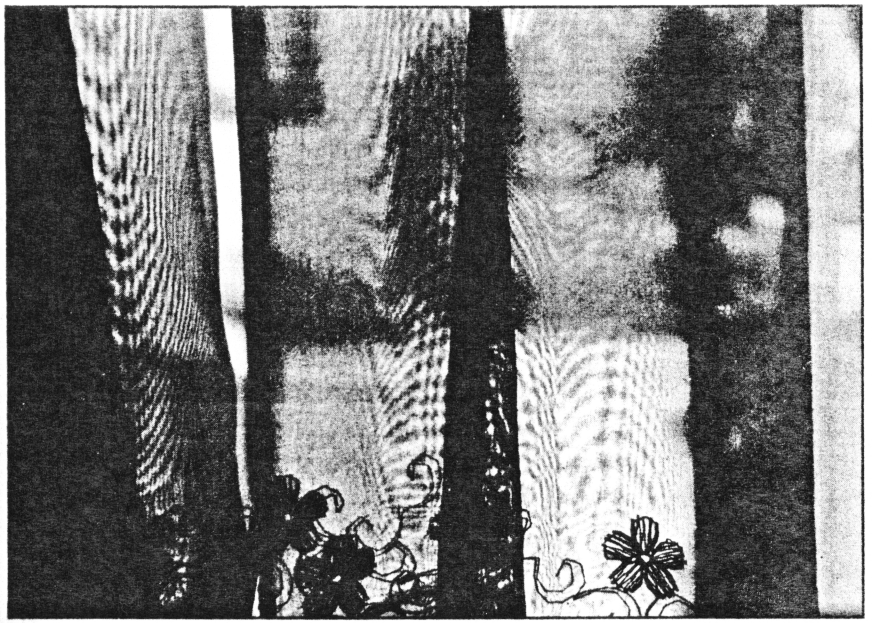
1. THE SENTIMENTAL FRUITS OF SCIENCE



Popular science writers are forever proclaiming the profound importance of such matters as the ultimate fate of the universe, or the events that took place during the first billionth of a second of time. We often write as if people were poised on the

edges of their proverbial seats, anxiously waiting to learn whether or not the proton will decay (in 10^{32} years!)* or whether there is mass tucked away mysteriously inside neutrinos. Breathlessly, we keep them up to date on such esoterica as the search for "bottom quarks" and "intermediate vector bosons."† Sometimes I wonder how many readers struggling to get their socks on in the morning doubt whether exploring these far-out corners of the universe is necessarily so important. It is surely not obviously useful.

Sixteen years ago, I sat in the musty lobby of a small hotel in the Soviet industrial city of Kharkov, having just returned from a visit to a collective farm. Thirty or so Americans and Russians squirmed together in the tiny uncomfortable room to watch on a scratchy black-and-white TV as two American astronauts walked on the moon. The image on the screen was a barely discernible blur; yet it was quite clear that both Russians and Americans were deeply impressed by these first tentative extraterrestrial steps. We agreed completely when Neil Armstrong described it as a giant leap for humankind.

It was many years later before I learned that some of my best friends back home had considered the whole venture a waste of time, a squandering of scarce resources. Worse, even supporters of the space program seemed to be countering with all the wrong arguments. Recently I was reminded of this when a man from Grumman started drumming up support for the shuttle by passing around samples of Mylar jogging suits and talking—again—of Tang. Then the editor of a major woman's magazine told me that I should write only of the practical aspects of science: "People want information they can use."

It's true, of course, that science has produced a prodigious array of practical fruits—and those are the fruits that we hear about.

*10^{32} is the number 1 followed by thirty-two zeros. To give you an idea of how large that is, consider that a billion is the number 1 followed by only nine zeros. Physicists think the entire universe is only between fifteen and twenty billion years old. Waiting for a proton to decay is like waiting for Godot.

†As far as physicists know, the quark is the most elementary constituent of matter. Quarks make up protons and neutrons, which make up the atomic nucleus. The five known quarks are called up, down, strange, charmed, and top (also called truth). The theory requires a sixth quark (bottom, or beauty) which has not yet been found. For a description of bosons, see "Forces, Motives, and Inertia."

The spin-offs from the space program alone have brought us everything from improved mapping of the earth's surface to a deeper knowledge of what lies beneath its crust; from advanced microprocessors to zero-gravity production lines for making flawless crystals and pure drugs; from space-age medical technology to steamlined sailboats and lighter, more durable sportswear. But any spin-off is, by definition, a somewhat peripheral point. Science is not the same as technology. There's nothing *practical* to be gained (for a long while anyway) from probing protons or searching for signs of extraterrestrial life.

There is, however, a far more central point to science. The point is what my friend the physicist calls "the sentimental fruits of science." "Science is useful not only in a practical way," he says,

> but also in that it determines how we think and feel. Religions have always embodied a view of nature. Even the Bible begins with an account of cosmology. Today, such thoughts about nature come primarily from science. They are as imaginative and as fantastic as ever. But today people ascribe a very limited role to science. They continue to talk of the arts and music as culture, but neglect the fact that our view of ourselves and our perception of what our world is like are equally and vitally a part of culture.

Victor Weisskopf calls modern science the "greatest cultural achievement of our time." Isaac Asimov describes the telescope as an instrument that dramatically changed our *cultural* history (emphasis his): "When Galileo looked at the moon with a telescope and saw mountains, craters and 'seas,' that was the final piece of evidence in favor of a plurality of worlds. Earth was not the only object on which life could conceivably exist." The telescope so expanded our view of the universe that "the great man-centered drama of sin-and-redemption, constructed in earlier times, looked puny against the new universe."

Or as Stephen Jay Gould has noted—in this case in reference to Darwin: "Major ideas have remarkably subtle and far-ranging extensions. The inhabitants of a nuclear world should know this perfectly well, but many scientists have yet to get the message."

Last Christmas I took my son to see the show at the Hayden

Planetarium at the Museum of Natural History in New York. It was an excellent opportunity to enjoy some sentimental fruits of science. As the show opened, we looked up at the spotty cover of stars we see every night, surrounded by the bright lights and tall buildings of the city on the horizon. Suddenly the "city lights" went out, and the starry skylights lit up with a splendor that made the audience gasp. I was immediately overwhelmed with a sense of what it must have been like to live on a flat earth under such a lively canopy of stars, where the constellations were as real and as close as mountains and meadows, rather than on a spinning ball floating at the edge of an ordinary galaxy, one of several hundred billion in the universe.

It also reminded me that seeing stars is all a matter of perception. We rarely wonder where the stars spend their days, but turning on the sun has the same effect as turning on the lights in the city: the canopy is there all the time. But like anything else, we can't see it when so much "extraneous information" gets in the way.

The stars are an obvious place to start searching for "sentimental fruits." After all, it was an understanding of the motions of the planets and stars that first plucked people from their center-stage spot in the solar system. Although some people had obviously figured out as far back as the third century B.C. that the earth orbited around the sun (and not vice versa), this wasn't incorporated into the popular culture until well after Copernicus—in the sixteenth century. Conventional wisdom put the earth at the center of things; the universe was here for us. Imagine what that meant for people's sense of destiny, personal responsibility, and awe.

In some ways, however, the things we've learned through science have shown us that the earth is more central than ever—that life is even more precious because of its improbability. Our planet is but a fragment of an exploding star, basking in the light of a second-generation sun; its composition a consequence of a slight contamination by foreign elements in the original hydrogen gas cloud that formed the solar system. In a very real sense, our rocky home is the sediment that sank to the bottom (really the center, but then "down" is always toward the center of the earth) when the lighter elements were blown or boiled away. Animals arose on land only after plants accidentally polluted their environment with

a "poison" (to them) called oxygen. This knowledge has not necessarily made us more or less humble, but it has certainly, says my friend the physicist, "changed the nature of our humility."

A closer look at the cosmos also shows that the seemingly static universe is dizzy with change; even the stars use up their resources, die, and are born again. But the sometimes violent births and deaths of stars, the continual evolution of the universe, was unknown only a few centuries ago. Until the time of Galileo it was simply assumed that the stars we see today are the same stars that existed at the beginning of time, the same stars that would exist forever. The universe—like the status of slaves—was fixed.

At the opposite end of the size scale, the twentieth-century development of quantum theory shattered the notion that atoms behave like billiard balls, and that everything they (and therefore we) do is predetermined. A great deal of uncertainty lies at the heart of atoms; the meaning of a seemingly simple idea like cause and effect turns out to be immensely rich and complicated. But the result is that things today look far more flexible than they did in Newton's clockwork, preset universe.

Charles Darwin's formidable (and in some corners still forbidden) fruit was the knowledge that species, like stars, can change. The forms of life that inhabit the earth are not immutable. We, like the universe, *evolve*. Strict biblical creationists wouldn't be creating such a stir about Darwin if the question of where we came from and what our ancestors looked like wasn't an issue that itself stirred deeply within our souls.

It wasn't until the last century that Darwin for the first time firmly established the scientific basis for a kinship among all living things—a vastly extended family tree. And if Darwin's ideas still remain unacceptable to certain people, it is not because something was wrong with his science. It is rather, says Gould, because of the "radical *philosophical* content" of his theory: "The true Darwinian spirit might salvage our depleted world by denying a favorite theme of Western arrogance—that we are meant to have control and dominion over the earth and its life because we are the loftiest product of a preordained process."

Darwin's theories have been widely misinterpreted to mean that people are the top dogs on the evolutionary tree. But his true point was just the opposite—our intimate connection with all other

forms of life. Gould has devoted many an essay to discrediting those who misuse Darwin in order to justify the dominion of whites over blacks, rich over poor, men over women. All Darwin said was that through evolution all forms of life become well adapted to their particular environment. There was no mention of "higher" or "lower" species.

Naturalist Loren Eisely puts this quite beautifully:

> We today know the result of Darwin's endeavors—the knitting together of the vast web of life until it is seen like the legendary tree of Igdrasil, reaching endlessly up through the dead geological strata with living and related branches still glowing in the sun. Bird is no longer bird but can be made to leap magically backward into reptile; man is hidden in the lemur, lemur in the tree shrew, tree shrew in reptile; reptile is finally precipitated into fish.

Understanding evolution does not lead to the inevitable conclusion that people are but well-bred apes. Rather, it makes us appreciate the care that a million years of adapting to nature has put into fashioning every creature on this planet—including every man, woman, and child. Even more, it makes it impossible to deny the intimate connections between the members of our human species. Young, old, male, female, black, white, Israeli, or Syrian, we are all incredibly similar. Racism and religious wars are both waged under the banner that "other" people are different. Yet "this new insight of science," my friend the physicist says, "has made it much harder to believe that other people are really, fundamentally, different from ourselves."

Even our view of strictly physical forces such as gravity can have a profound effect on the way we view ourselves. Newton blew up a storm in the prevailing cultural winds of the eighteenth century with his Universal Theory of Gravitation not because he "discovered" gravity (everyone knew things fell toward the earth) but because he discovered that gravity was universal. Before him, it was assumed that the laws of nature on earth were fundamentally different from those in the heavens. Newton showed that the fall of the apple and the orbit of the moon were controlled by the *same* forces.

In this sense, the need to go to the moon or smash atoms is on a par with the need to have natural history museums: science provides a handle on who we are and how we fit into the scheme of things. Materialistically speaking, the Apollo landings certainly were a waste. Well-equipped robots could easily have accomplished the same things. But the moon has simply not looked the same since we can look up and say, "Someone was walking around up there." The idea is *emotionally* entrancing—like E.T. The moon shots were *sentimental* journeys. They were important not because they were technologically fruitful, but because they were *awe*-inspiring.

It's the same sense of awe that comes from stargazing or from lying on your back and feeling that you might at any moment fall "down" into outer space, that you are stuck to this earth only by the invisible glue of gravity. Or the feeling that you get when you examine your finger and imagine the unseen activity that goes on inside a single cell—Lilliputian worlds within worlds. It makes you stop and think: to realize that even the hardest rock is almost entirely empty space—a lattice of elusive bundles of energy held together by bits of electric charge; to know that the sky is only as high as the comparative thickness of your condensed breath on a marble. What a thin skin our planet has!

I have a poster on my office wall that shows a spiral galaxy with a large arrow pointing to a middle-sized star on one of the outer rims; words attached to the arrow read, "You Are Here." The small print on the bottom tells me that there are some hundred billion such galaxies in the universe, each containing at least a hundred billion stars.

This kind of information should not leave us feeling that people and their achievements are insignificant. Weisskopf titled his popular book *Knowledge and Wonder* because wonder is every bit as important as knowledge in the attempt to understand nature. "A good society is one which celebrates its own existence," he says. "It's important not to leave all the awe to the religionists." When his students get depressed, he tells them there are two things worth living for: Beethoven and quantum mechanics. What he means is that the beautiful things created by nature and by people are worth our constant respect and admiration (not to mention preservation).

Contemplating our cosmic navels is a good thing if only because it feeds our souls—and a lot better than Tang. The sight of Venus dangling near the crescent moon on a clear night like a diamond earring stirs our emotions in the same way great art does. Recently I sat in box at Lincoln Center and listened to Joan Sutherland sing Lucia, amazed at the emotional impact produced by the subtle stirring of sound waves inside my ear. It was not unlike the feelings people get from looking out over the ocean, or listening to a bird sing, or probing the innards of protons.

I have a friend who likes to ask the following "science" question: How would you hold one hundred tons of water in thin air with no visible means of support? Answer: Build a cloud. What he's saying is no more elaborate than "Gee whiz!"

Understanding our place in the sun requires an understanding of the sun's place in the solar system, the cycles of the sky, the nature of the elements, and the improbabilities of life. If what we learn leaves us a little stunned by our limitations and potentials, so be it. Science gives us a sense of scale and a sense of limits; an appreciation for perspective and a tolerance for ambiguity.

(I'm not saying that science isn't a part of our everyday lives in the ordinary sense, either. If it weren't for the technology that has come from science, I wouldn't be typing on this typewriter;* I would be scrubbing diapers on a washboard instead of covering my baby's bottom with layers of disposable plastic. I feel a little bit guilty about the plastic, of course. I know it pollutes the environment. Perhaps in talking about the fruits of science, we should have three categories: practical fruits, sentimental fruits, and rotten fruits. The rotten ones have the increasingly scary potential to spoil all the rest. But it's undoubtedly easier to fight back against their dangers with knowledge rather than ignorance. In any event, the understanding of the nucleus doesn't build the nuclear bomb.)

Nobel laureate Steven Weinberg concluded his account of the First Three Minutes in the life of the universe with a curious statement: "The effort to understand the universe," he wrote, "is one of the very few things that lifts human life a little above the level of farce and gives it some of the grace of tragedy."

I prefer a more positive version of the same sentiment that

*Actually, the typing of this manuscript finally compelled me to buy a computer.

came from Robert Wilson—the sculptor and physicist who built the giant atom smasher at the Fermi National Accelerator Laboratory near Chicago. He expressed it in response to the continual questions of a senator who demanded to know what probing protons had to do with the national defense:

"Is there anything connected in the hopes of this accelerator that in any way involves the security of the country?" asked the senator.

"No, sir, I do not believe so," responded Dr. Wilson.

"It has no value in that respect?" asked the senator again.

"It only has to do with the respect with which we regard one another, the dignity of people, our love of culture. It has to do with these things: Are we good painters, good sculptors, great poets? I mean all the things that we really venerate and honor in our country and are patriotic about.

"In that sense, this new knowledge has all to do with honor and country but it has nothing to do directly with defending our country—except to help make it worth defending."