes in the direction of control, the reproducible and creator-independent making of things. But this tendency in science is undermined by the realities of first-time creation. A molecule needs to be made, and of course things do not go as planned. So something is improvised, by chance. And then that chance is prettified by adumbrating a reason, and things are made more rational than they were. This is the failure of science —not the richness of its imaginative creation, but its preening with supposed logic, its over-rationalization of a most human choice.

Serendipity is the only place science gives to chance in its stories. And then it takes it back a little by saying (this is Pasteur's version), "Chance favors the prepared mind."

A conjunction of chemistry, alchemy and ceramics

It took place in 1706–1713, in a story you know well. Europeans rediscovered what Chinese potters knew, the art of making porcelain. The protagonist in this story of Meissen was Johann Friedrich Böttger, who in his life and work illustrates how little separated alchemy from chemistry in the time.

Böttger (figure 10) was an alchemist in the classical vein, a believer in the philosophy of essential transformation central to alchemy (and chemistry). He was also a very good,

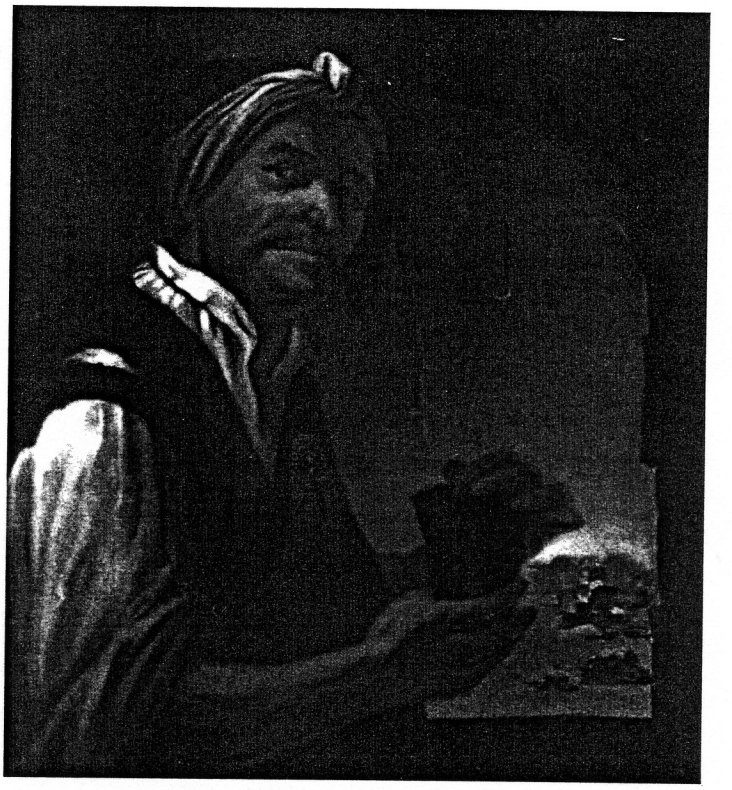

Figure 10. A portrait, presumed to be of J. F. Böttger. The painter is not known. The portrait is in the collection of the Bavarian National Museum

practiced chemist, familiar with metallurgical techniques and the arts of pharmacy. It was a precarious profession, to be an alchemist, a calling which required great political skills as well. For to gain patronage, one had to promise gold or medical cures. And to practice, with refinement and skill, the art of eternal creative procrastination, always assuring more, always asking for more. No wonder that alchemists were always on the move! Like the story of the goose that laid golden eggs—were they to produce results, their patron might think twice about having such an economic force loose and available to others. Augustus the Strong, the Elector of Saxony and King of Poland, imprisoned Böttger in Dresden, in part for his failure to produce gold, in part to secure his supply, should Böttger succeed.

Did one need an alchemist to make

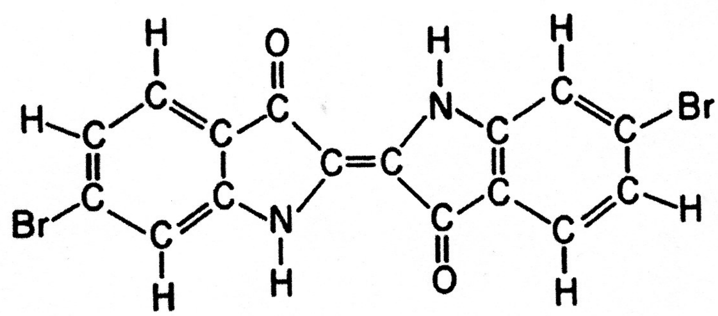

Figure 11. the chemical structure of dibromoindigo.

porcelain? Could a chemist of the time have done it? The question assumes a distinction of alchemy and chemistry that I am convinced is not of the time. A strict distinction between the protochemists of the time and alchemists is an ex post facto simplification of world of overlaps, beautifully exemplified by all that Böttger did in his short life. Arguing for a lack of separation with which I sympathize, historians William R. Newman and Lawrence M. Principe have suggested that the bridging word "chymistry" should be used to describe alchemy and chemistry in the period.

I like that word. And yet, and yet, even as I see Böttger keeping careful laboratory notes of his firing sequences, I wonder if it all could have been done without the underlying alchemical imperative. One could make stoneware, one could make glass. But anyone who has held a fine Song or Koryo cup in one's hand, rotated it, following the fine crackle, I think feels that porcelain is something more. To aspire to transform mere clay into that refined essence that catches light and begs to be held, as no other ceramic does—that takes more than laboratory skill. The synthesis, I have to call it that, of porcelain demands faith in the nature of the transformative process, and the unvoiced conviction that one can improve on nature. Scary, but it can be done, with porcelain or a high temperature superconductor, both ceramic.

I think it took an alchemist.

How Much Does One Need to Know?

Not much. A lot. Just enough to create. I am speaking of the knowledge of the materials we work with, both as they "rest," and as we transform them.

Is it important to know that steel is an alloy of iron and carbon, and that the carbon is there in several ways—part a solid solution in the interstices of metallic iron, part in discrete Fe_3C and Fe_5C_2 compounds.

Should one care that the chemical structure of indigo is the one in Figure 11, such that to have it bind better to wool and linen one has to "reduce" the molecule to a colorless form, which, once absorbed into the

biopolymers, is oxidized back to a molecule colored "like unto the sea and the sea is like unto the sky and the sky is like unto the sapphire, and the sapphire is like unto the Throne of Glory," as Rabbi Meir said of the wondrous dye?

The art is wonderful, the overall change possessed of sufficient mystery to make the spirit soar when the blue of the dye reappears as the oxygen of the air hits the wool. Need we care about what happens on the molecular level?

Do we need to know the complex crystal chemistry, the balance of liquid and solid phases, that follow the expulsion of water from kaolinite, its collapse to a spinel structure, the transformation into mullite crystals accompanied by the formation of cristobalite, the sericite (Böttger used alabaster) melting, dissolving the cristobalite, seeping into the interparticle interstices, the large acicular mullite crystals growing?

It does not hurt—more than that, it pleasures.

First a practical argument for trying to understand, at every level, in crafts or science: The chemical synthesis, or a certain glaze is going great. But one day the catalyst fails to do its expected magic. And the next firing doesn't give the red and green you want. What does one do? Throws away that catalyst, that batch of glaze. Tries another. And then, that fails too. There must be a reason, which will not be revealed by prayer or anger. There is an argument here for trying to comprehend, at least piecewise, enough to fix something when it goes wrong. As it will.

But I think the primary argument for understanding is ultimately psychological and aesthetic, rather than practical. Paulus Berensohn writes:

" The molecules of clay are flat and thin. When they are wet they become sticky with plasticity and hold together as in a chain. A connecting chain. I like picturing that connection in my head.

"I am making my connection with clay. Clay turns me on and in. It seems clearer and clearer that I was drawn to clay by its plasticity. For it is plasticity that I seek in my life. To be able to move into new and deeper forms as well as make them. Making the connection and being plastic."

Knowledge not only satisfies, but it also bolsters the mind when things don't work. The intuition to try something else comes from knowledge subconsciously assimilated. One can go on, there are reserves of intuition to take a new tack. Knowledge also counters alienation—that of art from science, that of us from our materials and tools. These molecules are similar, they are different. They share some things, differ elsewhere. We see the world as connected. As making at least a little sense. And go on to make the next thing, as we are driven to do.

Tectonics

I have another calling, as a writer. In a visit to the Penland School of Crafts, I watched, and tried my hand too briefly, a ceramics class of Paula Winokur's. Here's the beginning and end of it.

Genesis

Not God, or Rabbi Loew.
Today it's just Roald,
squeezing a ball of clay,
his small stake in creation.
Did they begin this way,
two thumbs
hesitant in clay? Yes,
for now
there is the other,
a hole
in the wholly round.

ROALD HOFFMANN, *born in Poland in 1937, came to the U. S. in 1949. Educated as a chemist at Columbia and Harvard, since 1965 he has taught at Cornell University. He has received many of the honors of his profession, including the 1981 Nobel Prize in Chemistry.*

Dr. Hoffmann is also a writer of essays, non-fiction, poems, and plays. Through his writing, he has carved out for himself a land between chemistry, poetry, and philosophy.

Where
people were, there
are shards.
There is clay
on my hands,
there is clay
in my hair.
It'll wash off.
Not the clay
in my heart.

Hands and Minds Combined

There is no question that ceramics is about hands and the senses, especially vision and touch. Science is about tools, and handwork too. The tools of science may be fancier, all those laser spectroscopes. But on the "optical bench" are carefully mounted mirrors, machined vacuum chambers, and yes, even now, blown glass containers. And ceramic objects too, even ones that conduct heat and electricity. All designed and made artifacts.

For art and for science, this—that both thinking and doing are engaged and cooperating—is our finest link. The world is disintegrated, separating mind and body. We cater to the mind through a novel or a Bach Cello Suite on a CD. And to the body through those Nautilus machines, or just a long, warm bath. Art, craft, and science integrate mind and body. At the end, there's craftsmanship, the proud, cunning work of human hands and mind, joined in the service of creation. Effecting change.