The Power and Poverty of Science

Stanley L. Jaki

Today the name of Vannevar Bush may mean very little. Only half a century ago he was the captain of an American science that had just proved itself an unparalleled source of power in a global contestation. Yet even he greatly underestimated that power when in 1950 he declared that transcontinental ballistic missiles were mere wishful thinking. Within ten years rockets began to carry man around the Earth. In still another decade man landed on the Moon. A manned exploration of Mars may not be too far away.

A hundred years ago it was still not unscientific to dismiss talk about atoms as needless theorizing. Yet Ernest Rutherford, who shortly afterwards did more than anyone else to unveil the structure of atoms, scoffed, as late as 1934, at the idea that man would ever harness the awesome power of atomic energy. Within a decade the first atomic bombs provided the power to end a devastatingly vast war already in its fifth year that conceivably might have dragged on for another year and could have claimed another million or so victims.

By then radar proved itself indispensable to decide the issue of the war in Europe, a fact that quickly became known. For years nothing was disclosed about another crucial fact, the breaking of the German secret code, made possible in part by reliance on a device which at that time was not even known under its present name, computer. Computers were still unwieldy monsters filling entire rooms and had to be cooled by large refrigeration units. Worse, dozens of electron tubes were breaking down in those "calculating machines" every day, often stopping their operation. Today, computers far more powerful than the one used for landing on the Moon can be put in a briefcase.

Compared with these feats, utterly trivial should appear any reference to automobiles and airplanes, both of which made their debut about a hundred years ago.

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Within a few decades Henry Ford put America on wheels and the world quickly followed suit. The Parisian taxis that in October 1914 rushed the needed reserve units to the Marne anticipated history. Military trucks made possible the quick outflanking of the Iraqi defenses and were in turn supported by incredibly sophisticated machines known as Stealth bombers, Patriot missiles, and satellite communication systems.

Iraq merely played the role of proxy for a now defunct Soviet Union that failed to understand and utilize the power of science to the full, in spite of swearing by a so-called "scientific" philosophy. Ironically for the dialectical materialism institutionalized in the Soviet Union, the tools of production made by science determined the course of history. The Soviets were still building steel mills when the West was already shifting to factories pouring out plastics. The Soviet Defense ministry still did not have a computer in each of its offices when in America computers began to appear in high schools.

Whatever the stakes for democracy in the Desert War, it was certainly about the Middle East oil whose control largely determines the global struggle for markets. Oil is a basic source for the enormous variety of items with fantastic properties which a new branch of science, materials science, delivers at a breathtaking pace, almost to order. Herein lies the source of the power which science displays in the field of economics. The freedom and vigor of that economics, which is a free-market economics, depend not only on the value of freedom as an ideological commodity, but also on the profuse availability of items to be marketed.

Among those items are products indispensable for the improvement of daily life, such as a variety of foodstuffs undreamed-of a century ago. The same is true about the maintenance of health through the expansion of medical skill and care, which represents the largest market of them all. This indispensability of science for economics has increased at an accelerated rate during the last three or four decades. Herein lies a still not fully appreciated facet of neocapitalism, best known for the rapid rise of its main indexes, among them the Dow-Jones industrial average. The latter stood at 155 in January 1927. Almost 20 years later it was still at that level. But during the next 25 years it increased fourfold, from 165 in June 1945 to 650 in June 1970. During the next 20 years, it increased sixfold, standing as it did at 4000 in October 1994.

Since then it increased, on the average, by more than a thousand each year. Tellingly, as even the layman had to learn, the so called tech-stocks fueled this unique growth in the history of the stock market.

Parallel to this rise, and preceding it by about 20 to 30 years, there has been a similarly accelerated rate of growth in the number of scientists, especially in what has become known as the developed part of the world.[1] The temporal priority has been a causal priority as well, as can easily be seen by a cursory look at the reliance on science by major industrial firms. Investment is increasingly governed by new opportunities offered by scientific inventions.

Herein lies a reason for the huge difference between classical capitalism and neocapitalism. The former stretched through times during which the progress of science and industry may seem stagnant in comparison with their rate of growth during the last 70, and certainly the last fifty years. The dynamics of neocapitalism is due largely to its ever closer alliance with that power which science has become in modern life. The rapid growth of shareholders is not so much a cause as a symptom of the vigor of neocapitalism and its free market economies. That vigor is manifest in the accelerated rate at which science delivers to the market ever new and ever more exciting products. For whatever is new will be bought—an almost foolproof rule that guides the art of advertising. Yet, it is not the advertising skills but the skills of science that provide those novelties and do it at a rate inconceivable 50, let alone 100 years ago.

It should therefore be worthwhile to search for the true source of this awesome power tied to science. One certainly touches the deepest source of that power by echoing the words of a Nobel-laureate physicist, P. W. Bridgman, who defined the method of science as "doing one's damnedest with one's intellect." Undoubtedly the intellect, the human mind, is the deepest reality of which one has a direct evidence. Yet it would be strange to claim that only scientists are doing justice to the seemingly inexhaustible capabilities of the human mind. The one who first drew figures of animals with a piece of charcoal, and did it wearing animal skins, relied on the mind's symbol-making ability that sets man apart from the brutes. Was it not the greatest feat in intellectual history when the various sounds of human speech were generalized as a set of visual figures?

One should, however, be reluctant to characterize as science either of these two extraordinary achievements of symbolization and generalization. This reluctance is instinctive as well as correct. Although no one would dispute that science is symbol-making and generalization, science is clearly such in a very special sense that makes it different from all other ways of making symbols and generalizing. It should seem obvious that cogitation is science only insofar as it involves quantities. The impression that one has thereby expressed something very profound can be disputed all the more easily because quantities lie at the very surface of everything available to the senses in any form.

Everything sensible has some magnitude, or size. It is through its size, or magnitude, that every thing is perceived in the first place. Although this was observed by Aristotle over two millennia ago, its validity remains unshaken regardless of its age and Aristotelian provenance. Again, just because Aristotle stated it, and emphatically so, one need not doubt the primary position of quantities among all categories of human conceptualization. He might have been more detailed in noting that insofar as human perception registers first the size of things, human perception measures them at least implicitly. For to note the size of something, however broadly, is to compare it to some arbitrary unit of length, or area, or volume, a unit equivalent to a quantity.

Long after Aristotle, as science began to emerge as we know it today, it proved itself to be in a sense nothing else but a registering and correlating of quantitative properties displayed by the objects available, directly or indirectly, to our sensory perception. And since quantities are everywhere, science is universal. This universality should seem to be a source of the unparalleled applicability of science and therefore of its power. Further, since quantities are the same across all space and time, from them there accrues to science a uniformity which is not matched by any other field of human inquiry.

The power which this uniformity gives to science displays itself in its predictive power, again a unique property of science. Predictions made by historians remain mere guesses, however educated. This is why nobody would call history an exact science, except perhaps those historians who think, for instance, that we know nothing really about the causes of the

American Civil War until we have fed into a computer all the votes cast by members of the Congress during the previous 30 or so years. One need not subject to computer analysis the sundry opinions of physicists to be convinced that the predictions of physics are exact. But they are exact only because they deal exclusively with quantities, which in turn have an exactness unique to them. This is what assures to science a unique control over things.

This control did not, of course, take on from the start the measure to which we are now accustomed. The moon, the sun, and the planets were not controlled just because Ptolemaic astronomy allowed an exact prediction of their position. In that respect, the first form of Copernican astronomy was not an improvement on Ptolemy's geocentric ordering of the planets. But a control it was in the sense that it liberated man from considering the celestial bodies to be under the control of mysterious forces and man himself to be under such control. Science, or the quantitative analysis of the motion of bodies across space and time, has not ceased revealing its power to liberate man from thinking that mere matter had a mysterious hold on him and that it could be manipulated only by magic, be it called astrology and alchemy.

In gaining control over things in motion, the first major step consisted in Galileo's development of the medieval idea of uniformly difform (accelerated) motion as evidenced by the free fall of bodies on the surface of the earth. From there it was one step, though a step worthy of Newton's genius, to his formulation of the third law of motion, a part of his broader theory of motion in a central field of force. This made possible a wide variety of predictions about arcane celestial motions, such as the liberation of the moon, as well as the return of the comets. Halley himself celebrated this latter feat of Newtonian physics as one that liberated man from seeing in comets irrational hidden forces operating in nature.

With Newton all became light, or so at least his younger contemporaries thought, who rightly felt very much enlightened through the power of Newton's physics. They were, at the same time, as was Newton himself, very much blinded by the new light. A supreme irony lay in the fact that Newton's third law, according to which force is proportional to the product of mass and acceleration, left him and all scientists in a conceptual quandary. At that time Bishop Berkeley appeared to be a useless gadfly when he pointed out to the Newtonians their inability to go straight from the mathematical formula for what they called force to the idea and reality of the force itself.

For a while little attention was paid to this by most scientists and philosophers. The rush for control advanced apace and left little room for other considerations. Lavoisier saw his achievements in chemistry as something equal to those of Newton's. The isolation of oxygen as a true element certainly ushered in previously unsuspected powers of science. Organic chemistry soon opened its first chapter with the artificial production of urea. Today, parts of biology (it should be enough to think of the double helix structure of DNA molecules and the genome project) match the exactness of physics as well as its awesome powers. That power of science, let it not be forgotten, is tied to its ability to register, measure, correlate, and verify quantities. Quantitative specifications alone secure that procedure.

Physics itself, this paragon of exactness in science, kept extending its range. The 19th century witnessed the rise of physical optics, of thermodynamics, and last but not least of electromagnetism and electrodynamics. Atomic physics, nuclear physics, particle physics, plasma physics are but the principal names of new areas (and new powers) of the exact sciences. They are exact because they can specify quantitatively the criteria of the truth of their conclusions. For it is always those quantitative specifications that are the object of the experimental verification of scientific theories. Or as Einstein once remarked: If only one of the consequences of the theory of general relativity is disproved by experiment, the entire theory ought to be discarded.

Some time before this, towards the end of the 19th century, some physicists, who wanted to see to the bottom of things, began to be deeply puzzled by the success of their theories. Some of them concluded that there were only quantitative relations but no entities such as force. They are still to make sense of the fact that the relations useful in science are purely quantitative relations, yet those relations obviously do not make up the whole of physical reality. Were they to appreciate this fully, it would dawn on them that the marvelous power of science is also its dire poverty. This is still to be suspected by most non-scientists overawed by the power of science.

Actually, scientists themselves, and here I mean especially physicists, who cultivate the most exact branch of science, physics, still find the very idea of scientific theory slipping through their scientific fingers. Their inability to articulate this received its classic expression a hundred years ago from Heinrich Hertz, who verified experimentally the existence of electromagnetic waves as predicted by Maxwell's theory. After having given much thought to what it was he had discovered, Hertz seems to have thrown up his arms as he wrote: "Maxwell's theory is Maxwell's system of equations."

No phrase tells more, in such a concise way, of the power and poverty of science, and of the fact that the two go together. For Maxwell's theory, no less than Newton's theory or Einstein's theory, can be compared to a huge architectural structure which is totally useless in a most important sense: From the structure itself one cannot infer what it is related to in the great world of material reality. One need not be a theoretical physicist to perceive this. It is enough to recall that the same inverse square allows one to predict the variations of attraction between any two pieces of matter, as well as between any two bodies on which free electrical charges have been produced by rubbing them. The quantitative relations of attraction in both cases are exactly the same. But knowing only those quantitative relations, one would not know whether one deals with electrical or with gravitational attraction, much less would one know what gravitation is and what electricity is.

Other cases of this intrinsic irrelevance of the equations of physics to the nature of material reality could be listed to no end. The Fourier equations are useful to handle the quantitative parameters of a great variety of effects propagated in a physical medium, be it gas, fluid or solid. The so-called Mathieu equation can handle equally well the balancing act of an acrobat standing on the top of a sphere and the vibrations of a distended surface such as a drum. But in spite of their equality in some quantitative aspects, who would doubt that the two realities are not the same at all?

In sum, it is not quantitative relations that give physical meaning to physical science, but some clearly non-quantitative perceptions, judgments, and conclusions. All these are heavily present as the edifice of a scientific theory begins to be erected. One may consider all those judgments, conclusions, assumptions, and premises as the scaffolding without which no edifice can be raised. The wider is the bearing a physical theory wants to achieve, the more such scaffolding it needs. But once the physical theory in its mathematical form is in place, the scaffolding can go. And so it does. Maxwell started formulating his theory with speculations about rods, pulleys, and rubber bands to visualize for himself the transmission of electromagnetic forces through the dielectric. But once he had formulated his famous equations, there was no longer any need for those mechanical props, although they seemed to tie those equations to reality. Maxwell's theory revealed itself to be nothing more (and nothing less) than Maxwell's system of equations, in itself a pure mathematical formalism.

The fact is that once the mathematical formalism is in place, the scaffolding is not so much removed as detached by itself from the edifice as something utterly irrelevant for the purpose it was meant to serve. This still leaves unanswered the question about the true nature of the edifice, left in its splendid isolation, so to speak. Is it a physical edifice? Not at all. In fact, hardly an edifice in the ordinary sense of that word. Equations are a set of numbers, or rather numbers or quantities that are to replace any letter of the alphabet that occurs in those equations. Only then do those equations perform the function proper to them, that is, yield quantitatively exact results that are also predictive about similarly quantitative features of a physical reality. But of that physical reality those equations contain nothing at all. They do not even touch upon it directly.

A similar story can be told about Bohr's formula to calculate and predict radiations emitted by the hydrogen atom. The formula, which seemed to have a magic power in dealing with physical reality, revealed more and more of that magic as it became generalized, first through Heisenberg's matrix mechanics and then through Schrödinger's wave mechanics. The physicist felt less and less the need to be concerned about the scaffolding (a largely philosophical commodity) than about the edifice itself. But the paradox of riches versus poverty could not be evaded. In fact, it looms large except for physicists who instinctively adopt positions once held by Pythagoreans and Platonists without suspecting their untenability. The physicist, for whom philosophy is usually bunk, may not even care to cover up his philosophical nakedness by invoking the name of this or that major philosopher. He merely compounds nakedness with fallacies, such as when he suggests, on the basis of purely mathematical statistics, that events ontologically happen though without a cause. The marvelous mathematical edifice of quantum mechanics is full of the ghosts of this fallacy.

The physicist will not do much better by invoking the name of Plato and of his theory of ideas. Just to invoke Plato is not equivalent to proving that geometrical figures and other quantitative relations exist outside the mind, and much less that they give rise to material reality. Only a proof of this would turn the poverty of exact science into a philosophical cornucopia out of which reality pours forth. In the absence of such a proof, which is a task for philosophy and not for mathematics, the poverty of science remains total: Its exact formulas and measurements remain in themselves mere numbers, devoid of any physical reality. To his philosophical discredit the physicist may attribute a metaphysical existence to numbers and formulas, but that existence remains locked up in a conceptual stratosphere separate from physical reality, the reality which alone ought to be of final interest for science.

There is no point in reifying, in a Platonist mood, reference systems, such as the ones that are accelerated with respect to one another. One must have on hand real bodies in order to make the mathematical formalism of Einstein's general theory of relativity meaningful for physics. There is no point in discarding the very physical ether of Newtonian physics and then replacing it furtively with a field, first a mere formalism and then full of physical energy, disguised as zero-point oscillations in the vacuum. The clever use of new words does not resolve age-old, nagging problems. The problem is that physical content cannot be obtained from mathematical equations alone, however successful. Poverty can never supply the commodities it lacks.

That poverty, or the mathematical formalism of exact science, cannot even secure its own ultimate certainty, whatever its astonishing power in dealing with the physical world. The day may, of course, come when physical theory will find, for the moment, nothing in the physical world that presents a problem to it. Such an expectation is certainly obligatory for anyone who holds that God "arranged everything according to measure, number, and weight" (Sirach 11:20) and that he made man in His image, endowing him thereby with a mental ability to see precisely that arrangement. Apart from this one can entertain such an expectation with an eye on the acceleratedly growing range of the applicability of mathematical physics. It would, naturally, be foolish to think that just because unexplained phenomena have for the moment stopped flowing into the ken of the physicist in possession of a presumably ultimate theory, they will never do it again. Yet the physicist can never be certain that his ultimate theory is truly such. As long as Gödel's incompleteness theory is valid, such certainty is denied to the physicist.

For those who cannot follow the steps that led Gödel to his epoch-making conclusion, there is a far simpler pointer to the radical poverty of exact science. Everyone may sense something dramatic in the plain phrase, science cannot handle even the multiplication table singlehanded, since no less a physicist than Eddington uttered it. The truth of that phrase should be obvious to anyone who reflects on an elementary fact: basic mathematical operators signified by + − x and ÷ must be explained in words in order to know what to do with them. Even numbers themselves must be explained in words. Not only have the numbers from 1 to 9 been written down in a great variety of ways, but even greater is the variety of the words in countless different languages that can stand for them. Nor can 0, a sign clearly of something, stand for nothing, unless one decides with words that it should stand for literally nothing.

All this should be plainly evident, but perhaps more convincing if confirmed from the mouth of a prominent mathematician, Hermann Weyl. He warned that in mathematics one must have directives given in words in order to understand "how to handle the symbols and formulae."[2] Indeed, without any reference to religion, it should be clear that in the beginning was the word, even if only that kind of word which is man's articulation of the fact that knowledge begins with registering external reality. Science is subject to this rule as long as it does not want to be divorced from experiments performed with real instruments about a real world. This may seem a mere quibble except to those stunned by some prominent quantum cosmologists' claim that they can produce entire universes by concentrating their consciousness on the wave functions corresponding to those universes. They brazenly think that thereby those functions would "collapse" into reality. One wonders why those physicists do not experiment with creating silver dollars, let alone heaps of them, by letting some wave functions collapse as they think hard about them. By thinking hard on the problem of gravitation, Newton had no such inane cogitation in mind.

The words, let it be repeated, without which mathematics cannot make its very first steps, are not numbers. They, and the immense majority of words, constitute a class of their own. To illustrate this difference, let the meaning of an integer, say 1, be represented by a square. The appropriateness of such a representation should seem obvious, because just as a square, the number 1, as do other integers, denotes something well defined, that is, precisely circumscribed. Such a number can be neither more nor less than what it is. The adding of integers, which results in a strictly defined quantity, would then be readily illustrated by the precise contours of the juxtaposition of squares. This preciseness prevails throughout the realm of numbers and of geometrical figures even though, such as in the case of irrational and imaginary numbers, the exactness cannot be calculated in a definitive way.

Suppose one tries to represent in a similar way the meaning of other words, say, the word *politics*. The dictionary defines it as "the art or science of government." Clearly, the meaning included in this definition cannot be strictly circumscribed, that is, defined. If one tries to represent the extent of the meaning by an area, it cannot have a clear line for its boundary. *Politics* has a meaning which can include more or less, as almost all words do, except numbers. This indefiniteness becomes even more pronounced when one tries to compose the meaning of the word *politics* from the partial superimposition of the three words used for its definition. The word *art* has a meaning which is anything but definite. The same is true even of *science* and of *government*. The meaning of each of these three words would be represented by an area with no strict contours. Their partial superimposition can only increase the measure of that indefiniteness. Clearly, the extent of the meaning of most words resembles not a block but a patch of fog. Worse, the shape of those patches, without strict contours, is forever changing as if they were so many amoebas. In fact they have less definiteness than amoebas do. For unlike amoebas that are enclosed within a membrane, patches of fog appear to have edges only from a distance. One hardly ever knows the moment when one begins to be enveloped by a cloud.

In fact even words that denote strictly circumscribed entities will not reveal a definiteness when a close look is taken at the definition. A good illustration of this is the word *block*. Leaving aside the problem posed by the fact that any better dictionary would list over a dozen different meanings to that word, enough problems remain in its most obvious meaning, "a solid piece, as of wood, with one or more flat sides." The words *one or more* by themselves exclude definiteness. But even the word *solid* does not lend itself to a unique meaning. There is no way of deciding where solidity begins and ends.

It is this indefiniteness, so different from the definiteness of numbers, that sets the exact sciences apart from all other areas of discourse, called humanities, including religion and theology. The difference is the one between what can and what cannot be measured, or the difference between the metric and the non-metric, the quantitative and the non-quantitative. The difference assures to science both its precision and exactness but also reveals its dire poverty. Science is about quantities because it has to measure, and unless science measures, it runs the risk of becoming a science-coated pseudo-humanistic discipline. This, it should be noted, is all too often the case with far-flung dicta of evolutionary biologists. In measuring, science obtains its precision, but also reveals its penury with respect to anything else except quantities. The humanities may appear woefully inexact in their conclusions as compared with the numerical exactness of science, but the inexactness, if handled wisely, assures them of untold riches.

That properly wise handling begins with the assertion of reality, external, physical reality. It is a philosophical step, whether one likes philosophy or not. Although it is a logical step, it is not a step of logic. While the relation between the object and the subject (the known and the knower) cannot be constrained within the cubbyholes of logic, it remains a supremely rational facet. The registering of reality is not a scientific step either, even though through its quantitative aspects one registers physical reality. This is a philosophical starting point towards the quantitative account of the quantitative aspects of things in motion, which is physics, the most exact of all sciences. To register reality is also the first step towards any other forms or levels of reality, unless one fancies reasoning to be a continual hanging in mid-air, or one resigns oneself to be a solipsist, muttering to oneself idealist flights of fancy.

There is nothing inexact in the act of registering reality through its immediately perceived quantitative aspect. What is registered is the reality of a thing with extension, its very existence, without measuring it with any precision. Such a grasp of reality can justly be called *exact* because this word also denotes strict and incomplete accordance with a fact. For unless this direct tie of man with reality is not doubted or undermined, there remains no real content whatever to the edifice or structure of exact science. This apparent inexactness of philosophy or of the humanities in general is the key to the enormous richness of reality, of which nothing is higher and more important than religion.

This is a point of the utmost importance for a sane and fruitful understanding of the relation between religion and science. Nothing is more dispiriting indeed than to see theologians begging from science for morsels of certainty and for tidbits of approval. It is the sight of the impoverished rich begging for sustenance from the have-nots. In a sense one can understand those rich, though they also deserve a goodly dose of pity. For that begging is a symptom of the fact that nowadays only such items seem to be approved and successfully marketed that are wrapped in copious references either to sex, or to sport, or to science, the three s's of an increasingly wayward culture.

In such a culture there may be some justification for listing scientists who are also believers in God. Scoffers at religion who shore up their shallowness with copious references to science may be momentarily stopped in their tracks with a reference to such a list.[3] There is a perennial effectiveness in the argument called *solvitur ambulando*. But to give too much importance to such a list may mislead those whom it is meant to serve. They should not derive more from that list than a momentary respite in a patently hostile cultural ambiance, which everywhere in the developed world, that is, in a world developed by science, is rapidly shedding the last remnants of its religious heritage.

That world is not, of course, averse to claiming some religiosity. But what it wants in the form of religion is some higher form of aestheticism. Within such religion there is no personal God to worship, no God who can and does give a revelation, and proves that revelation by miracles, precisely because it sets a choice between heaven and hell and does so with no apologies to man, ancient or modern, scientific or not. No wonder that spokesmen of an aesthetically desensitized "revelation" feel utterly uncertain about themselves and seek solace and support from what they believe to be science, but what is actually a philosophical misrepresentation of it. In that misrepresentation of it, science has only power but no poverty. It is made to look like an edifice bursting with all the choice commodities, although it is a bare shell of purely quantitative correlations. One would look there in vain for anything that gives to man a sense of purpose, let alone a purpose that abides beyond death, for anything that can qualify as moral value.

This may sound sacrilegious to the high priests, some of them in clergymen's clothing, of that science-coated religion which may best be called higher aestheticism.[4] If this vignette reminds one of higher criticism, which has always been a rationalist mysticism, so much the better for the sake of clarity. Higher aestheticism is indeed the logical offspring of higher criticism. Let its high priests remind themselves of Einstein's admission, made in old age, that he had not all his life derived a drop of ethical value from science. Let them remind themselves of the guideline, "never use the words higher or lower," which Darwin, the evolutionist, set to himself, although he honored it in the breach.[5] Let them also awaken themselves to the fallacy of the pabulum which Einstein dangled before some men of religion: science without religion is lame, religion without science is blind.

The fallacy will not be noticed until one has his eyes opened to the principle that religion is not about *how* the heavens go, but *how* to go to heaven. The difference between these two *hows* is the difference between quantities and everything else, the difference between the power and the poverty of science, or conversely, the difference between a religion that has something to offer which science utterly lacks in its radical poverty, and a religion that, once it has divested itself of its riches, begs science for placebos of wealth.

Once that difference has been noticed, duly pondered, and thoroughly assimilated into one's mental awareness, the proper relation between science and religion may be perceived, provided, of course, that one has the courage to spell out the basic dictates and principal ramifications of one's religion. In fact something even less may do, speaking *in abstracto*. This 'less' simply demands that one should have the utter readiness to submit to the arbitration of science anything in one's religious assertions that implies something quantitative about external physical reality. This is the price a man of religion has to pay to science, while denying to science competence about anything which is not quantitative.

The price should be rigorously paid, with not a penny withheld from the bargain, if the man of religion is to hope reasonably for peaceful coexistence between science and religion. Of course, the other side, the scientific side, also should be willing to strike that deal which is far from being certain. The fantastic success of science with quantities has misled quite a few scientists, indeed, the majority of the scientific establishment, into believing that science is the only kind of knowledge worth having. In that misguided belief of theirs they all too often let a great many non-scientific, plainly philosophical and ethical principles ride piggyback on science, without being ready to acknowledge it.

With this reservation in mind the man of religion may hope for a peaceful coexistence with science provided he does not let science overstep the limits of its competence. He must not hope for a harmony, which implies some integration, let alone for some higher fusion. Religion and science are about two different *hows* that are conceptually irreducible to one another. Man may chafe about this irreducibility, but one cannot change it. Undoubtedly in God's mind there is a conceptual continuum from quantities to values and back, but this is his secret. For man the only sane option is to learn to live with that irreducibility and accept humbly that what has been separated by God for him, he should not try to join together, in the sense of fusing them together. An excellent precept for philosophizing is the motto, "distinguish in order to unite," provided the unification does not aim at abolishing unchangeable differences. Man, in order to keep his sanity, must be on guard against false gods who *à la* Hegel claim to have overcome that conceptual irreducibility between the realm of quantities and the other, far greater realm of human experience, which for shorthand may be designated as the realm of qualities or values.

A shorthand, indeed, to be used cautiously. Otherwise it may lead to shortchanging that much wider experience through surreptitiously excluding from it the full range of plain existence statements and let that range slip imperceptibly into the domain of science. Yet one cannot insist strongly enough that, strictly speaking, the scientific method does not entitle the scientist to assert the reality of the instrument which is in his very hands. The scientist must assume that reality, with or without philosophical articulation, so that he might start investigating some quantitative properties of it. This may seem an unduly strict restriction on the scientific method, but unless one insists on it, one gives science *carte blanche* to do things that only God can do.

Thus if science is thought of as restricted to quantities, all that senseless talk about science demonstrating the creation of the universe will be nipped in the bud as so much plain rubbish. Creation, properly so called, is creation out of nothing, and not creative writing or something even less. But is nothing, or the total absence of reality, something with quantitative or measurable properties? Once this is pondered, the inanity of any talk about the moment of creation as having taken place 16 billion years ago becomes immediately apparent. Science can, of course, safely make measurements 16 billion years back into cosmic history. (Creationists should take note . . .). But this is something very different from saying that creation took place at that time.

In these days, when books on scientific cosmology cover half of all coffee tables, it may come as a shock to learn what may be the most gigantic evidence of the radical poverty of science: The scientific method is incapable of demonstrating that there is a cosmos, or universe, taken in a strict sense, that is, standing for the strict totality of consistently interacting things. No man, not even scientists or their scientific instruments, can get outside the universe in order to observe and measure it. Without such a feat, any discourse of scientists about cosmology, provided it is about the universe and not merely about a supercongeries of galaxies, remains, no matter how intricate mathematically, a philosophical discourse, although in their case almost invariably deprived of even an elementary measure of philosophical sophistication.

Nowhere is Einstein's dictum, "the man of science is a poor philosopher,"[6] more valid than in reference to scientific cosmology. One can only wish that he himself had taken to heart that dictum of his, whose truth is amply brought out by the history of science during the last four hundred years. In that case Einstein's good, commonsense warnings might, in view of his enormous prestige as a scientist, have awakened many who should know better. They would not now boldly speak from prestigious chairs about the ability of science to create entire universes literally out of nothing. Their "boldspeak" regularly appears in headlines in the science sections of prestigious dailies.[7] The comment which all this truly deserves has been anticipated by the Psalmist: "They have set their mouths in the heavens and their tongues dictate to the earth" (Ps 73:9). Their countless hapless victims were portrayed in advance in the same Psalm: "So the people turn to follow them and drink in all their words." Worse, some of them think that they gain thereby in religious depths.

Once this warning about the cosmic range of the impotency of science is swallowed as a much needed pill, it will be easier to see through the fallacy of certain evolutionists who delight in disproving the existence of design and purpose in the universe. It is not their scientific business to say a single word on that score. They should still digest the devastating remark which A. N. Whitehead made before a prestigious audience in Princeton in 1929: "Those who devote themselves to the purpose of proving that there is no purpose, constitute an interesting subject for study."[8] Theologians who spend their lives in squeezing from science proofs for cosmic design and purpose cut no less sorry figures.

Any statement about purpose is a radically philosophical proposition. If, however, a theologian eschews philosophy for fear that proper respect for reason would undermine his understanding of faith, he should stop talking even about faith and theology. For ultimately, the truth and cogency of all discourse, the scientific as well as the far more extensive non-scientific kind, must rest on philosophy, or rather on one's theory of knowledge. Those who do not wish to face up to this requirement will engage in fog-mongering with plenty of specious smokescreening thrown in for good measure.

The scientific class of these dubious entrepreneurs have, of course, one saving grace, which their non-scientific or humanistic counterparts cannot have. The grace that saves something of even the most unphilosophical discourse of scientists is the set of quantitative relations invited by their topic insofar as it is scientific. Quantities carry with them a built-in clarity which other words, so many patches of fog, do not possess, however indispensable they are for explaining even the clarity of numbers.[9]

The issue of a proper understanding of the relation of science and religion therefore boils down to a proper understanding of what we do when we use words in reference to reality. Such an understanding is worlds removed from the often self-defeating objectives of linguistic philosophers, especially of their Oxford branch of logical positivists who have claimed so many hapless theologians as their victims. Articulated understanding or philosophy is not a talk about talk, for in that case solipsists would be the only consistent philosophers.

Hardly less miserable are those theologians who sought, and are still seeking, liberating vistas in the Copenhagen interpretation of quantum mechanics, which is not science but a philosophy and a very bad one at that. One can but pity those theologians who look for such vistas in Bohr's principle of complementarity or in Heisenberg's principle of uncertainty. Complementarity cannot be a truly basic and therefore really first principle unless one pairs it with non-complementarity and sets up this pairing as an absolute starting point in reasoning. This can, however, be done only by sinking human cogitation into the abysses of illogicality where no statement can carry an unambiguous meaning. Abysses do not cease to be such by paying no attention to them.

A good illustration of this inattention is Bohr's brave protestation of intellectual humility (made at the start of each of his lecture courses) that "every statement I utter should be taken by you not for a statement but a question."[10] Bohr did not seem to suspect that this statement of his could not also be a question. He was consistent on practical or political side. In terms of the universal range he attributed to the principle of complementarity, Bohr took the Soviet system as something complementary to, that is, something on equal footing with, Western democracy and freedom. Tellingly, though inconsistently, he sought safety and freedom in the Western and not the Eastern direction. The theologian cuts a similarly odd figure from the viewpoint of logic (to say nothing of other viewpoints), when he claims that adultery should not be considered a sin because virtue and sin are complementary and therefore on the same footing. Again, can a Christian theologian, who should believe in the God called He Who Is, take non-existence as something complementary to, that is, on equal footing with that God? But is not precisely this what process theologians, so confident of their being steeped in the science of evolution, imply in the ultimate analysis? They still have to come clean on the point of whether a "God" who evolves can be worshipped? Or should the theologian be allowed to play hollow games with that basic word in his subject matter?

Similarly unsparing reflections are in order about the theological exploitation of Heisenberg's principle of indeterminacy. That principle, insofar as it is science and not something else, means nothing more and nothing less than that conjugate variables cannot be measured with full precision as long as one applies the statistical formalism of quantum mechanics. Heisenberg failed to see this limitation of his finding when he proposed it in 1927 and concluded in the same breath that thereby the principle of causality was overthrown once and for all. There followed an orgy in uncausal reasoning, clothed in science, aimed at the defense of the freedom of the will.

Yet within two years it was pointed out that Heisenberg's claim was an elementary fallacy in reasoning which prevented him from perceiving a basic limitation (and poverty) of exact science. The one who did this in the pages of *Nature* was a prominent philosopher of the University of Liverpool, although it could have been done by any sharp-witted undergraduate. It is plain elementary logic to note that there is a *non-sequitur* in the basic dogma in Heisenberg's reasoning which is a pillar of the Copenhagen philosophy: an interaction that cannot be measured exactly, cannot take place exactly.[11] For the first part of the proposition is operational, whereas the second part is ontological. But to rush from the operational into the ontological is to commit that elementary failure in logic for which the Greeks of old had already coined a phrase, *metabasis eis allo genos,* or jumping from one category into another. One aspect of that failure in logic is to fail to recognize that there is no direct conceptual access from quantities into qualities and everything else.

Finally, Einstein's theory of relativity. Many are the theologians dabbling in science who took that theory, of which they could not read even two pages, for the pretext to relativize their theology in order to make it suitable to an utterly relativistic culture. Of course, scientists, including Einstein himself, were not eager to enlighten those theologians on a point which remained largely hidden even to him. The point is that Einstein's theory of relativity is the most absolutist theory ever proposed in the history of physics.[12] It is a theory much more profoundly absolutist than Newton's physics with its absolutely stable medium, the ether. Yet Einstein failed to stress the absolutist character of this theory even though as early as 1922 he recognized that it would have been more proper to call it the theory of invariance. Thus the merry-go-round of the relativization of everything in the name of science started whirling, and no attempt was made at stopping it by precisely those to whom our culture listens most, scientists of course, in addition to sportsmen and sexologists.

For those who find all this heavy going, there is a royal road to see something of the very basics that govern the relation of science and religion. That road is the course of science through its history. The first thing to note is the relative youth of science in comparison with arts, literature, and philosophy. That youth, a mere half a millennium at most, emerges against a dark background, about which it is very dangerous to speak nowadays when all cultures must be viewed as equally productive and equally noble. Yet with respect to science all the great ancient cultures were most unproductive. In fact, in all of them science suffered what may best be called a stillbirth. For just as a stillbirth is preceded by a long maturing in the womb, full of great promise, in the same way there were in all ancient cultures technical inventions and theoretical insights that suggested a brilliant future. That future never materialized in any of them.

This pattern of repeated failures is the most monumental and most ignored facet of the entire history of science. There are various reasons for this. In the ongoing dechristianization of Western culture, it has become unfashionable to recall the fact that science is unmistakably a child of the West, and in fact of a still Christian West. A logical reluctance if one considers that the dechristianization of the West received its major impulse from that Enlightenment for whose spokesmen science would function as the true savior of mankind, but only if another Savior, Jesus Christ, had first been duly removed from the center stage. It is incompatible with such an outlook on Western intellectual history to give serious consideration to the incontestable fact that science experienced its first viable birth through John Buridan's formulation, in 1348, of the theory of impetus.

When translated into the theory of inertial motion, the impetus theory would immediately reveal its immense potentiality for science, which is the quantitative study of the quantitative aspect of things in motion. Moreover, if one views that theory against the failure of great minds, such as Aristotle and Avicenna, to seize on it, one can grasp even more forcefully the measure of Buridan's achievements. But then one has to face up to the fact that Buridan was led by a Christian dogma, the dogma of creation out of nothing and in time, to his epoch-making insight. For those who see in science, especially in physics, a cornucopia for everything it must be unbearable to recognize that the greatest poverty of science was remedied by theology and by a truly dogmatic type of it at that. Most importantly, the remedy came in a potentially quantitative form, which could lend itself to genuinely scientific application.

Looking in such a way at the origin of modern science saves one from trying to locate it in some sociological factor or in some industrial need, and even in some generic, though theologically coated movement, such as the rise of Puritanism in England.[13] Those fond of this latter factor are also often led by a visceral dislike of the Middle Ages, which they try to paint as black as possible. This perception still haunts many Protestant theologians who speak about the convergence of science and religion. The same perception makes uneasy most Catholic theologians busy with the same subject. In this age of ecumenics taken in a wider than theological sense, they feel they would lose the sympathy of their Protestant and secularist counterparts were they to be outspoken concerning the medieval, Christian origin of physics, which is science at its best, that is, at its most exact.[14]

Historically it should be absolutely clear that Christianity provided the spark whereby science became a self-sustaining enterprise. After Buridan the advance toward that self-sustaining form of science was almost inevitable, and after Copernicus, who relied heavily on Buridan, irresistible. With Newton, there was on hand a science of physics that began to progress in terms of its own purely mathematical strength. Since the formulation of

Newton's theory of motion in a central field of force, there is no need for physics to rely on anything else, including theology. The conceptual analysis of the work of Faraday and Maxwell, two equally devout Christians, shows that their crucial contribution to electromagnetism was independent of their religious beliefs, even though they may have thought the opposite. Even more is this true of Planck and Einstein. The only theologically relevant facet in their creativity is that it implied a middle-road epistemology, the only basis on which a theologian can speak reasonably about the rational proofs of the existence of God and even about the rationality of revelation.

Surprising as this may seem, truly creative scientists never cared about articulating in detail a methodology of science. Scientists, to say nothing of philosophers of science, who did that, almost invariably went wrong. It is not possible to do science, let alone creative science, on the premises laid down by Bacon, Descartes, Hume, Locke, Comte, and Ernst Mach, to mention only a few well known figures. In our century one may add to this hardly flattering list such names as Bachelard, Koyré, Kuhn, and Feyerabend, or all those who confused the psychology and sociology of being at grips with this or that scientific problem with the problem itself.

Does this mean that nothing positive can be said about the relation of science and religion in the midst of such confusion? The first thing to note is that in order to say something positive about that relation, one has to say something positively clear about what science and what religion one has in mind. Shadow boxing, artful camouflaging, escaping into vague generalities (so that everyone may be pleased and publishers may make handsome profits) are procedures unworthy of self-respecting intellects.

Owing to the fact that such intellects are not the ones which the public loves to hear most, it may be risky to call attention to a facet of human curiosity which is at work both in science and in theology, or simply in the humanities. To be sure, the curiosity appears with different nuances in both of those domains. This should be clear to anyone who had not yet discarded philosophy as useless ballast. That curiosity invariably prompts questions that appear in this form or are reducible to it: Why such and not something else?

The first to phrase in terms of such a question the dynamic of human inquiry, though without noting its universal relevance, was Leibniz, a philosopher, a scientist, a theologian, a historian—all in one. Of these the historian was most at a loss, partly because history is so full of all sorts of suchness that, as Chesterton once noted, they can be mined to demonstrate any case of progression or retrogression. The scientist is far more fortunate because the items of suchness he notices are all quantitative ones. Compared with all other items of suchness, or patterns, they are the most straightforward, whatever the complexity of the mathematics they invite. The theologian too looks at peculiar facts (the facts of salvation history, for instance) and tries to find in them an overarching pattern or principle. The case of the philosopher, unless he has cast his lot with a phenomenology that tries to make do without ontology, is, of course, the most fundamental: For in asking the question—why such and not something else?—he looks for the ontological ground that explains that suchness.

A particular example may shed much light on these differences and also on the nature of the convergence between science and religion as governed and mediated by philosophy. Until the middle of this century, speculation about cosmogenesis was dominated by

Laplace's nebular hypothesis. Such a cosmogenesis tried to explain the present, exceedingly peculiar, suchness of physical reality by tracing it back to a primordial nondescript state of affairs about which nothing in particular was known, except that it was nebulous.[15] The enterprise should have appeared doomed to failure because of the logical fallacy it rested upon. Homogeneity, if it is truly such, never gives rise to heterogeneity. Quite a different picture arises from modern scientific cosmology. However far it carries one back into the cosmic past, it always shows an exceedingly specific state of affairs that lends itself to strict quantitative evaluation. Quantities are specificities par excellence.

Assuming therefore that at least one of the major cosmological models coincides with the true universe, one can consider the question about its total suchness as a question, the answer to which must be sought in a factor beyond the physical universe, or metaphysics in short. But even apart from taking any of our present scientific cosmological models as referring to the real universe, the absolute totality of things, it is possible to argue that any set of suchness finds its explanation only in another set. Invoking therefore the principle that prohibits regress to infinity, one can still argue that cosmic suchness must have a creative (in a strict sense) choice for its existence, a choice that can be credited only to God, who is personal and omnipotent, that is, not subject to some process. For any harmony set up between science and process-theology is a selling out of any sane discourse about a God who can truly be worshipped, and not merely dreamed about in terms of some higher aesthetics, such as panentheism, which so readily reveals itself as plain pantheism.

Those with more (or less) philosophical acumen will simply say that even the existence of a telephone pole demonstrates the existence of God. For the size of such a pole or any piece of matter is a pointer to its ontological existence, which is clearly limited and therefore not self-explaining. Those who cannot or dare not probe these philosophical depths, visible from the surface of everything, should disqualify themselves from talking about science and religion. It makes no sense to enrich an impoverished religion by ransacking the poverty of science and distracting thereby from the riches of true religion. Any discourse about the latter should be part of that *logike latreia* (or reasoned worship) which Paul himself specified (of all places in his Letter to the Romans, 12:1) as the hallmark of genuine service of God.

Notes

The reader who wants to have more details about the various arguments presented in this essay may wish to consult the following books of mine: *The Relevance of Physics* (Chicago: University of Chicago Press, 1966), which contains the first formulation, in terms of Gödel's theorem, of the impossibility of a physical theory that would be truly a priori; my Gifford Lectures, *The Road of Science and the Ways to God* (Chicago: University of Chicago Press, 1978), which deal with the methodology discernible in creative science; *Science and Creation: From Eternal Cycles to an Oscillating Universe* (Edinburgh: Scottish Academic Press, 1974), concerning the invariable stillbirths of science in all ancient cultures. *The Purpose of it All* (Lanham Md.: Regnery-Gateway, 1991) on the thorough inadequacies of standard evolutionary philosophies; my Forwood Lectures at the University of Liverpool, *Is there a Universe?* (Liverpool University Press, 1993), and *Bible and Science* (1996; 2d edition, Front Royal, Va: Christendom Press, 2000), and *Means to Message: A Treatise on Truth* (Grand Rapids, MI: Wm B. Eerdmans, 1999).

1. For curves illustrating a similar growth in the number of scientific journals and of the percentage of populations having science-related jobs, see D. J. de Solla Price, *Little Science Big Science*

(New York: Columbia University Press, 1963) and his *Science since Babylon* (New Haven: Yale University Press, 1961).

2. Weyl gave this warning just a year before his death in a lecture, "Knowledge as Unity," delivered at the bicentenary celebration of Columbia University on October 18, 1954, and published in *The Unity of Knowledge,* ed. L. Leary (Garden City: Doubleday, 1955), p. 22.

3. Such an excellent list is K. Kneller, *Christianity and the Leaders of Modern Science: A Contribution to the History of Culture during the Nineteenth Century* (1911; reprinted with my introduction by American Council on Economics and Society in its Real-View-Books series, 1995), xxviii + 403 pp.

4. A telling example was given in a report by *The New York Times* (Jan. 18, 1997, p. 29) about the Jewish Reconstructionist Federation, whose leader Rabbi Mordechai Liebling promotes the views which Rabbi Mordecai M. Kaplan promoted in his book, *Judaism as Civilization,* first published in 1934. There God is not a Creator but a creative force, and religion's chief sources are designated as art, literature, and music. This is exactly the case with any form of Christianity that shies away from dogmas or reinterprets them beyond recognition.

5. On a piece of paper which he kept inserted in his copy of R. Chambers' *Vestiges of Creation.*

6. The opening phrase in his long essay, "Physics and Reality" (1936). See A. Einstein, *Out of my Later Years* (New York: Philosophical Library, 1950), p. 58.

7. For a recent example, see the headlines, "Physicists confirm the power of nothing, measuring force of quantum foam," and "Physicists confirm power of nothing in 'Foam'." *The New York Times,* Jan. 21, 1997, pp. C1 and C6.

8. A. N. Whitehead, *The Function of Reason* (Princeton University Press, 1929), p. 12.

9. For further details on this contrast and on its implication for work on artificial intelligence software and hardware, see my invited paper, "Words: blocks, amoebas, or patches of fog? Artificial intelligence and the conceptual foundations of fuzzy logic," in *Applications of Fuzzy Logic. Technology III. Proceedings. SPIE-The International Society for Optical Engineering. Vol. 2761* (Bellingham, Wash.: The Society of Photo-Optical Engineers, 1996), pp. 138-143.

10. This statement of Bohr received wide circulation through its being quoted in J. Bronowski's *The Ascent of Man* (Boston: Little Brown and Co., 1973), p. 334, who failed to note the illogicality of Bohr's dictum. The same is true of John A. T. Robinson, who uses it as a foil at the end of his Introduction to his *Redating the New Testament* (1976).

11. For details see my essay, "Determinism and Reality,' in *Great Ideas Today 1990* (Chicago: Encyclopedia Britannica, 1990), pp. 277-302.

12. For details, see my article, "The Absolute beneath the Relative: Reflections on Einstein's Theories," reprinted in my collection of essays, The *Absolute beneath the Relative and Other Essays* (Lanham, Md.: University Press of America, 1988).

13. The inconclusiveness of such a perspective is well illustrated in the collection of essays, *Puritanism and the Rise of Modern Science: The Merton Thesis,* edited by I. Bernard Cohen, K. E. Duffin and Stuart Stickland (New Brunswick: Rutgers University Press, 1990).

14. The first to articulate, and on a vast scale, that historical connection was, of course, Pierre Duhem, the subject of various monographs of mine, such as *Uneasy Genius: The Life and Work of Pierre Duhem* (The Hague: Nijhoff, 1984); *Pierre Duhem: Homme de science et de foi* (Paris: Beauchesne, 1994, in English and Spanish as well). In *Reluctant Heroine: The Life and Work of Hélène Duhem* (Edinburgh: Scottish Academic Press, 1992), I provided a vast documentation, mostly from previously unpublished material, about the conspiracy of editors and academics to prevent the publication of volumes VI-X of Duhem's immortal work, *Le système du monde.*

15. For details, see ch. 7 "The Nebulous Advance," in my *Planets and Planetarians: A History of Theories of the Origin of Planetary Systems* (Edinburgh: Scottish Academic Press, 1978), and ch. 2 "Nebulosity Dissipated," in my *God and the Cosmologists* (Edinburgh: Scottish Academic Press, 1989).