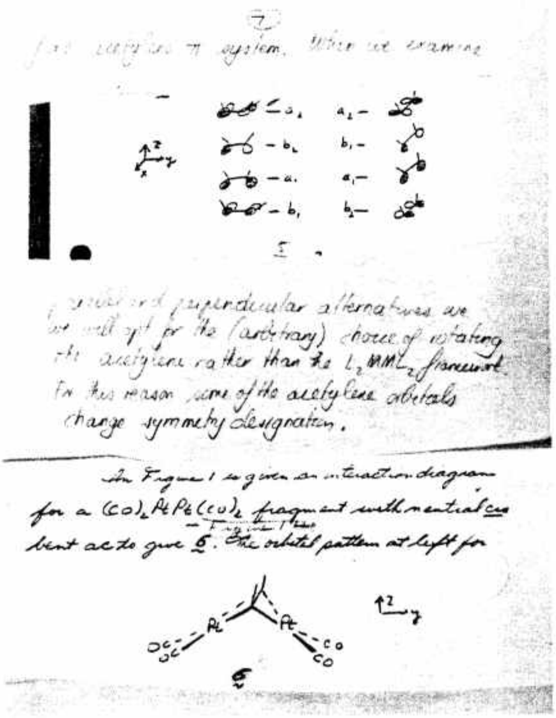
Art in Science?

By Roald Hoffmann



◀ **Figure 1. Manuscript page**

◀ **Figure 2. Manuscript page**

Here (Figures 1 and 2) are two manuscript pages from articles I've written. And there (Figures 3 and 4) are the ways they appeared in print, in the *Journal of the Chemical Society: Dalton Transactions* and *Inorganic Chemistry*, two magazines you are unlikely to have read recently.

The context of these images is the following: I'm a theoretical chemist. What you see is the initial draft and final printed version of fragments from two of the 325 articles I've written. Articles are the stock-in-trade of the professional scientist. By and large we do not write books; our achievements, such as they may be, are judged by these scholarly articles. In general they're written in English (well, really in a jargon that has some vague relationship to English), printed in journals with limited circulation (these, among the world's best chemistry journals, have circulations near five thousand each), glanced at only by other chemists, and read carefully by a few hundred people. On the basis of these articles my work is evaluated and I make a living.

That explains circumstantially Figures 3 and 4, the final printed pages. What about the manuscripts, Figures 1 and 2? Clearly these are collages. There are samples of writing in two hands on them; one is my own, the other that of the graduate student (David Hoffman) or postdoctoral fellow (Kazuyuki Tatsumi) who has worked with me on this research.[1] In science there is much, much collaboration. My papers typically have two or three coauthors. I pose the question, my coworkers and I discuss an approach to a solution, they do most of the tough work, we talk further, a presentation of intermediate results is made, they're off to test various unreasonable suggestions I make, they write a draft, and I revise it into a final paper. In what you see in Figures 1 and 2, each a page of the manuscript of the final paper, I've pasted in photocopies of a piece of my collaborator's draft that I decided to keep.

Figure 3. ▶ Printed page

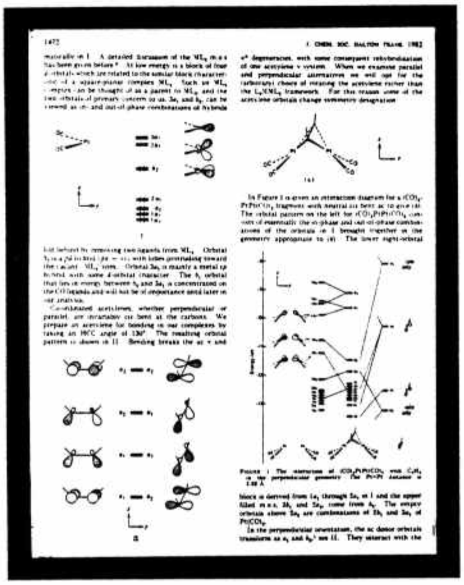
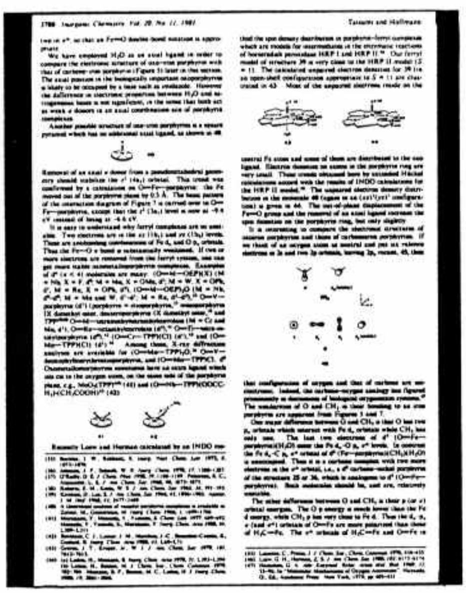
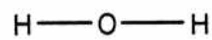
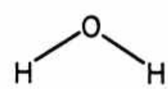

1472 J. CHEM. SOC. DALTON TRANS. 1982

Figure 4. ▶ Printed page

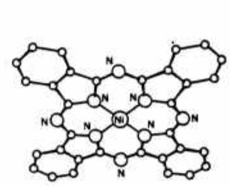

1788 Inorganic Chemistry, Vol. 20, No. 11, 1981 Tatsumi and Hoffmann



▲ *A*



▲ *B*



▲ *C*

The actual drawings that the scientific journals print are reproduced from india ink originals on tracing paper. These are masterfully done (see Figures 3 and 4) by Jane Jorgensen and Elisabeth Fields, two illustrators who have worked with me many years. They trace the ink drawings from carefully designed pencil sketches made by me or my coworkers.

Are these art, these collagelike manuscript pages and the final product? They look like science, and I've *told* you they are science. But what I would like to claim is that there is much more art in these assemblages of symbols than the scientist would admit or the artist allow.

Let us focus first on the most obvious visual feature of my printed scientific articles, and this is the preponderance of little drawings of molecules. These are "chemical structures." In a visual code they represent molecules. The representation is three-dimensional. And it is realistic, at least on the face of it. But is it?

The shape or structure of molecules is critical. Every chemical, physical, and biological property depends on the three-dimensional arrangement of atoms in space.[2] For example, if water (H_2O) were "linear" (see *A*) and not "bent" (see *B*), as water really is, it would not be a liquid at ambient temperatures at the surface of the earth, and life as we know it would not exist. Another example: the mirror image of a molecule that is the essence of oil of wintergreen smells like spearmint.

What chemists can learn, with the help of machines costing many thousands of dollars and a man- or woman-week of work, is the identity of atoms in a molecule, their three-dimensional structure, and the way they are connected to each other (H_2O and not H_3O; H-O-H and not H-H-O). The three-dimensional structure is presented usually as a ball-and-stick model, a typical example of which is shown in *C*. This molecule happens to be a phthalocyanine, representative of an important class of pigments that modern chemistry has added to the palette.

It turns out, however, that this representation is ambiguous. The atoms don't sit still; they vibrate around certain preferred sites. And when we look at them, we don't see the nuclei, whose positions *C* represents, but the electron clouds around them. Chemists know this—the ambiguity of the model—but they will not admit to it unless forced to by an argumentative, perverse insider.[3]

But let us pass by that and continue. The model of the molecule is three-dimensional. The media available for disseminating its absolutely crucial structure are two-dimensional—a sheet of paper, a screen. And what's worse, the people who need to communicate this information are neither talented nor trained to produce effective two-dimensional representations; chemists are not sent to drawing classes. So what do they do? They improvise a primitive visual code, combining some elements of mechanical drawing with a code (a wedged line means *in front;* a dashed line, *in back*). And, with the aid of models, they indoctrinate into that code novices in the second year of college chemistry. It's quite miraculous that, from these primitive representations floating in some undefined space, chemists can reconstruct in their minds three-dimensional networks of some complexity. Here is testimony to the strength of symbolic codes and the inherent, irrepressible ability to see structures as three-dimensional.

I have written elsewhere of the symbol code of these structures and the peculiar relationship of the code to primitive art and the genres of caricature and cartoons.[4] What my colleagues have evolved is a method of representation that selects for emphasis some aspects of the model. Then they put a selected feature visually up front. If at another time they want to represent a different aspect of the molecule, no problem; just bring that part of it up front. It is no coincidence that photographs have found little use in chemistry journals (or anatomy books). Not that I want to argue that a photograph is a realistic representation. A photograph has *too much* detail and, at the same time, *not enough*—not enough of the essence of the molecule that one chemist is desperately trying to communicate to another.

In the drawings before you, let me call your attention to the history that is being developed by the crossing out in Figure 2. Kaz Tatsumi and I were faced with the problem of representing a disklike molecule called a porphyrin, with a molybdenum or niobium atom at its center. Porphyrins are chemically close to the phthalocyanines mentioned earlier. With iron in the ring, porphyrins are the active piece of the oxygen carrier, hemoglobin, in our red blood cells. Slightly modified, with a magnesium in the middle, they are chlorophyll. Anyway, we first made the choice of showing all the atoms in the ring (but not the hydrogens at its periphery). Then we decided this was an inadequate (or overly detailed) representation and opted for a schematic ring with four lines, like spokes, to the metal in the middle. You see direct evidence here of choices being made, of representations altered for expressive purposes.

My claim is that these chemical structures are art—not great art, but art nevertheless. Even if their creators are unaware that they are producing art, even if they would deny the act, the "conceit" of being artists (which is what many scientists would call it, revealing thereby an interesting ambiguity toward art), what they are doing is the following: From a certain reality, that of a molecular model (which, like all realities, turns out to be on close examination a representation of a representation of . . .), the creators of these drawings try as hard as they can to abstract the essence. Then they attempt to communicate that essence to others, using a certain visual vocabulary. There is a concentration in what they do, an intensity that makes the object marked for communication come to life. There is also a distancing from the object (it's rendered from outside; it is remote) and a drawing in. Significant formal considerations—the relationship of the parts of a molecule to its whole—are essential.

An argument can be made that what is missing is (a) the chance, therefore unique, aspect of artistic creation, and (b) the affective realm, the play of the emotions, in this process of commu-

Notes

1. Figure 1 is an early version of Figure 3, from David M. Hoffman and Roald Hoffmann, "The Transformation of Parallel and Perpendicular $L_2M(\mu\text{-acetylene})ML_2$ Complexes," *Journal of the Chemical Society: Dalton Transactions* (1982): 1471–82. Figure 2 is an early version of Figure 4, from Kazuyuki Tatsumi and Roald Hoffmann, "Metalloporphyrins with Unusual Geometries. 2. Slipped and Skewed Bimetallic Structures, Carbene and Oxo Complexes, and Insertions into Metal-Porphyrin Bonds," *Inorganic Chemistry* 20 (1981): 3771–84.

2. For a good introduction to molecules and their shapes see P. W. Atkins, *Molecules* (New York: Scientific American Library, 1987).

3. Roald Hoffmann and Pierre Laszlo, "La Représentation en Chimie," *Diogène,* 147 (July–September 1989): 24–54.

4. Ibid.

5. Gunther Stent, "Prematurity and Uniqueness in Scientific Discovery," *Scientific American,* December 1972, 84–93.

6. Some of these points are explored in Roald Hoffmann, "Under the Surface of the Chemical Article," *Angewandte Chemie International Edition in English* 27 (1988): 1593–1602.

7. Here I am grateful to Alexis Smith for a clarifying discussion.

nication. To expand on the first point, which I think has some merit: while an artist's oeuvre reveals similarities, each work is different, a varied creation. The aleatory aspect, capitalized upon, is central. Scientific representations aspire, on the other hand, if not to anonymity, then to perfect paraphrase.[5] All those chemists who wind up drawing slightly different structures want other chemists to see the same molecule. And they do.

I will not argue too strongly with that. However, it has been my personal experience that, despite the announced or perceived intent of perfect paraphrasability, the creative moment in chemistry derives from a perception (often spatial) of a molecule in just one way and not another. We see that in the work of great synthetic chemists, master makers of molecules. The model turned in the hand in just one way, a redrawing of a structure with a certain unrealistic distortion, allowed them—and only them—to see it in a certain manner, to take it apart in the process of finding a startling way to put it together.

As for the emotional realm—well, I would agree that it is suppressed in the prescribed discourse of scientists. But first of all, to those privy to the code, that little free-floating picture can have tremendous emotional impact: something novel, something beautiful, a challenge to make, envy of the man or woman who made it.

Second, we have learned from literature and Freud what the consequences of suppression are. Here is a creative activity of human beings—science. Deep down it is driven by the same complex mix of psychic motives that drive any creation. The id will out. But the people who are doing this creative activity claim to be just reporting the facts and nothing but the facts. At best they may be fooling themselves; the very same impersonal, neutered language in which they choose to express themselves becomes charged with rhetorical impulses, claims to power, all the things they (we) foolishly thought we could suppress.[6]

Perhaps my argument here is overextended, for the emotional effect of the chemical representation is less obvious in the structures than it is in the *language* of the chemical article. And the printed pages shown in Figures 3 and 4 do not appear to be a spontaneous creation.

It could be that the manuscript pages (Figures 1 and 2) fit the art model better. Their collagelike aspect certainly testifies to planning, to construction. But these word-image constructs have the feel of art, the pencil stroke made here and not there, the words (and pictures) crossed out. My sketch of a molecule is just that, a sketch; but as David Hockney could draw a "better beach chair" had he wanted to, I could have drawn a more realistic representation of my molecule. The information in that sketch suffices, at least to me. There is more expressive power in that little drawing than in my final finely drawn product; it bears crude witness to my struggle to understand *and* explain, to conceptualize *and* articulate.[7]

There's no chance that any scientific journal would publish that initial sketch. Or even a "better" one, drawn by a more effective chemical artist. Perhaps that is the impoverishing aspect of this particular mode of human symbol transfer. **Q**

Roald Hoffman is the John H. Newman Professor of Physical Sciences at Cornell University. A Nobel laureate and a published poet and essayist, Hoffmann is collaborating with California-based artist Vivian Torrence on Chemistry Imagined, *a work that brings about a union of science and art.*