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SCIENCE & THE OUTER GLOOM

OR: WHAT GOES ON OUT THERE IN OUR HEARTS?

We pass our days in a pool of light—a light fashioned by science, powered by an industrious economy. Yet, we cannot assert a circle of light without at the same time asserting, by the very circumference of that circle, the horizoning darkness. Within the circle are reason, reasonableness, and custom by which we usually claim to live. We thank—often at their prompting—industry and science for the circle of light.

Yet skeptics like William Blake and his recent exponent Theodore Roszak[1] tug us passionately outward toward the dark and uncertain horizon. So bright is the light of modern technological organization, so ever-present its benefits—indeed, modern life resembles nothing so much as the interior of an over-illuminated fast food joint—that one may be disinclined to stumble outward into the buggy gloom. This the more so if one earns one's bread by the light of technological reason; if one is, for example, a teacher, a scientist, a salesman, a truck driver, . . .

Behind the horizon there has always been much baffling activity, false dawns and rumblings—whether of cannon or of sweet rainstorms remains much debated. Voyagers from it have returned with tales of Shangri-La—a land of myths, dreams, symbols, and moods; but they tell also of monsters and of the terrifying pit at the edge of the world—domination, exploitation, cruelty, war. Fascination with this horizon has recurred like a dream throughout intellectual history primarily, I suppose, because it represents an inescapable part of what it means to be human—a heritage, perhaps, from a prerational homeland, beyond the encircling horizon.

If we now consider whether irrationality represents any kind of horizon—new or old—for science and scientists, we may be inclined to doubt it. The "hard" sciences, at least, are firmly within the circle of rationality, with at most a pinch of chemotherapy thrown over the left shoulder to ward off demons. The point of science is to examine the physical world, a small part at a time, in the light of reason, and to leave behind unreason. And it is certainly true that we have stayed away from the sunny uplands of nonrationality—from myths, dreams, and emotion—and have dealt only, and then ambivalently, with domination, exploitation, and war. (As one of my colleagues pointed out recently, these one-sided renunciations work both ways: the radical mystic condemns the constructive and creative side of rationality, but may be ready enough to use it for exploitative ends.)

Science and Literature

However, a scientist may experience a delighted shock to recognize grand themes of science appearing in imaginative literature, including that literature that hovers nearest fantasy and myth. I refer not so much to science fiction. which is generally far too self-consciously scientistic to achieve this, but to the literature of such writers as Walt Whitman, John Barth, and Jorge Luis Borges. Their imagery derives its power from the *embodiment*—as opposed to the mere citation, or display—of high rationality about the physical universe in the high irrationality of poetry and fiction. Let me first illustrate with a common but powerful insight—that of Walt Whitman into the human meaning of cycles of nutrients in the ecosphere:

And as to you Death, and you bitter hug of mortality, it is idle to try to alarm me.

. . . . .

And as to you Corpse, I think you are good manure, but that does not offend me.
I smell the roses sweet-scented and growing
I reach to the leafy lips, I reach to the polish'd breasts of the melons.
And as to you Life, I reckon you are the leavings of many deaths,
(No doubt I have died myself ten thousand times before.)

1. Roszak, Theodore, *Where the Wasteland Ends*, New York, Doubleday, 1972.

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Or, if the notion of the conservation of matter seems too homely, there is John Barth's evocation of Gibbs' *grand ensemble* through the mind of Henry Burlingame in *The Sotweed Factor*, in which Burlingame leads his young pupils to the idea that the world as we know it—in which, for example, France is shaped like a teakettle—is only one of infinitely many imaginable worlds, in most of which France would *not* be shaped like a teakettle, if there were a France at all. The same idea is given alternative realizations by Jorge Luis Borges ("The Garden of Forking Paths"; "The Babylon Lottery"). And, while we speak of thermodynamics, Borges' story "The Library of Babel" is as good a realization of the heat death of the universe (expressed in information-theoretic, rather than thermal, entropic terms) as I care to contemplate.

Such citations are easily multiplied. For example, a vision of mankind as that temporarily organized subset of matter privileged to contemplate itself is given as convincingly by Kurt Vonnegut, Jr. in *Cat's Cradle* as, more recently, by the logician G. Spencer Brown[2] or the physicist J. A. Wheeler[3]. But the ultimate lesson is clear. Literature and science confront the same universe and must remain, at heart, true to that universe.

Thus I think that, to the abuse that has been heaped on C. P. Snow since his discovery of the Two Cultures, we might add the observation that literati are not all *that* illiterate in science. To take Snow's own example, I suggest as a superb formulation of the Second Law of Thermodynamics the following by Dylan Thomas:

> *The force that through the green fuse drives the flower*
> *Drives my green age; that blasts the roots of trees*
> *Is my destroyer.*
> *And I am dumb to tell the crooked rose*
> *My youth is bent by the same wintry fever.*

Let me at once make three comments about these literary parallels to scientific insights: (1) Thomas' poem or Borges' story would be a terrible starting point from which to calculate the efficiency of a turbine or the pH of a buffer. The kind of "science" embodied in literature is static and contemplative, not of much use for prediction or control. But I shall want to say later that the same is true of an important part of science. (2) I am not concerned with the question of overt, linear "influence" in the literary historical sense. I don't know if John Barth ever read a line of Gibbs, though I strongly doubt it. His insight into the infinite possibilities of infinitely multiple worlds, and the limitations inherent in living in only one of them at a time may stand on its own. (3) If I were only playing a game of spotting accidental parallelisms, the game would reduce to a sort of intellectual stamp-collecting. On the contrary, I suggest that the great "scientific" truths are great human truths, and the fact that representations of them appear simultaneously in the apparently unconnected worlds of physics and literature may signal their existence as entities in a central, human core. What one might call such entities presents a problem. I shall adopt a suggestion of Frederick Thompson and call them myths, thus consciously and intentionally placing them in a class with other deep and recurring myths such as those of creation, the cycle of the seasons, and so forth.

Scientific "elegance" and non-rationality

Let me, then, postulate science as an activity that springs from very near the center of the human personality, where the fundamental furniture of myths, dreams, and symbols are also stored. Is it possible that the sources of highest rationality and highest irrationality are in fact coupled? What convinces me that they are is the fact that at the heart of science lie the related notions of *elegance* and *power*. The greatness of such concepts as the Second Law or symmetry groups is in the fact that in a small and pleasing package they contain much truth. In them the confusion of the perceivable world lies compressed as in a seed.

For purposes of manipulation, it is their power of generating mathematical formalisms that makes these concepts important; yet the other side of elegance is an aesthetic one, in which contemplation is sufficient, and it is of this side that I want to speak. In a scientific context, aesthetic considerations are non-rational. This is a striking and important thought because here, at the very heart of science, we find an envoy from beyond the horizon, whispering delights into the ear of the king of rationality—an envoy, fortunately, from the sunny uplands of myth, symbol, and dream.

Perhaps a relatively simple example will illustrate what I am describing. It is clear from any amount of experiment and reasoning that water molecules are v-shaped. If they were not, they wouldn't stay together as a liquid at room temperature. If asked *why* they are bent, I would answer in what, to a quantum physicist, might be a brutal oversimplification: they are because the oxygen atom has four spin-pairs of electrons in its valence shell, and the spatial correlations of these pairs keeps them as far apart as possible on the coordination sphere of the oxygen—namely at the corners of a tetrahedron, so that I expect the H-O-H angle to be in the neighborhood of 109°. I would rather carry in mind the seed of this simple theory of molecular geometry than to look all day at a computer printout of the molecule's shape based on *ab initio* numerical calculation of the minimum-energy bond angle—just because, although the numerical calculation *may* be more accurate, the other is more elegant. I prefer to believe in it (subject to its limitations) partly because I can easily apply it to many other molecules without elaborate re-programming, but primarily because it appeals to me in a way that is, at heart, sensuous. I can get from it a *feel* for molecular geometry that the limitations of my mind prevent me from attaining through numerical approximations. This is not to say that I, or any other scientist, would cling to any model, however elegant, after it has been proven false or seriously misleading—and in fact, there are a few cases in which the simple theory of molecular geometry fails. But I would drop it then in full confidence that, whatever principle lies at the heart of molecular geometry, it is even more elegant and powerful than this one, not less.

Considerations of elegance—that is, considerations essentially non-rational—are very important to creative science.

2. Spencer Brown, G., *The Laws of Form*, New York, Bantam Books, 1973.

3. Wheeler, J. A., "The Universe as Home for Man", *Am. Scientist 62*, 683 (1974).

They may be closely related to the mythic structure of the mind on which great imaginative writers draw. Unfortunately, most scientists, by their own avowal, are not involved in fundamentally creative work. Of course, even the most humble working-out of well-understood principles can be done in a way that involves operational creativity, experimental economy, and so forth. But permit me to assert, because it is true of myself and of the scientists that I see, that most of us are doing hack work most of the time—work, that is, more closely allied with domination and exploitation than with myth and aesthetics.

In particular, I recall my academic training, which was excellent; I regret that the small creative flourish of the doctoral research was so heavily compromised by the exploitive concern to get results, be done with it, and get the degree. I do not claim that, because I allowed *my* education to be inelegant, everyone's is; yet as I talk to graduate students and university teachers, it does not seem so very unusual, either. The point I want to make in bringing up graduate education is the close relationship that I suspect exists between irrationality in the dark sense (exploitation and domination) and inelegance and unfreedom. Where the scientist is forced by his circumstances to be preoccupied with exploitive ends, his work is likely to be inelegant and thus alienated from the core of his humanity.

In an earlier essay in *Science* [4] I tried to show that the science that has been so successful in the past 400 or so years has succeeded by projecting multidimensional worlds onto mental spaces of reduced dimensionality, and then working out the properties of the resulting projections. And indeed there is nothing wrong with doing that as long as one bears in mind that information is sacrificed in the process of projection. It seemed to me that one way of retaining the complex worlds lost in this process was to regard the abstractions of science as bearing a complementary relationship to directly perceived nature, and to accord to the complementary models of nature—the abstract and the sensuous—equal significance when we talk about nature. This would imply that the sensuous model is part of science, just as wave and particle formalisms are equally important, complementary expressions of quantum physics.

It is also possible that there may be moral consequences of such an expansion of the frame of science. It is the process of projection and abstraction that fosters the scientist's claim of objectivity, and thus of the ethical neutrality of his science. Most of the response to that essay in *Science* came from psychologists, and it dawned on me that I had stumbled into the midst of a running debate among psychologists over the significance of mentalistic, or intuitive states *vs.* behavior as the key to the human psyche. Perhaps psychologists ought to read Niels Bohr on this question—it appears to have been one of his earliest applications of the idea of complementarity, made even before the so-called Copenhagen interpretation of quantum mechanics was fully formulated. In any case, the results, if any, of this debate among psychologists are, to my mind, as important to the future of science as any of the classic debates among physicists. If a human is to be understood as a bundle of conditioned responses only, then science (and with it mankind) will have made permanent its pact with dark irrationality—with exploitation and domination.

If science is to remain free, and not become the permanent handmaiden of exploitation, it must have a strong and self-reliant—that is, creative—soul of its own. To me, this implies that science should become more strongly mythic and aesthetic in nature. In this process a knowledge of his own mind will become as important to the physicist as that of mathematics and mechanics. In this connection it is surely no accident that the creative geniuses of science have nearly all been deeply interested in philosophy, psychology, art, and music. One need only mention the great physicists of the 20th century —Einstein, Bohr, Schrodinger, Oppenheimer, Heisenberg —to realize that each of these men was deeply involved with ultimate questions of human values—questions that are, as we have found over the centuries, not amenable to *ab initio* rational analysis. These men were not studying philosophy and art as hobbies. Reading their philosophical writings forces one to the conclusion that the deep study of science had led them inevitably to the consideration of other forms of truth, and that they saw these other truths as of a piece with their science.

Training for a humane science

We can't all be great geniuses. In the often-quoted preface to their *Thermodynamics* [5], Lewis and Randall describe the "cathedral" of science as being the result of giving ordinary human effort a direction and a purpose. And there is no reason that the ordinary human efforts we workmen give to science cannot be as involved with humanity as the extraordinary ones of the great architects. We certainly don't need more scientists, but we do need more humanists trained in science. Perhaps science as a whole, big and little, would be a better, more independent enterprise if we recognized more explicitly that the best science—the elegant and creative science—flows from a non-rational human core, from which flow also aesthetic and moral judgments. Scientific training founded on such a human core might fit a scientist to function creatively and freely in a complex and complementary world. At present, our education of scientists is, in the world of ideas, severely monastic. No wonder, then, that we produce monks with little knowledge of the full range of human experience. No wonder that so much of science is so many illuminated manuscripts, to be compiled, abstracted, indexed, and re-indexed [6].

Since I take the position that much damage is done to the growth of scientists during their scholastic years, I have the responsibility, and the temerity, to suggest what I think would be a better pattern of training. Because I am not optimistic about the possibilities of great reform in science education, I have allowed myself the luxury of pessimistic unreality in the list that follows. Nevertheless, these are the things that I wish I had known about before I started the practice of science; and I think that they ought to be an organic part of the education of any scientist:

4. Blackburn, T. R., "Sensuous-Intellectual Complementarity in Science", *Science* 172, 1003 (1971).

5. Lewis, G. N., and Randall, M., *Thermodynamics*, New York, McGraw-Hill, 1923.

6. Butler, J. N., "Information Pollution and the Ignorance Explosion", *Chemical Technology 1972*, 139.

SCIENCE	I:	Myth and symbol;
SCIENCE	II:	Languages; linguistics and metaphor;
SCIENCE	III:	Psychology, "deep" and behavioral;
SCIENCE	IV:	Music and dance;
SCIENCE	V:	Poetry and the novel;
SCIENCE	VI:	Oriental religions and philosophies;
SCIENCE	VII:	Elementary physics, etc.

I intend these not as required courses, to be endured and forgotten, but as advised accomplishments; the scientist who omits them should be subject to no sanction but the regret that he had thereby chosen so much less freedom.

Victor Weisskopf, in an essay in *Science*[7] suggests that a doctoral thesis consisting of "a lucid and impressive presentation of some aspect of modern science" might be "worth more than a piece of so-called 'original' research of the type found in many Ph.D. theses, and . . . may require more maturity and inventiveness." To synthesize creatively from the work of others is, indeed, far more valuable than to extend (*i.e.*, to exploit) a graduate advisor's ideas to yet another molecule (or particle, or animal). I can only add that to show the overall significance, if any, of one's own work to the central core of human experience would be an even more worthwhile feat, calling for considerable sensitivity, humility, and judgment.

"Relevance" in the teaching of science

Let me close with a parting note on the subject of relevance in education. As a textbook writer and teacher, I may be entitled to deliver myself of some unkind words at least about my own writing and teaching, and about some that has found its way into print and speech before mine. The sudden arrival of the wave of "relevance" on the beachheads of science brought (and left behind) a remarkable deposit of matter that would have seemed out of place ten years ago; planks torn from the decks of industry, tangled garlands of ecology, and of course the great (and stinking) leviathan of nuclear weaponry. I cannot wholly regard this disjointed flotsam as a welcome addition to the intellectual landscape. The *ad hoc* use of scraps of technology to exemplify a catalog of abstractions is too superficial to answer the urge that motivated the cry for relevance in the first place. The process is sometimes referred to as adding flesh to the bare bones of theory—and that is a very apt, if nauseating, way to describe the result. You cannot make a person by slapping some flesh onto a skeleton. There is only one way that I know of to do it, and it is a pleasant, but ultimately time-consuming, process.

If the relevance of science is not there from its inception, it can't be superimposed later. The course of learning that I outlined above is intended to allow the student's mind to grow as a whole, beginning from what I take to be the most fundamental and uniquely human seed. Rational science in that context would be like the skeleton of a living being; supporting and being moved by live, supple flesh—the whole structure vital, healthy, and humane because it is human. □

7. Weisskopf, V. F., "The Significance of Science", *Science* 176, 138 (1972).

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KATHE AGODOA

MOUNTAIN

Mother, I once said, there might be a place
more beautiful than Minnesota. No sense
looking outside your own backyard, she said.
But two years ago I was canned in a little
yellow car, a tin insect crawling up
a winding winding winding road—for god's sake
in Montana they call strange paths freeways—
winding until it crested, and, as I slowly
slid down into the valley an azure-range
rose up before my view. My God, I said.
(what's so unusual about that? I say "my god"
so often my three year old says to me: My God,
Mother, can I have my breakfast now?) My God!
I said, the first time I saw the mountains.