

Protean

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Science often advances upon willful transgression of a seeming interdiction. Examples which leap to a chemist's mind are noble gas compounds, strained hydrocarbons such as tetrahedranes, activation (by organometallics) of even methane, and, to mention just one brilliant, more recent achievement, inclusion of an allene within the confines of a six-membered ring while preventing its conversion into a benzenoid.^[1] Such feats require all the cunning of a scientist in coaxing and, yes, coercing the system at hand to obey instructions from a daring imagination.

As always, it is hard. Not for nothing is our playroom called a *laboratory* (*labor*, from Latin, to work or to suffer). And when the task is done and the time arrives to convey to others (who might not be privy to the anguish of the work) all that struggle and the majesty of the achievement, the scientist quite naturally lapses into metaphor. One such metaphor, founded in male 19th century language as much as in history, is "Unveiling the Secrets of Nature",^[2] which may appear as some more or less prurient variant. Another example, evoking the thorny, twisted path to understanding and the long hours of toil in the laboratory, is "Wrestling with Nature."

The latter metaphor has been central to experimental science since at least the Elizabethan Age, and is the subject of this small essay. While the roots of the metaphor lie in Greek myth, it makes a striking debut in science in a seminal brief for experiments. This arresting phrase also marks a bifurcation in the way science is viewed by nonscientists, even—and especially so—in our day.

The textual proof here is that of Francis Bacon (1561–1626), in his book *Of the Advancement of Learning* from 1605. Bacon writes:^[3]

"For like a man's disposition is never well known till he be crossed, nor Proteus ever changed shapes till he was straitened and held fast; so the passages and variations of nature cannot appear so fully in the liberty of nature, as in the trials and vexations of art."

He repeats the imagery in his remarkable work of 1620 *Novum Organum*, which was a clarion call to replace what passed as Aristotelian reasoning about the world^[4] by experiment. Francis Bacon likens matter to Proteus, the "Old Man of the Sea", and describes scientific endeavor, as it strives to discipline matter, as follows:^[5]

"And the manipulations of art are like the bonds and shackles of Proteus, which reveal the ultimate strivings and struggles of matter."

By "art" Bacon clearly means experiment, as this passage makes clear:^[6]

"...every interpretation of nature which has a chance to be true is achieved by instances, and suitable and relevant experiments, in which sense only gives a judgment on the experiment, while the experiment gives a judgment on nature and the thing itself."

Three hundred and sixty-five years later, Primo Levi, in his wonderful chapter on hydrogen in the book *The Periodic Table*, writes:^[7]

"We would be chemists, Enrico and I. We would dredge the bowels of mystery with our strength, our talent: we would grab Proteus by the throat, cut short his inconclusive metamorphoses from Plato to Augustine, from Augustine to Thomas, from Thomas to Hegel, from Hegel to Croce. We would force him to speak."

What is going on here, and who is Proteus? Here is a pithy description:^[8]

"Proteus is a prophetic sea divinity, son of either Poseidon or Oceanus. He usually stays on the Island of Pharos, near Egypt, where he herds the seals of Poseidon. He will foretell the future to those who can seize him, but when caught he assumes all possible varying forms to avoid prophesying. When held fast despite his struggles, he will assume his usual form of an old man and tell the future."

The episode of Menelaos wrestling with Proteus in the *Odyssey* is one of the topoi of literature. The old man from the sea, when the hero and his companions try to catch him in their arms, first becomes a bearded lion (Figure 1), followed by—the sequence of creatures the magician turns himself into is not unlike the list of the years in the Chinese calendar!—a snake, a leopard, a huge boar, flowing water, and a high and leafy tree. But Proteus has to submit to the brute force of

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Figure 1. The struggle between Proteus and Menelaos as drawn by Patten Wilson.^[9]

Menelaos and his companions; firmly held, he finally consents to act as a seer—with the uncanny ability of a poet, that is, the ability to describe in vivid and memorable words the images which flock into the mind.^[10] Indeed, Proteus is an inspired speaker: when Socrates teases Euthyphro during their dialogue, he tells him that “like Proteus, you must be held until you speak”!^[11]

But how did we get from a wrestling match with Proteus (definitely male) to one with nature (mostly feminine in European culture)? Might there be an element of covering up anything remotely homoerotic as one moves on the trajectory out of the Renaissance and toward Victorian times? Is it just an erosion of classical culture as science leads the democratization of the professions? Bacon also resorts to the other metaphor:^[12] “...nature reveals herself more through the harassment of art than in her own proper freedom.” Whatever the reasons, by our own time, excepting stylists such as Primo Levi, Proteus is left in peace in his cave, and nature alone is cross-examined.^[13]

Francis Bacon, as an Elizabethan mind, was a master at crafting metaphors—think of his “idols of the tribe, idols of

the marketplace”.^[14] He also compared experimental scientists, good at collecting data, with ants; while theorists, he said, are more akin to spiders, “who make cobwebs of their own substance.” Not everyone was happy with the Lord Chancellor. One of our icons, Justus von Liebig, had this to say:^[15]

“Bacon attaches a great deal of value to experiments in research. But he understands their meaning not at all. An experiment not preceded by theory, i.e. by an idea, bears the same relation to scientific research as the sound of a child’s rattle does to music.”

Back to chemistry: we are indeed familiar with the real world being unruly, unyielding to our efforts to make it behave, and apparently uncontrollable. Quite a few chemical reactions (“metamorphoses” as they were termed in former times) seem to us like Proteus in their changes, whether they are predictable or not. Cascade reactions, which one of us was perhaps instrumental in naming,^[16] come to mind. We also know quite a few tricks to stop the old man of the sea in his tracks, when he comes to haunt chemical dynamics. The trapping of reaction intermediates is just such a tactic. So, to return to cyclohexa[1,2,4]triene—evidence for the fleeting existence of the parent hydrocarbon came from such trapping.^[17] Use of radical traps to expose certain chemical species (or to divert them from their appointed rounds) is a common trick.

Turning from reactivity to structure, there also we find an uncanny ability of matter to masquerade in an unpredictable diversity of shapes. Jack Dunitz and Joel Bernstein have written a wonderful account of vanishing polymorphs, crystal forms which were once synthesized, but then could not be recreated. Or so it seemed.^[18] Seed crystals have mysterious ways of propagating. The phenomenon is of great importance in the pharmaceutical industry, with respect to the differing efficacies of polymorphs, control of their production, and their patentability. Polymorphs belong to the realm of “the same and not the same”.^[19]

The “Wrestling with Nature” metaphor brought about a debate that roils the waters of Proteus’ father to this day. Bacon was accused of being the first of a long series of villains to “put nature on the rack”, a rationalizer of torture in the service of science.^[20] Goethe’s revulsion at Newton’s incarceration of a passage of light through a slit (and its subsequent analysis into the component colors by a prism) is emblematic. As are Donne, Wordsworth, and Ruskin’s impassioned denunciations of science and of the attendant industrial revolution. The line continues, to some (but hardly all) of the environmentalist and animal rights critiques of the interventionist nature of science.

This is not the place to enter into this debate. Our opinion is that modern commerce and technology, with the collusion of science, has some things to be ashamed of, such as the use of

animals in the devising of new cosmetics. And much more to be proud of, our truly democratizing science.

As a community, we have become aware that voyeurism of nature is neither innocent nor totally unobtrusive. We now know that it brings about its own retribution, perhaps like Acteon, who is direly punished for having watched Artemis in the nude. Werner Heisenberg has taught us that any measurement interferes, however slightly, with the system being studied. Is this a limitation to our knowledge? Yes, and no. To be sure, it encourages a more courteous approach to reality, forcing us to question macroworld intuition thoughtlessly applied to the microworld, forcing us to be delicate (as we should have been from the beginning) in asking our questions of nature. Take modern chemical dynamics, that remarkable crossroads of classical and quantal. The indeterminacy principle (for that is closer to what Heisenberg called it) has nontrivial consequences in the new kinetic art. It makes us think: To build and shape a femtosecond pulse, what range of energies does it take? And if we want to inject a precise dollop of energy into a bond, what does that entail for the time scale of the process?^[21]

Is intervention an absolute correlate of experimental science? The question merits a lengthier discussion. Surprisingly (given Bacon's startling metaphors and the resistance to them), it is only recently that philosophers have begun to explore the subject. An examination of the question is found in Ian Hacking's idiosyncratic work *Representing and Intervening*.^[22] In an important essay on "Experimentation and Scientific Realism", Hacking writes: "Interference and interaction are the stuff of reality."^[23] J. E. Tiles, in the essay "Experiment as Intervention" says of Hacking's analysis that it was "received in some quarters with a mixture of incomprehension and hostility."^[24] This is a minor surprise to us. We agree with Tiles that philosophers of science ought to consider that experiment does not only follow from observation (as classical empiricists mistakenly and narrowly assume; this is valid for Liebig as well). At times, experiment is driven by an overtly interventionist stance.

"Nature's narrative of herself" is a fiction. Any acquisition of knowledge involves intrusion. Only the size of the perturbation changes. Accordingly, we have learned to care. We do not want our curiosity to devastate its object, butterfly-like in its fragility. Instead of roughhouse "wrestling with nature," regardless of the consequences, we have made ourselves adept at gentler sports. Examples are various "noninvasive" spectroscopic techniques, for instance, spin tickling in nuclear magnetic resonance spectroscopy, or resorting to isotopes in order to effect as gentle a perturbation as we know how.^[25] And, of course, we can use all the fine information isotope effects give us....

We try to make our intrusions as delicate as a caress or a kiss. Though, God knows, some kisses can upset a world.

And, yes, we are part of nature too. When trying to understand a complex system or phenomenon—electrocyclic reactions, say, before they were understood—one's mind and one's art seem too limited. We cope with a complex skein of imprecise facts. We wrestle with how to explain phenomena.

Lack of sleep from contending with the truth of the matter is reminiscent of another wrestling match on the world's

spiritual stage. It is the story of Jacob wrestling with someone throughout the night. Here is how it is told in Genesis, chapter 32:^[26]

"Jacob was left alone. And a man wrestled with him until the break of dawn. When he saw he had not prevailed against him, he wrenched Jacob's hip at its socket, so that the socket of the hip was strained as he wrestled with him. Then he said, 'Let me go, for dawn is breaking.' But he answered, 'I will not let you go, unless you bless me.' Said the other, 'What is your name?' He replied, 'Jacob.' Said he, 'Your name shall no longer be Jacob, but Israel, for you have striven with beings divine and human, and have prevailed.' Jacob asked, 'Pray tell me your name.' But he said, 'You must not ask my name!'"

As we begin to see things for what they are in this world of chemistry, we are overwhelmed with the feeling of having striven with concepts both divine and human.

Proteus in time became an adjective. To be protean is to be variable in form, to take on or exist in various shapes. Was there ever a science that was more about change than chemistry? And is not the richness of our enterprise, the multitude of molecules we can make, the necessary complexity of the living state due to isomerism, so many chemical incarnations of Proteus? The adjective that serves as the title of this essay is an apt descriptor for chemistry itself.

- [1] M. A. Hofmann, U. Bergsträsser, G. J. Reiss, L. Nyulász, M. Regitz, *Angew. Chem.* **2000**, *112*, 1318–1320; *Angew. Chem. Int. Ed.* **2000**, *39*, 1261–1263.
- [2] For a lovely example, see the poem by one of our heroes, Humphry Davy, cited by D. Knight, H. Davy, *Humphry Davy: Science and Power*, Blackwell, London, **1993**. The metaphor presumes the enterprise of science is discovery. But chemists especially know that our business is, in substantial part, creation; see Chapter 19 in ref. [19].
- [3] See the version edited by G. W. Kitchin: F. Bacon, *Of the Advancement of Learning*, J. M. Dent, London, **1915**, p. 73.
- [4] We put it this way out of respect for Aristotle. Bacon and his era reacted against the scholastics, who "merely polished the idol of Aristotle's investigations—thousands of years after his time." Aristotle was (occasionally) a close observer of nature, as his *Historia Animalium* shows; his was "the boldest scientific thinking of his day." The Baconesque quotations here are from Michael Weisberg, Stanford University, private communication.
- [5] See the version edited by L. Jardine and M. Silverthorne: F. Bacon, *The New Organon, Book I*, Cambridge University Press, Cambridge, **2000**, p. 227.
- [6] See the version edited by L. Jardine and M. Silverthorne: F. Bacon, *The New Organon, Book I*, Cambridge University Press, Cambridge, **2000**, p. 45.
- [7] P. Levi, *The Periodic Table* (Translated by: R. Rosenthal), Schocken Books, New York, **1984**, p. 23.
- [8] www.pantheon.org/mythica/areas/greek; Copyright: **1999** Encyclopedia Mythica. All rights reserved. Protected by the copyright laws of the United States and International treaties.
- [9] An illustration from: Homer, *Odyssey* (Translated by: H. B. Cotterill), George G. Harrap, London, **1911**.
- [10] Homer, *Odyssey, book 4* (See, for example, the version in ref. [9], pp. 398–460).
- [11] Quoted from: Plato in *Plato in Twelve Volumes, Vol. 1, Euthyphro, 15d* (Translated by H. N. Fowler), Harvard, Cambridge, **1966**, p. 15.

- [12] See the version edited by L. Jardine and M. Silverthorne: F. Bacon, *The New Organon, Book I*, Cambridge University Press, Cambridge, **2000**, p. 21.
- [13] There is a related, but we think, different metaphor that has been loose in the philosophical literature. This is “carving nature at its joints”, brought to our attention by Michael Weisberg. It goes back to Plato’s *Phaedrus* (265e), and we think it refers to scientists (or philosophers) getting classifications or categories “right”.
- [14] For a reminder of the lasting validity of Bacon’s metaphor, see: S. J. Gould, *Science*, **2000**, 287, 253–261.
- [15] Liebig has much more to say, mostly uncomplimentary, about Bacon. He devotes one lecture and two long polemical essays (published in the *Augsburger Allgemeine Zeitung* in 1863 and 1864) to the other baron: J. von Liebig, *Reden und Abhandlungen*, C. F. Winter, Leipzig, **1874**, pp. 220–295. See also a discussion of Liebig’s essay in: G. Bachelard, *La formation de l’esprit scientifique*, J. Vrin, Paris, **1969**, p. 58–59.
- [16] A. Cornélis, P. Laszlo, *J. Am. Chem. Soc.* **1975**, 97, 244–245.
- [17] M. Christl, M. Braun, G. Müller. *Angew. Chem.* **1992**, 104, 471–473; *Angew. Chem. Int. Ed. Engl.* **1992**, 31, 473–476. Isobenzene is also formed during the cycloaromatization of 1,3-hexadiyne to benzene as a reactive intermediate. Compare with: W. R. Roth, H. Hopf, C. Horn, *Chem. Ber.* **1994**, 127, 1765–1779, a process first described in 1969: H. Hopf, H. Musso, *Angew. Chem.* **1969**, 81, 704; *Angew. Chem. Int. Ed. Engl.* **1969**, 8, 680. Henning Hopf informs us he proposed the intermediate for the 1,5-hexadiene-5-yne ring closure in his 1972 Habilitationsschrift, but didn’t dare to mention it in print at the time.
- [18] J. D. Dunitz, J. Bernstein, *Acc. Chem. Res.* **1995**, 28, 193–200. One of us was moved to write a poem by this article (R. Hoffmann, “On First Sight,” *Cryst. Growth Des.* **2000**, 1, 3).
- [19] R. Hoffmann, *The Same and Not the Same*, Columbia University Press, New York, **1995**; R. Hoffmann, *Sein und Schein – Reflexionen über Chemie*, Wiley-VCH, Weinheim, **1997**.
- [20] P. Pesic, *Isis* **1999**, 90, 81–94. Pesic’s article, entitled “Wrestling with Proteus; Francis Bacon and the ‘Torture’ of Nature”, on which we draw heavily in this essay, lists a number of such interpretations of Bacon’s metaphor. The Latin word Bacon used—*vexatio*, *vexare*—is best translated, as Pesic suggests, by “vexation.” In the usage of the time, and in Bacon’s works, it was quite distinct from torture. The earlier (1605) use of “trial or vexation” by Bacon in English (our first quote; see ref. [3]) in a parallel context, is clear evidence for Pesic’s point.
- [21] R. Hoffmann, *Am. Sci.* **1999**, 87, 308–311; R. Hoffmann, *Am. Sci.* **2000**, 88, 14–17.
- [22] I. Hacking, *Representing and Intervening*, Cambridge University Press, Cambridge, **1983**.
- [23] I. Hacking in *Scientific Realism* (Ed.: J. Leplin), University of California Press, Berkeley, **1984**, pp. 154–172.
- [24] J. E. Tiles, *Brit. J. Philos. Sci.* **1991**, 44, 463–475. We are grateful to Michael Weisberg for bringing this article to our attention.
- [25] Hans Christian von Baeyer has written an insightful, meditative essay on how one might and does study nature incisively but nondestructively. H. C. von Baeyer, *The Sciences* **1989**, Sept/Oct, 6–9; reprinted in: H. C. von Baeyer, *The Fermi Solution*, Random House, New York, **1990**.
- [26] Gen. 32:25–30, The Jewish Publication Society of America, Philadelphia, **1962**.