Time for the Stars

More than once in the past decade, I've been drawn into a heated discussion over the vast sums being budgeted toward a military defense in space. Much of this money has been suddenly offered to the scientific community. Should it be accepted? For me, in addition to the ethical and practical questions, this raises the issue of applied science versus pure science.

I am worried that our country has become increasingly shortsighted to the value of pure science. One recent example was the court-ordered breakup of American Telegraph and Telephone, leaving its basic research group, Bell Laboratories, in a vulnerable spot. Another was the congressional veto of a relatively cheap exploratory mission to Halley's Comet, which visits the solar system only once in a lifetime. Certainly, few

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people would deny the material comforts, the economic advantages, the power to make war or peace that applied science brings. But in pursuing these other goals, we have paid less and less attention to the value of science for its own sake.

Our national preoccupation with applications goes back to the cultural and political origins of our country. In Europe, science was traditionally considered a part of culture, and a person could devote his life to science as a gentleman and a scholar. Isaac Newton, as a fellow of Cambridge University, needed no justification for his studies of physics. Carl Friedrich Gauss, who made brilliant contributions to mathematics and astronomy in the early nineteenth century, was supported through the patronage of the duke of Brunswick. In contrast, when science got under way in America, in the middle 1800s, the democratic ideals of our young country demanded a direct accounting to the people, a direct benefit to society. Scientific research was usually supported only if it was part of a practical or technical enterprise, like the U.S. Weather Service, founded in 1870, the U.S. Geological Survey, founded in 1879, or the National Bureau of Standards, founded in 1901. Gradually, our nation began to take pride in and identify with its technological achievements (which exclude pure science by definition). The American hero of science is Thomas Edison, not Willard Gibbs, who made fundamental contributions to the theory of heat. During World War I, even the great physicist Robert Millikan said that "if the science men of the country are going to be of any use to her, it is now or never." Since World War II, of course, our coun-

try and all countries have been keenly aware that military might can be achieved through science.

Also since World War II, science has become a big business. In many areas of science, the romantic days of the lone scientist, uncovering the secrets of nature with homemade equipment, are gone. Experiments today often require large teams of scientists, large budgets, and large bureaucracies to manage them. Some of these operations could not be mounted unless they utilized the existing military-industrial complex. And the pace of society in general has quickened. Under constant pressures, we grasp for the short-term payoff.

Why should our nation, or any nation, support pure science? Why should a nation pay for an activity that brings it no clear economic or military advantage? Why should a nation support an activity that seems *useless*?

It seems to me that pure science has several different values. In order of increasing range into the future, pure science entertains us, it provides the soil from which technology grows, it changes our worldview, and it grants us cultural immortality.

On an immediate, day-by-day basis, learning new things pleases us, and there is no doubt that we learn from pure science. Furthermore, what we learn is "true," it concerns the real world, and it can be understood in broad terms by every intelligent person. Nonscientists are entertained by learning what comets are made of, just as they are entertained by seeing a new Neil Simon play or reading a new book by Gabriel García Márquez. Everyone is a potential consumer of pure science. If pure science cannot pay for itself in the marketplace, as movies and books do, it is perhaps because its pleasures lie in knowledge. Still, this knowledge brings a special kind of happiness, and the happiness of a nation's people counts for something.

Pure science may seem useless in the usual sense, but over a long period of time it surely leads to economic and technological benefits. If we stop paying for pure science today, there will be no applied science tomorrow. Darwin's work on evolution and Mendel's on the heredity of plants laid the foundations for the science of genetics, which eventually led to the discovery of DNA, which led to genetic engineering, which is now exploding with unimaginable applications. Faraday's discovery of how a magnet can produce electricity made possible the first hydroelectric power plant, fifty years later. Yet Darwin and Mendel and Faraday were not supported with any such profits in mind, nor could they have been. A nation cannot bet on pure scientists like betting on horses. It can, however, build stables. I remember a Robert Heinlein novel about a research outfit called The Long Range Foundation. The Long Range Foundation was chartered as a nonprofit corporation, dedicated to future generations. Its coat of arms read "Bread Upon the Waters," and it prided itself in funding only scientific projects whose prospective results lay at least two centuries away. It was happy to waste money. Unfortunately, the directors could never do their job right, and the foundation's most preposterous projects quickly began piling up embarrassingly large profits.

The third value I mentioned is the ability to change our worldview. This quality is often subtle, but its importance cannot be overestimated. I think Henry Adams understood the value of pure science when he wrote, in the early 1900s, that Madame Curie's discovery of radioactivity suddenly made the unknowable known. Since ancient times, Western man had worshiped this ultimate material unit called the atom—indestructible, impenetrable, exquisitely unfathomable. Then, at the end of the last century, Madame Curie found that atoms of radium hurled out tiny pieces of themselves, and our view of nature would never be the same again.

It might be helpful to give a couple of examples of this in more detail. I will choose from astronomy, which is the most useless science I know and my personal profession. Actually, astronomy was once highly practical. Early civilizations used it for tracking the seasons, planting crops, and navigation. Since then, astronomy has advanced to its present condition.

As a first example, consider Kepler's discovery that the orbits of the planets are elliptical. Before Kepler, there was universal agreement, dating back many centuries, that the orbits of heavenly bodies were circular. To defer to Aristotle, whose opinions on many things molded the Western worldview, the circle was the natural figure for heavenly motions because of its uniqueness and perfection. Only circular orbits were proper for the divine and eternal planets. In fact, Aristotle arranged the entire cosmos in a sequence of rotating spheres, centered on the Earth. Once nominated, the circle showed great staying power. When people later noticed that the planets changed in brightness—and hence distance from Earth—during their orbits, astronomers invented an elaborate set of circles upon circles, whereby each planet performed a small circular orbit about an imaginary point that itself traveled in a large circular orbit about the Earth. Even Copernicus, who demolished the idea of an Earth-centered cosmos, clung to the idea of circular orbits.

Kepler had the good fortune of being the student of Tycho Brahe, a wealthy Danish astronomer who spent night after night observing the planets from his private island. Brahe's naked-eye reckonings of planetary positions were the most accurate ever taken. Kepler inherited this gold mine of data around 1600. His job was to make sense of it. In addition to having good material to work with, Kepler owed his success to two other factors: he was a dedicated Copernican, and he believed in the Platonist ideal that nature follows mathematically simple laws. What were the laws governing the motions of the planets? What were the shapes of the orbits? Kepler struggled with countless trial orbits of compounded circles. Eventually, he was forced to admit that they just wouldn't fit Brahe's data. Then he discovered ellipses. (Every artist knows the ellipse; it is a foreshortened circle.) One ellipse for each planetary orbit was also much simpler than two circles. The sacred circle had been replaced by the accurate and economical ellipse.

Kepler's success gave strong support to the Copernican system, in which the Earth is simply another planet, orbiting the sun. We know that Newton, as a student, studied Kepler.

When Newton presented his incomparable *Principia* to the Royal Society in London, it was introduced as a mathematical demonstration of the Copernican hypothesis as proposed by Kepler. Newton's *Principia* in turn, with its laws of motion and gravity and its unflagging application of these laws to pendulums and planets, provided a firm scientific foundation for Descartes' view of the universe as a giant mechanical clock. After Kepler and Galileo and Newton, nature became rational.

My second example of how pure science changes our worldview is the fairly recent discovery that the universe is expanding. The galaxies are flying away from each other. When this observed motion is mentally played backward in time, the galaxies crowd closer and closer, stars and planets and even atoms are squeezed together and disrupted, until, some ten billion years ago by the best estimates, the entire contents of the now-visible universe were compressed to a size smaller than an atom. That was the beginning of the universe. It is called the Big Bang.

Virtually every culture in recorded history has had its myths about the origin of the universe and when that origin occurred. Many have believed in no origin at all. Aristotle, for instance, gave numerous philosophical arguments why the universe had to be unchanging and everlasting. One of his arguments went something like this: If the universe had a beginning at some finite time in the past, then there would have been an infinite time before that when the universe did not exist, but had the potential for existing. However, the nonexistent universe could not have slumbered for an infinite time in such a state of pure potentiality. Therefore, the universe has always existed in its present state of perfect composure. Isaac Newton arrived at a similar conclusion by a somewhat more scientific (but still erroneous) approach. Newton argued that if the universe were expanding or contracting, there would have to be a center about which such motion took place. In an infinite space, however, no position in the universe should be so privileged. Therefore, the universe must be always at rest.

The discovery of what the universe is actually doing came in the 1920s. Using a large telescope and various instruments, the astronomer Edwin Hubble was able to determine that other galaxies are moving away from our galaxy, with speeds proportional to their distances. The closer galaxies are retreating from us more slowly than the farther ones. This is exactly the situation for dots painted on the surface of an expanding balloon. From the vantage of each dot, representing a galaxy, it appears that the other dots are moving radially away from it, with speeds proportional to their distances. The view is the same from any dot, and no dot is the center. That was Newton's mistake. Newton didn't realize that expansion could occur about *every* point in space. He didn't have the right picture in his mind. He also didn't have much equipment. I think that if Newton were here now, or Aristotle, or Moses Maimonides, or Francis Bacon, they would sit still for a lecture on the origin and motion of the universe.

It is too early to know the consequences of our discovery

that the universe is expanding. There is no doubt, however, that our worldview has been changed. One sign is that Einstein insisted at first on a static universe—even when his own cosmological equations naturally predicted a universe in motion. For centuries before Hubble, the majestic tranquility of the heavens symbolized the eternal and the immutable. That soothing symbol is now gone.

One can list many other discoveries that are too new to judge. What are the consequences of learning that time flows at a variable rate, depending on the motion of the clock, or that all life forms on Earth get their blueprints from the same four molecules? I don't know, but I am certain that these recent discoveries have begun to seep through our culture and alter our thinking.

Discoveries in pure science are not just about nature. They are about people as well. After Copernicus, we have taken a more humble view of our place in the cosmos. After Darwin, we have recognized new relatives hanging from the family tree. We need to be periodically shaken up. We need periodically to break free from the endless cycle of one generation passing dimly into the next, one human lifetime after another. We got stuck some centuries back, and it was called the Dark Ages. Changing our worldview helps us break free.

I come now to cultural immortality, which, of course, transcends individual nations. To quote Thoreau:

> In accumulating property for ourselves or our posterity, in founding a family or a state, or acquiring fame

> even, we are mortal; but in dealing with truth we are immortal, and need fear no change or accident.

Pure science deals with truth, and there is no greater gift we can pass to our descendants. Truth never goes out of style. Hundreds of years from now, when automobiles bore us, we will still treasure the discoveries of Kepler and Einstein, along with the plays of Shakespeare and the symphonies of Beethoven. The civilization of ancient Greece has vanished, but not the Pythagorean theorem.

Some years ago, I went to Font-de-Gaume, a prehistoric cave in France. The walls inside are adorned with Cro-Magnon paintings done fifteen thousand years ago, graceful drawings of horses and bison and reindeer. One particular painting I remember vividly. Two reindeer face each other, antlers touching. The two figures are perfect, and a single loose flowing line joins them both, blending them into one. The light was dim, and the colors had faded some, but I was spellbound. If our civilization can leave something like that for posterity, it will be worth every penny.