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W. H. Kadesch
Iowa State Teachers College

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Science Changes Its Mind

By W. H. KADESCH

In an interesting book bearing the title "Architects of Ideas" Trattner tells us that "in every age previous to our own there was supposed to exist a body of knowledge final and infallible. Frequently people thought of this knowledge as having been revealed directly from heaven. Embodied in rigid tradition and held sacred by all authorities, it was considered heresy to question any time-honored belief."

The great development in human culture that Mees has called the Helix of History began somewhere in the eastern hemisphere five or six millenia ago. For many centuries advancement was slow. Succeeding turns of the helix fell very close together. It was not until relatively very recent times that Kepler, Galileo, da Vinci, Vesalius and other kindred spirits succeeded in liberating the mind of man from the bondage of tradition, and in starting the advance that has placed Science in the honored position among human activities and achievements that it occupies today.

But there are many intelligent persons who still do not understand the spirit and purposes of science, nor comprehend its methods. The view expressed by one highly respected gentleman of my acquaintance who dislikes change and craves stability is probably typical of the point of view of many of his kind. Disturbed by any modifications in scientific matters he declares that he would have more confidence in science if it would tell the same story now that it told last year or the year before. How, he asks, can a layman know what is the truth if scientists so often reverse themselves. Why don't they make up their minds?

It is not to be denied that science has often abandoned a position that once was firmly held and that seemed quite secure. Not once, but many times it has altered or reversed its judgment. Let us call to mind a few such instances, and in each case note the conditions that impelled the change.

The scientific world, so far as one then existed, entered the sixteenth century with complete confidence in two great leaders. One of these was Aristotle, who had taught the Greeks Astronomy and Physics, and had done it so convincingly that no one arose in almost two thousand years to question the truth or finality of anything he had written. The other leader to whom we refer was Galen. This great physician was born about five hundred years after Aristotle, and achieved in medicine a degree of supremacy substantially matching that attained by Aristotle in the physical sciences. The dominance of these two men for so many centuries is eloquent testimony of their greatness. But it also reveals the lethargy that paralyzed the intellectual world from early in the Christian era to near the end of the fifteenth century. Then in the early fifteen hundreds came Vesalius to discover errors in the teachings of Galen, to cast doubt upon his omniscience in the field of anatomy, and to turn anatomists from the writings of the ancients to the human body itself, for the answers to their questions. Half a century later arose Galileo to challenge Aristotle. Galileo doubted the truth of the assertion that heavy objects fall faster than lighter ones, and, what is most significant, proposed that nature herself be called upon to decide. And so he arranged to drop his two objects simultaneously, a light one and a heavy one, from the top of the tower of Pisa, with the people waiting below to see which should first reach the earth. The results were revolutionary. Aristotle was proven wrong.

And so it transpired that in the physical field as well as the biological the deadening dominance of authority was broken. Nature herself, not the writers of past ages, would henceforth be asked to supply the answers. Science had definitely and completely changed its mind.

A second great revolution in thought was soon to follow. The sixteenth century inherited a conception of the world that was highly gratifying to the human ego. The universe was considered to have been created for the special benefit of man. The earth on which he lived was the immovable center around which sun and moon, stars and planets all revolved. Each of these bodies was assumed to be attached to a crystalline sphere and to revolve with it. The innermost sphere was that of the moon. Then, in order, came the spheres of Mercury, Venus, the Sun, Mars, Jupiter, Saturn, and the fixed stars. A ninth sphere was added later to provide for the precession of the equinoxes, and a tenth, or primum mobile, which rotated once in twenty-four hours and carried all the others with it, was added to account for day and night. But crystalline spheres or deferents, as they were called, were not enough. To account for the alternate approach toward the earth and recession from it, of these celestial objects, it was necessary to assume that each object also had a second motion. This was in a smaller circle called an epicycle, whose center was fixed in the surface of the appropriate crystalline sphere.

With improved methods of observation came more exact knowledge of the movements of all heavenly objects. This revealed more and more irregularities. These could be accounted for on the basis of a central earth only by assuming that each epicycle carried still another epicycle of a higher order. In his great book on the Revolutions of Celestial Objects Copernicus showed that the apparently complicated movements of these objects could be accounted for more simply. But this could be done only at the cost of great damage to man's sense of self-importance. It meant the placing of the sun at the center of the system, and the relegating of the earth to a distinctly minor position. This bold suggestion was rejected for a time not only because of the offense it gave to man's self esteem, but because it also contradicted the doctrines of the church. It was rejected even by the great Tycho Brahe, but for a much better reason than either of these. Tycho had spent his entire scientific life in measuring the positions and movements of the planets and other celestial objects. His records were unprecedented in their extent and accuracy. His own observations, more than any others, added to the complexity of the Ptolemaic picture. This was a fact he must have greatly regretted. But he knew that if the earth revolved about the sun, as Copernicus claimed, the stars should show a parallax. His most careful observations failed to reveal any such effect. And so, to the last, he held to the Ptolemaic view.

Then came Kepler with his computations of the orbits of the planets. Hitherto the perfect circle had been regarded as the only geometric figure worthy to be considered as the orbit of any object in a perfect universe. Kepler showed that on this basis the universe must be something less than perfect. He found that the planetary orbits are not circles as Copernicus and everyone before him had supposed, but ellipses. Disturbing as this discovery was in one respect, it acted as a very welcome sedative in another. Combined with the Copernican idea that the sun, and not the earth, is the central body around which the planets revolve, it canceled all need for deferents and epicycles and enormously simplified the whole conception of the celestial world. In view of this great advantage and of the convincing nature of the evidence science promptly changed its mind.

The objection that the parallax that the Copernican view demanded was not observed was later removed when the powerful optical instruments that superseded the measuring quadrant revealed the effect for which Tycho had looked so carefully but in vain.

Let us consider next the nature of heat. Prior to the middle of the eighteenth century heat, temperature, and fire, all meant very much the same thing. The first distinction between heat and temperature seems to have been one that considered them in the relation of cause and effect. Heat was considered as a substance. Temperature was a condition of an object that was altered when heat, or caloric as it was later called, was added or removed. When the properties of caloric other than its ability to alter temperature were investigated, unexpected difficulties were encountered. For example, when added to any material that did not suffer a permanent change in properties, there was not the slightest change in weight. But to the calorists this difficulty was not a serious one. Caloric, evidently, was a weightless substance, like magnetism, or the electric fluid. A more serious obstacle to the caloric theory arose when Rumford in the boring of cannon was able to liberate what seemed to be unlimited quantities of caloric from a very limited supply of material. He was able to increase the amount of caloric simply by using a blunt drill instead of a well sharpened one. Even worse for the caloric theory was the fact that Davy succeeded in melting ice without adding any caloric at all. He had simply to rub two pieces together. So it was clear that caloric could not be a substance. Dalton's theory of the atomic nature of matter offered the possibility of a solution. Heat, the anti-calorists thought, might be simply the energy of motion of agitated particles.

First Mayer, then Joule, showed that when work is done in generating heat the amount of heat produced is in a direct proportion to the amount of energy so used. Each unit of work always yielded the same definite amount of heat. In view of this overwhelming evidence science abandoned the caloric theory and adopted in its stead the view that heat is a form of energy.

Now let us turn our attention for a moment to a question in biology. One of the most persistent of the biological ideas handed down from the time of Aristotle and beyond was that of spontaneous generation of life. This view was universally accepted well into the seventeenth century. And there were many circumstances that seemed to speak decisively in its favor. One of these was the fact that infusions of hay that were perfectly clear when first prepared were seen by Leeuwenhoek with his newly invented microscope soon to become cloudy with actively moving forms. Other observations pointing in the same direction were made a century later. Needham sealed boiled mutton broth in vials so securely as to prevent the entry of any form of life. Yet in a few days the broth was found to be swarming with "animalcules." At about the same time Spallanzani prepared infusions with several varieties of seeds, boiled for half an hour. The vessels containing the infusions were loosely stoppered with corks. In the course of a week they also contained microscopic life. However, by completely excluding the air and boiling as before, infusions were prepared in which no animalcules later appeared. Notwithstanding this result, belief in spontaneous generation of the minutest organisms still persisted. Pasteur fought it as late as 1859. Sometimes a supposedly sterilized flask of broth went bad, and bacteria appeared. Pasteur contended that in such a case parent bacteria must have gotten in with air that entered through imperfect sealing. But it required more than words to silence his critics, who argued that life must begin somewhere, so why not here at this lowest stage. To answer this contention Pasteur prepared a very simple experiment. He put an infusion of a putrescible substance into a flask and drew the neck of the flask out into a long thin S shaped tube which was left open. He then heated the infusion to the boiling point, held it at that temperature for a long time, then set it aside. There was no putrefaction for weeks, or even months. When it appeared that there would be no change in the infusion the long neck of the flask was cut off, and the broad open end placed upward. Dust from the air could then fall into the flask and upon the surface of the infusion. In only a few hours the broth in that region was found to be teeming with organisms.

After more than twenty centuries of acceptance of the view that at least some low forms of life might be generated spontaneously science was now convinced that this does not occur — that even these low forms are produced from preexisting life of the same kind. Once again science reversed itself.

Science as practiced by the chemist has likewise often changed its mind. One historic instance has been so well described by one of our honored members that I feel impelled to quote him verbatim. This chemist tells us that "until a century ago it was believed that organic compounds must originate in living material — never in a test tube. Then came an epoch-making 'accident' in chemistry. In 1828 Friederich Wöhler, a German chemist, was working with an inorganic substance, ammonium cyanate (NH_4CNO). Following an evaporation there appeared long, glistening, needlelike crystals not at all resembling his inorganic salt. Analysis showed them to be urea — $(NH_2)_2CO$ — an organic compound produced in animal bodies. Within the test tube Wöhler had converted an inorganic compound into an organic one. He had broken the barrier between inorganic and organic chemistry. He had shown that the synthesis of organic compounds can come by way of the living cell or from the lifeless contents of the test tube."

Doubtless one of the most dramatic changes of mind science has ever undergone took place in the field of biology in the last half of the last century. It is recorded in ancient writ that God created all the various living forms that appear upon the earth, and commanded each to reproduce according to its own kind. This was taken to mean that the forms that are now found thriving here are identical with those that were present from the beginning. Linnaeus, for example, asserted that there are "as many species as issued in pairs from the hands of the Creator." The work of biologists down through the centuries was directed toward discovering in increasing detail what these forms are, how they are constructed, how they are nourished and grow, and how they reproduce. This sort of study revealed that the number of forms of life inhabiting the earth is very great, and that the differences between many of them are very slight. To those who studied the question most deeply it seemed that nature is not immutable. From the relationship found among the various forms it seemed clear that there must have been development — variation — evolution of certain forms from earlier existing ones. This view had been held by some scientists for many years. With the publication of Darwin's great book on The Origin of Species the majority of scientists who had previously rejected it were quickly converted.

In presenting his monumental pile of evidence in support of organic evolution — evidence that he had accumulated over many years of the most careful observation — Darwin sought also to elucidate and to establish a means by which evolution is achieved. Both he and Wallace had been greatly impressed by Malthus's historic essay on Population. They saw that organisms produce far more offspring than can be supported, that those offspring differ among themselves, and that, on the average, those that are best adapted to their environment will survive. Darwin contended that the survivors pass on their characteristics to their offspring, and that the race or species thus gradually evolves.

Darwin's evidence that evolution has taken place, and still continues, is overwhelming. That it occurs in the particular way in which he believed it to do was not long accepted. One implication of evolution by the small variations of natural selection is the existence of forms of life intermediate between a species and its antecedent. However, not a single instance could be found either of a living organism or of fossil remains that exemplified the chain by which evolution was assumed to progress. On the other hand, closely related but distinct species are frequently found existing side by side. In the course of the ages conversion of species must have taken place, if not by natural selection then by some other process. A theory of sudden changes of species called mutations was proposed by Kölliker. Proof of the mutation theory was soon discovered by Devries — a theory that has been a milestone in the transition from the old ideas to the modern conception of heredity. A paper written by Greogor Mendel in 1866 and left almost unnoticed until 1900 threw an entirely new light on the subject. Mendel's experiment indicated that sudden abrupt variations rather than the almost imperceptible ones of Darwin's Natural Selection were to be expected. The exhaustive studies of Morgan and others on the fruit fly have yielded a vast body of evidence indicating that there is a close parallelism between the physical characters of the flies on the one hand, and the behavior of chromosomes on the other. The theory of the gene, based on these observations and on Mendelian laws, is now considered the most complete and satisfactory presentation of the phenomena of heredity yet offered. Its acceptance represents one of the most important changes of mind yet made in the field of biology.

Let us return now to the field of physics; subject, radiation.

During the latter part of the seventeenth century two rival theories of the nature of light were current. One of these held that light is some kind of wave phenomenon. The leading champion of this theory was the Dutch astronomer Huygens. The other conception was that light consists of material particles emanating from heated objects, and producing a mechanical effect by their action on the eye. The chief advocate of this view was Newton. Huygens had two reasons for his preference of the wave theory. The first had to do with the speed of light. To him it seemed impossible that any material particle could move so fast. The second was a question of simple mechanics. It would be expected that material particles hurtling toward each other in dense streams in diametrically opposite directions would in many cases collide head on, and so destroy each other's motion. But it was not observed that two beams of light traversing the same space in this way offer each other even the slightest obstruction. Newton's reason for choosing the corpuscular theory was the apparently straight-line propagation of light under all circumstances. In every other known case of wave motion, such as sound, or surface waves on water, whenever the wave passes an obstructing object it bends around, at least to some extent, into the region behind the obstruction. Newton was unable to find any tendency of light to bend into the shadow. The issue was temporarily decided on the basis of whose opinion carried greatest weight. So, for the next hundred years, Newton's corpuscular theory prevailed. However, early in the nineteenth century Young, by means of a double slit, and Fresnel, by means of both biprisms and mirrors, showed that two similar beams of light traveling almost in the same direction can destroy each other. For streams of material particles this would be impossible, so Newton's corpuscular view was abandoned and the wave idea universally accepted. The evidence in support of the undulatory theory was strongly reenforced by the theoretical work of Maxwell in the 1860's and the experimental work of Hertz in the 1880's. Optical science had undergone a change of mind only a little less spectacular and even more complete than that of biology when it went almost all out for Dawinism.

But in unequivocally rejecting the corpuscular theory of radiation and embracing the wave theory the science of optics later found that it had gone too far. It was like a new convert to religion who at first can see nothing but sin in his former way of life. A few years later and without any inclination toward backsliding, he may consider that the former way had some meritorious elements after all, and reincorporate them in his philosophy or practice.

The counter movement in radiation occurred as follows: It was found that the accepted principles of electrodynamics, in which light was regarded purely as a wave effect, failed to give an expression for the energy of black body radiation that accorded with the facts. Then, working on the assumption that radiant energy is emitted only in definite small units that he called quanta, the Dutch physicist Planck derived an equation expressing the relation between the average energy of a linear oscillator and the energy per unit volume of the radiation with which the oscillator is in equilibrium. Planck's formula not only gives results that are in remarkable agreement with the facts of radiation, but also yields values for various molecular constants, such as Avogadro's number and the magnitude of the electronic charge, that are in good agreement with experimentally determined values of these quantities. Quanta are now considered to be as well established as waves in all matters relating to radiation.

Although physicists universally have accepted the quantum as an essential element in their theory of the nature of light, they have, for equally compelling reasons, insisted on retaining the wave conception also. We have accepted the central ideas of the theories of both Huygens and Newton.

The establishment of the fact that light and other forms of electromagnetic radiation in many phenomena exhibit the properties of particles led de Broglie to ask the converse question: whether the electron, a seemingly orthodox particle, may not also possess the characteristics of waves. Preposterous as this suggestion at first seemed, it was promptly put to the experimental test. In America Davisson and Germer verified the truth of de Broglie's predictions for electrons of low energy. In Britain G. P. Thomson, son of the discoverer of the electron, verified it with no less certainty for electrons with energies of 100,000 volts or more. It has since been shown that protons also exhibit the properties of waves. Even the atoms themselves, once regarded as compact little pellets, likewise have a wavy nature. Schroedinger, Heisenberg, Dirac and others have built up a complete mathematical theory to describe the wave systems corresponding to particles of any kind whatever. Thus in the last few decades the scientist's conception of the nature of matter has completely changed.

Let us cite one more instance in which a change has occurred in man's conception of his physical world. Since very early times scientists pinned their faith on at least one great law — that of the conservation of mass. It is true that the alchemists hoped to produce gold, but they attempted to do so by transformation of baser materials, not by an act of creation. The more precise the available tests became the more firmly convinced the chemists were that no mite of matter however small could be destroyed. Neither could any new matter be created. Whatever went into the test tube came out again, in altered form but unchanged in amount. Since the latter part of the eighteenth century physicists have been equally sure that there is another entity everywhere, no less permanent than the atoms of the chemist. This entity is energy. This the physicist can transform with even greater facility than the chemist can dissassociate and recombine his atoms. With every movement some mechanical energy is transformed into heat or sound or some of the other kinds of energy of which the scientist has learned. Conservation of energy and conservation of matter were the twin pillars of nineteenth century chemistry and physics. But early in the present century Albert Einstein, then an obscure examiner in the patent office of Switzerland, did some very unusual thinking and set down a part of his thoughts in this very simple equation: $E = mc^2$.

In non-mathematical language this equation says that the matter of the chemist is not necessarily conserved — that under proper circumstances it can completely disappear as such. But whenever it does disappear an equivalent amount of energy comes into being. The equation also specifies just how much energy is produced in the transformation of any given amount of matter. According to this way of thinking matter and energy are not separately conserved. They are mutually transformable, one into the other. They are, in fact, not separate entities at all.

But instances of such transformations were not immediately observed. Techniques by which they could be closely studied had first to be developed. By 1932 methods had become available for measuring the amounts of mass disappearing in certain radio-active transformations, and the corresponding amounts of radiant energy released. Means had also been developed for producing such changes artificially, and studying the results. The reverse transformation by which radiant energy is converted into matter has now also become commonplace in many laboratories. In every instance of such a change the amount of energy involved in the annihilation or production of any amount of mass is that indicated by Einstein's simple equation.

Prior to 1939 no disintegrating atom was observed to yield more than two kinds of fragments. One of these was always relatively very light — never heavier than an alpha particle. The other carried nearly all of the mass of the atom, usually upward of 98 per cent. In January of 1939 Hahn and Strassmann in Germany discovered a new kind of transformation. They found that when an atom of Uranium absorbs a neutron it sometimes breaks into two approximately equal parts. The combined mass of the fragments produced in such a distintegration was found to be much less than that of the original atom. The mass that vanished was converted into energy of radiation, each gram so converted yielding 900 million million million ergs, or 25 million kilowatt hours. It is this excess energy, under a certain measure of control, that is utilized in the atomic bomb. This same energy, we all believe, will soon be brought under more complete control. And we hope that it will be used for the benefit of man, not for his destruction.

However that may eventuate, the point to be emphasized here is that with the accumulation of further knowledge of the atom and its ways, science has once more changed its mind.

The instances cited above are merely illustrative. The list might be greatly extended. The chemist, for example, might wish to mention the great advance that came with Mendeleef's announcement of the periodic table of the elements, and again with Moseley's discovery of atomic numbers. The astronomer might remind us of the abandonment of the nebular hypothesis of Laplace and the rise of the planetesimal theory of Chamberlain and Moulton, or of the waning of the planetesimal with the advent of the more attractive dust cloud theory of Whipple. The biologist might call our attention to the rejection of the idea of preformation in favor of epigenesis, or to the addition of vitamins to Liebig's list of essential foods.

What, then, should be our conclusion? We notice first that science accepts no man's unsupported opinion as authority. Evidence alone is recognized as a warrant for the acceptance of one interpretation of nature and the rejection of another — evidence wrung from nature herself by the most painstaking and persistent questioning. We see as a second point that there exists no body of knowledge that is regarded as final. Every theory, every conclusion, is subject to revision or rejection, but only on the strength of new and convincing evidence.

IOWA STATE TEACHERS COLLEGE
ADAMS STATE COLLEGE
ALAMOSA, COLO.