That's Interesting

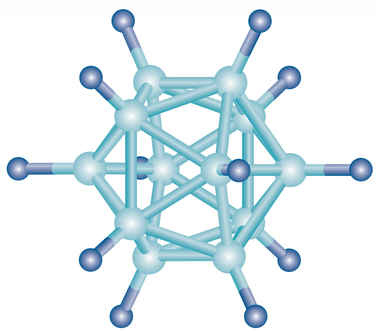
Roald Hoffmann

THE TITLE PHRASE, said with just the right intonation, could be dismissive: a polite, thinly veiled way of saying "I am not really interested." But my concern here is with the sincere variant of the expression—particularly in science, when it is said to oneself, sotto voce. For this statement is how curiosity is stirred. And, as I will argue in a continuation of a small campaign to value the "unmathematicizable" in science (I've also written about the importance of metaphor and storytelling), psychological interest is a progenitor of scientific creation itself.

As a descriptor of an experiment or theory, *interesting* resides more or less comfortably between *beautiful* and *strange*. Aesthetic judgment, such as attribution of beauty, is generally avoided by scientists as they write—paradoxically so, I'd say, for they would like nonscientists to value not just the technological utility of their labors, but also the elegance. Is it reticence that leads one to avoid writing "this molecule is beautiful" in a scientific paper? No, I think it is a fear of the spiritual, as if calling a molecule beautiful in a paper would put one in the company of art critics. Or, God forbid, priests. And *strange*, when used to describe a scientific observation, can carry a hint that something might be amiss: a spectrum not quite correctly interpreted, a mistake of sign in a derivation. But *interesting*, when said without a veiled smirk, is very much a positive valuation. That is, as positive about other people's work as scientists often allow themselves to be in public.

The word's etymology is revealing. The noun came into English from French, which took it from Latin. There, it derived from the verbal phrase *inter esse*, meaning literally "it is in between." (So the *Oxford English Dictionary* says; there is some debate about this point.) That construction, *inter esse*, meant that something made a difference and thus it was important. The claim for value in diversity was explicit: To be different, to be in the middle, neither this nor that—all these things mattered. In the same spirit, I entitled a book about chemists and chemistry *The Same and Not the Same*. Diversity in the structure and function of molecules is exactly what gives chemistry its power and value.

Curiosity drives discovery. But what, exactly, makes us curious?



The lovely icosahedral dodecaborate ($B_{12}H_{12}^{2-}$) ion was first synthesized in 1960, settling a debate about what its stable form would be. Here, boron is light blue and hydrogen is dark blue.

But when *interest* first came into English, it was used only in the legal sense of having a right or title to something. Only at the end of the 18th century did the word begin to signify curiosity about a person or thing. Now, as then, to be in between is to be not understood in a world ruled by dichotomizing logics. To be in between is to transgress. For instance, the late anthropologist Mary Douglas described how the Lele people of central Africa avoided eating flying squirrels. According to their taxonomy, the creatures were "not unambiguously birds nor animals," Douglas wrote in her 1966 book *Purity and Danger*. It's a tense place, that middle. But maybe, just maybe, it's the place where understanding is waiting to be found.

It Comes, It Goes

There is a strong psychological component in the word *interesting* and the feeling it describes. That's clear from the waning of interest, which is as much a part of the experience as is its rise. I recently caught myself saying "Electronically, the dodecaborate anion ($B_{12}H_{12}^{2-}$) is uninteresting." I remember the day in 1961 that the inorganic chemist Fred Hawthorne walked into the office of one of my research advisors at Harvard and told us that he had made $K_2B_{12}H_{12}$. Before that, I had read Linus Pauling's prediction that neutral $B_{12}H_{12}$ would be stable. And I had studied a calculation, performed by theoretical chemists H. Christopher Longuet-Higgins and M. de V. Roberts, which instead predicted that this polyhedral molecule would be stable only as a dianion. Hawthorne had just confirmed the prediction of Longuet-Higgins and Roberts. At the time, I couldn't have imagined a more interesting molecule.

But now, 50 years later, I had said it was not interesting. What I meant was that I had seen many substituted $B_{12}H_{12}^{2-}$ ions since the 1960s, so I was familiar with the structure. It is a "closed-shell" molecule, with a big gap between its filled and unfilled orbitals. Its salts are generally colorless and unreactive. All this was settled, and now I was looking for excitement, looking for electronic trouble, looking for molecules that were not insulators but conductors. The geometric beauty of the Platonic solid had ceased to move my jaded mind. A mo-

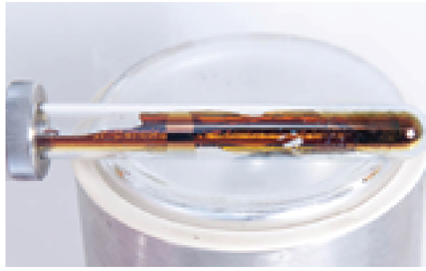
Roald Hoffmann is Frank H. T. Rhodes Professor of Humane Letters, Emeritus, at Cornell University. Address: Baker Laboratory, Cornell University, Ithaca, NY 14853-1301. E-mail: rh34@cornell.edu

lecular degenerate, that's what I was. I should put those words of disinterest in lovely $B_{12}H_{12}^{2-}$ back in my mouth. But my naysaying illustrates a point: Interest falls off as novelty fades. We get bored with that simple melody. Even our teenage children eventually (albeit too slowly for us) move on to the next hit.

Food for Thought

Abnormality, like novelty, can evoke interest. But any given anomaly may be viewed as interesting or not, depending on the cognitive setting of the observation. The observer first has to know what is normal in order to care about what is not. Tetraamminelithium ($Li(NH_3)_4$), pictured above at right, is a bronze-colored metallic liquid (this combination of properties is interesting by itself) that crystallizes into a metallic solid at 89 degrees Kelvin (–184 degrees Celsius). That is a low temperature, but so what? Other elements and molecules solidify at lower temperatures: molecular hydrogen (H_2) at 14 degrees Kelvin and helium not at all. But none of these other atoms or molecules is a metal. $Li(NH_3)_4$, a liquid and a metal, has a freezing point nearly 150 degrees lower than that of any other liquid metal. How am I to think about the way intermolecular forces (responsible for solidification of all compounds) interweave with the free motion of electrons that is the hallmark of being a metal, to make $Li(NH_3)_4$ melt at such a low temperature?

When we make new observations, we compare them to the way we think the world works. And that's something we are constantly revising: In one's mind is a dynamic, shifting conception of how the pieces of the world fit in, now and in times past. With some parts of this world, one accumulates a lot of experience, as I have with chemistry. I've been at it long enough to form an intuition. But most subjects, from Venezuelan literature to the ecosystem of the Kazakh steppe, I know less well. And I assess an observation differently when it pertains to a field that I do know. A new touring-ski wax will not get my attention, but when a graduate student of mine brought to a research-group meeting the structures of two related organometallic molecules, illustrated to the right, I sat up. Each of these molecules, synthesized by Kanazawa University's Kiyoshi Isobe and his collaborators, has a rectangle of sulfurs, bonded to iridium atoms in one case, to rhodium atoms in the other. Rhodium appears directly



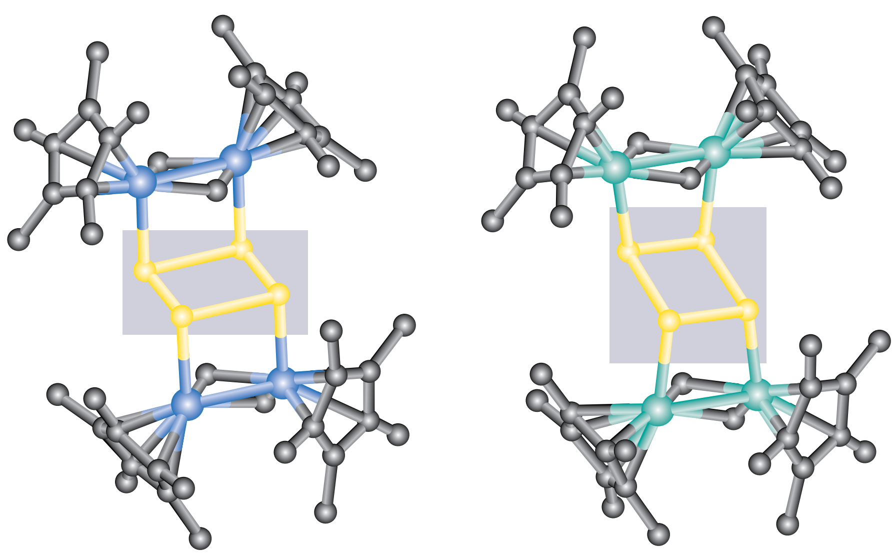
Shown here in its liquid form, tetraamminelithium ($Li(NH_3)_4$) is unusual because of its low freezing point, nearly 150 degrees Celsius below that of any other metal. (Photograph courtesy of Matthew Lodge.)

above iridium on the periodic table, and the two elements are expected to have similar properties: What happens for rhodium, in the way of molecular geometry, should happen for iridium. But the rectangle is turned one way in one molecule, the other way in the other. Now *that* was interesting! Enough so that it formed part of the Ph.D. work of Anne Poduska, the student who found the structure of these molecules in the literature.

Of course one also has to learn discrimination. Many of the world's anomalies are unimportant, little zags where a number of variables combine to make something appear more abnormal than it really is. Others are just experimental mistakes. But there are anomalies worth worrying about. The molecule with an unexplainable feature sits there, staring you in the face with its peculiarity. "Understand me if you can," it says. "Make me if you can." The challenge is there, put forth quietly as I sit at my desk. In response, I will build an explanation. For that is my métier. And the next issue of a journal will provide me with a new puzzle.

Anne and I readily admit that coming up with an explanation for our perplexing dance of rectangles did not shake up the world. And yet, and yet—everything is connected to everything else. I believe that by solving a thousand such bonding puzzles, each of tiny significance, and keeping one's eyes open for the inevitable connections between those little pieces of the world, ultimately one will have the world, at least the chemical part of it.

Incidentally, making those connections is inherently interesting, for it brings together two or more parts of our universe, parts that previously stood apart. Here is a personal example: Many inorganic molecules could be thought of as being built from fragments such as ML_3, ML_4 and ML_5 (where M represents a transition metal atom and L an associated ligand, such as CO, PH_3 or Cl). The Lego blocks of organic chemistry could be seen as CH_3, CH_2 and CH. I once realized (based on the foundational work of others) that, despite the traditional separation of organic and inorganic chemistry, the electrons in both sets of building blocks moved in orbitals that resembled each other. Here was a mapping that allowed one to see like features in the structures and reactions of both organic and inorganic molecules. Making that connection was one of the most satisfying experiences of my life. Which brings me to the joy of creation.



The elements rhodium *(Rh, blue)* and iridium *(Ir, green)* are chemically similar metals. But in these surprising molecules, incorporating Rh instead of Ir results in a change in the configuration of the *(yellow)* sulfur rectangles. Specifically, the compounds are $[\{Rh_2(\eta^5\text{-}C_5Me_5)_2(\mu\text{-}CH_2)_2\}_2(\mu\text{-}S_4)]^{2+}$ *(left)*, and $[\{Ir_2(\eta^5\text{-}C_5Me_5)_2(\mu\text{-}CH_2)_2\}_2(\mu\text{-}S_4)]^{2+}$ *(right)*.

Vivian Torrence

Novelty inspires interest. In *On the Crystal Scale*, a collage by Vivian Torrence, a miner surrounded by crystals singles out a unique form for closer scrutiny. The artwork represents such crystalline geometries on three scales: the landscape scale shown in the top section, the human scale in the middle and the invisible, molecular scale in the bottom section.

The Quiet Goad to Creation

So, an interesting thing is new and unusual, but not so new that one cannot describe it. I think of Heike Kamerlingh Onnes when, a hundred years ago, he saw the electrical resistance of mercury drop to zero for the first time. There were conflicting ideas among physicists of the time on what would happen to the resistivity of metals as they were cooled. Onnes was in the position to make the first measurements of the conductivity of metals at the lowest temperatures, just made available in his own laboratory by the newly liquefied helium. I also think of interesting molecules and interesting theories—such as the one that led Paul Dirac to the puzzling but valid negative-energy solutions to his foundational 1928 equation for the quantum-mechanical and relativistic behavior of electrons. Taken seriously, those odd solutions resulted three years later in the prediction of the positron. Such anomalies, faced by individual scientists in solitude, are, I believe, the stimulus to much creation.

In the psychological literature, I found support for my assessment that scientific interest springs from stimuli that are novel but understandable. In his book *Exploring the Psychology of Interest*, Paul J. Silvia calls interest "an eccentric emotion," and he describes the experiments he uses to characterize it. In one, his subjects viewed and rated randomly generated polygons with respect to interest. At the same time, he gauged the subjects' curiosity and openness to experience. In another experiment, participants rated as interesting (or not) some abstract images, and simultaneously appraised the comprehensibility of the same pictures. Silvia concludes that interest derives from an "evaluation of an event's novelty-complexity" and its "comprehensibility." Other psychologists have studied the adaptive function of interest, how interest derives from appraisal of a situation, and the obvious role of interest in learning. The late Daniel Berlyne, who was a professor of psychology at the University of Toronto, singled out novelty, complexity, uncertainty and conflict as the qualities appraised in a judgment of interest.

Interests and Obsessions

The psychology literature helped me understand a distinction between interest and interests that I couldn't quite put my finger on before. The strange case of the sulfur rectangles that Anne Poduska found was really exciting. But I also have less rousing interests. I am interested, quietly and expectantly, in the behavior of molecules under high pressure, such as that found at the center of the Earth. I'm interested in carbenes, metastable molecules with two groups attached to a carbon atom. I am also interested in Caucasian rugs and indigo and too many other things. Notice that I do not say that I am interested specifically in, respectively, silane (SiH_4) under high pressure, methylene (CH_2), an Akstafa carpet, or indigo made in ancient times from *Murex* snails in the Mediterranean, as used ritually by the Hebrews. My interests are broad and quiet. They are like beaches that I watch, waiting for interesting flotsam to wash up. But how do I decide which beach to watch, out of millions that I do not? Here the metaphor breaks down. I built those beaches. I did so out of a combination of chance and curiosity. The specific molecules I named, that particular Caucasian carpet, the Biblical blue—those were the novel initiating interests of my beach building. Now I wait quietly, with the confidence that something else will float up on the same shores.

That expectant interest is different from the feeling of mental arousal spurred by the atypical. Also different is a kind of interest that borders on obsessive. It happens to all of us. I watch the turning of a water wheel, one that once drove a millstone. Although its motion is repetitive, I can't stop watching it. Or perhaps I can't stop *because* the motion takes this form. I go out of my way to find other water wheels, so I can again immerse myself, figuratively, in contemplating them. Clearly there is interest here, as Michael Weisberg, a philosopher at the University of Pennsylvania, reminded me. The motion of the water wheel is fascinating (a lovely adjective, still true to its origin in the Latin *fascinare*—to bewitch). I am indeed enchanted as I watch the water wheel. But is this the sense of *interesting* that I want?

I don't think so. The familiar obsessive fascination with objects or motions might be one, normal end of a spectrum of autistic behavior. To me it seems to have something to do with resting states of mind, with meditation and biorhythms. The interest that puts us on the path to discovery is something else. It breaks a spell and feeds on mental arousal.

How Understanding Begins

I think that the exciting kind of interest is intimately connected to the beginning of understanding, and it is in this way that the psychological intertwines with the epistemological. Understanding rarely comes ab initio, by simply tracing the consequences of a theory. Even the epitome of Dirac's positron prediction had a small struggle for understanding embedded in it: Dirac first thought the proton was the antiparticle to the electron. He had to tweak his worldview to solve the puzzle and propose the positron instead.

Something is judged to be interesting because of our inability to explain it or, as Anne Poduska points out, it just has not been posited before. That judgment is not generally announced in broadsides or by community consensus. (There are exceptions, such a David Hilbert's 23 mathematical problems. He proclaimed them as interesting, and because of Hilbert's stature and intuition, they inspired a good deal of later research.) But I believe that, for the most part, the judgment ("now *this* is interesting") is made in solitude, or perhaps in the setting of a small research group. This is what happened for Anne Poduska and me in that small problem of the choosy sulfur rectangles.

Faced with a puzzle, and excited by it, I do try to understand the anomaly before me. My failure to find a ready explanation, and my feeling that the phenomenon is nonetheless understandable—these are both motivating psychological actions. In time, if I am fortunate, my thinking brings me to an explanation that makes sense not only to me, but to the community of chemists. I wouldn't have gotten there without thinking, "That molecule is really interesting."

Bibliography

Berlyne, D. 1960. *Conflict, Arousal and Curiosity*. New York: McGraw-Hill.

Pitochelli, A. R., and M. F. Hawthorne. 1960. The isolation of the icosahedral $B_{12}H_{12}^{-2}$ ion. *Journal of the American Chemical Society* 82:3228–3229.

Poduska, A., R. Hoffmann, A. Ienco and C. Mealli. 2009. "Half bonds" in an unusual coordinated S_4^{2-} rectangle. *Chemistry, an Asian Journal* 4:302–313.

Silvia, P. J. 2006. *Exploring the Psychology of Interest*. New York: Oxford University Press.

Silvia, P. J. 2008. Interest—the curious emotion. *Current Directions in Psychological Science* 17:57–60.