I have connected, in passing, our "scaled particle" results with actively evolving theories such as the Percus-Yevick theory (*16*) and have mentioned the knowledge of the first few coefficients in the development in density of the equation of state, the so-called virial series. The nature of the mathematical convergence of this series and certain related questions are currently under investigation and have an important bearing on the phase transition problem as well as on the behavior of the fluid at low density. At very high densities, near to close packing, an (asymptotic) expansion in the reciprocal density has recently been obtained (*19*). This, too, promises to shed light on the elusive mathematical problem of the phase transition and the structure of the "solid" phase.

To further understand real fluids we have to take into account the soft, primarily attractive part of the intermolecular potential. At high enough temperatures the soft (nonhard) core part of the intermolecular potential can be systematically treated as a small perturbing potential acting on a fluid composed of the hard cores of the molecules. Such a perturbation theory has been developed both for the equation of state (*20*) and for the transport coefficients (*21*). The thus corrected equation of state will predict a condensation and the appearance of a liquid phase that ceases beyond the so-called critical point. Space does not permit me to enlarge on these questions or on the bearing they have on phase transitions in general in other many-body problems (*22*).

References and Notes

1. The orientation of this paper is primarily pedagogical. No attempt is made to provide a historical setting or to review all the pertinent literature. The elements of the kinetic theory of gases used are adequately covered in T. G. Cowling, *Molecules in Motion* (Harper, New York, 1960).

2. T. G. Cowling, *Molecules in Motion* (Harper, New York, 1960) p. 43.

3. The hard-sphere model has a venerable history in kinetic theory as a result of the simplicity of the dynamics of these model molecules. Thus the binary collision cross section is independent of the relative velocity of the colliding spheres. Recently Y. Sinai, *Dokl. Akad. Nauk SSSR* **153**, 1261 (1963), has announced a proof of the ergodic theorem for the hard-sphere system in a rectangular box. Thus this system has the distinction of being effectively the only nontrivial many-body system for which the application of statistical mechanics is justified by theory. For a summary of the equilibrium properties of this system see for example, H. L. Frisch, *Advan. Chem. Phys.* **6**, 229 (1964), and references cited therein.

4. B. J. Alder and T. E. Wainwright, *J. Chem. Phys.* **31**, 459 (1959); *ibid.* **33**, 1439 (1960); *Nuovo Cimento* **9**, Suppl. 1, 116 (1958).
5. W. W. Wood, F. R. Parker, J. D. Jacobson, *Nuovo Cimento* **9**, Suppl. 1, 133 (1958).
6. B. J. Alder and T. E. Wainwright, *Phys. Rev.* **127**, 359 (1962).

7. See, for example, T. G. Cowling, *2*, p. 14 ff. Equation 2 is derived in the text, albeit for the special case of hard spheres.

8. J. O. Hirschfelder, C. F. Curtiss, R. B. Bird, *Molecular Theory of Gases and Liquids* (Wiley, New York, 1948), p. 134 ff.
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10. A most thorough discussion of this fluctuation theorem can be found in R. C. Tolman, *Principles of Statistical Mechanics* (Oxford Univ. Press, London, 1938), section 141.

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13. M. Born, and H. S. Green, *A General Kinetic Theory of Liquids* (Cambridge Univ. Press, London, 1949).
14. J. G. Kirkwood, E. K. Maun, B. J. Alder, *J. Chem. Phys.* **18**, 1040 (1950).
15. J. K. Percus, in *Classical Theory of Fluids*, H. L. Frisch and J. L. Lebowitz, Eds. (Benjamin, New York, 1965); the bibliography at the end of this monograph may be a helpful guide to further reading.

16. This result has interestingly the form expected from a "free volume" theory of diffusion. This can be seen more explicitly. One notes that the pressure p of a fluid is related to the statistical thermodynamic free volume [see for example T. L. Hill, *Statistical Mechanics* (McGraw-Hill, New York, 1956), p. 360] $v_f(\rho,T)$ through the equation

$$p = kT \int_0^\rho d\rho' \left[\frac{\partial \ln v_f(\rho',T)}{\partial \ln \rho'}\right]_T$$

Hence, for hard spheres, if this equation is substituted in Eq. 23

$$D = \frac{a\pi\bar{c}\rho}{8} \times \left[\int_0^\rho d\rho' \left[\frac{\partial \ln v_f(\rho',T)}{\partial \ln \rho'}\right]_T - \rho\right]^{-1}$$

which differs though from the usual Doolittle relation used to correlate the behavior of complex fluids.

17. B. J. Alder and T. E. Wainwright, *Transport Processes in Statistical Mechanics*, I. Prigogine, Ed. (Interscience, New York, 1958), p. 121.

18. A more detailed discussion of the nature of the phase transition can be found in F. H. Stillinger, Jr., E. A. diMarzio, R. L. Kornegay, *J. Chem. Phys.* **40**, 1564 (1964).

19. F. H. Stillinger, Jr., Z. W. Salsburg, R. L. Kornegay, *ibid.*, in press.
20. R. W. Zwanzig, *ibid.* **22**, 1420 (1954).
21. H. L. Frisch and B. Berne, *ibid.* **43**, 250 (1965).
22. R. Brout, *Phase Transitions* (Benjamin, New York, 1965).

The Ethical Basis of Science

Bentley Glass

It has been said that science has no ethical basis, that it is no more than a cold, impersonal way of arriving at the objective truth about natural phenomena. This view I wish to challenge, since it is my belief that by examining critically the nature, origins, and methods of science we may logically arrive at a conclusion that science is ineluctably involved in questions of values, is inescapably committed to standards of right and wrong, and unavoidably moves in the large toward social aims.

Human values have themselves evolved. Man arose after some two billions of years of organic evolution, during which species after species originated, flourished, and fell, or occasionally became the progenitors of species that were new and better adapted, on the basis of the evolutionary scheme of values. Fitness, like it or not, in the long run meant simply the contribution of each trait and its underlying genes to survival. High mortality or sterility led to extinction; good viability and fertility enabled a gene or a trait, an individual or a species, to be perpetuated. Man's own values grew out of his evolutionary origins and his struggle against a hostile environment for survival. His loss of certain unnecessary structures, such as bodily hair once clothing was invented; the homeostatic regulation of his body temperature and blood pressure, breathing, and predominant direction of blood flow; his embryonic and fetal growth inside the mother and his prolonged dependence upon ma-

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ternal lactation; the slow maturation that enabled his brain to enlarge so greatly; the keen vision so necessary to the hunter using his weapons—all of these and many other important human characteristics that contributed to the social nature of man and cemented the bonds of family and tribe arose adventitiously, were improved step by step, and endured because they promoted human survival. Our highest ethical values—the love of the mother for her child and of the man for his mate, the willingness to sacrifice one's own life for the safety of the family or tribe, and the impulse to care for the weak, the suffering, the helpless—all of these too had the same primitive beginnings.

But these ethical values are always, in the evolutionary scheme of things, relative, and never absolute. Whenever the environment becomes changed, the adaptiveness of existing traits becomes maladjusted, and the forces of natural selection lead to a realignment of the genotype, an alteration of the external features and modes of behavior, a modification of the species. What was once good is so no longer. Something else, in terms of reproductive fitness, has become better.

Finally, a crude, embryonic form of science entered the scheme of things, a method of observing and reporting accurately to other persons the movements of the stars, the planets, and the sun and moon, the behavior and migrations of the food animals, the usefulness of certain seeds for food and of certain stems for fibers, the poisonous properties of others. For generations all such practical lore was transmitted only by word of mouth, but the day came when useful knowledge could be written down and preserved inviolate from the forgetfulness and the twists of memory. These were the first simple steps in the development of science: observation, reporting, written records, communication. To such must be added the processes of human reasoning, at first mostly by analogy, so often wrong; then by improved analysis, by deduction from an established truth, or by induction of an established truth from a multitude of observations.

Seen aright, science is more than the instrument of man's increasing power and progress. It is also an instrument, the finest yet developed in the evolution of any species, for the malleable adaptation of man to his environment and the adjustment of his environment to man. If the human species is to remain successful, this instrument must be used more and more to control the nature and the rate of social and technological change, as well as to promote it. In this sense, at least, science is far more than a new sense organ for comprehending the real relations of natural phenomena and the regularities we call "laws of nature." It is also man's means of adjustment to nature, man's instrument for the creation of an ideal environment. Since it is preeminently an achievement of social man, its primary function is not simply that of appeasing the individual scientist's curiosity about his environment—on the contrary it is that of adjusting man to man, and of adjusting social groups in their entirety to nature, to both the restrictions and the resources of the human environment.

Ethics is a philosophy of morals, a moral system that defines duty and labels conduct as right or wrong, better or worse. The evolutionist is quite prepared to admit the existence of right and wrong in terms of the simple functions of biological structures and processes. The eye is for seeing, an evolutionary adaptation that enables an animal to perceive objects at a distance by means of reflected light rays. Sight conveys information about food, water, danger, companionship, mating, the whereabouts and doings of the young ones, and other vitally important matters. Should one not then say, "To see is right; not to see is wrong"? Similarly, the mind reasons as it does because in the countless ages of evolutionary development its characteristic mental processes led to successful coping with the exigencies of life. Humans whose mental processes, because of different genes, too often led them to wildly erroneous conclusions did not so often leave children to reason in similar ways. It is thus right to be guided by reason, wrong to distrust it. Does it not follow, finally, from consideration of the social role and function of science, that it is *right* to utilize science to develop and regulate human social life, adjustment to change, and rate of social transformation? Conversely, it is *wrong*—morally and ethically wrong—not to do so. We must use whatever light and whatever reason we have to chart our course into the unknown.

Those who distrust science as a guide to conduct, whether individual or social, seem to overlook its pragmatic nature, or perhaps they scorn it for that very reason. Rightly understood, science can point out to us only probabilities of varying degrees of certainty. So, of course, do our eyes and ears, and so does our reason. What science can do for us that otherwise we may be too blind or self-willed to recognize is to help us to see that what is right enough for the individual may be wrong for him as a member of a social group, such as a family; that what is right for the family may be wrong for the nation; and that what is right for the nation may be wrong for the great brotherhood of man. Nor should one stop at that point. Man as a species is a member—only one of many members—of a terrestrial community and an even greater totality of life upon earth. Ultimately, what is right for man is what is right for the entire community of life on earth. If he wrecks that community, he destroys his own livelihood. In this sense, coexistence is not only necessary but also right, and science can reveal to us the best ways to harbor our resources and to exploit our opportunities wisely.

The Subjectivity of Science

From the foregoing description of science as itself an evolutionary product and a human organ produced by natural selection, it may already be guessed that I do not adhere to the view that either the processes or the concepts of science are strictly objective. They are as objective as man knows how to make them, that is true; but man is a creature of evolution, and science is only his way of looking at nature. As long as science is a *human* activity, carried on by individual men and by groups of men, it must at bottom remain inescapably subjective.

Our sensory apparatus and the structure of the human nervous system, within which arise our sensations, grow and develop as they do from the first beginnings in the human embryo because of the particular genetic constitutions we inherit from our parents. First and foremost, we are *human* scientists, not insect scientists, nor even monkey scientists. The long past of our evolutionary history, with its countless selections and rejections of various kinds of genes and combinations of genes, has made us what we are. Try as we will, we cannot break the bonds of our subjective interpretations of the physical events of nature. We are born blind to many realities, and at best can apprehend them only by translating them by means of our instruments into something we can sense with our eyes or ears, into something we can then begin to reason about by developing abstract mental concepts about them, by making predictions on the basis of our hypotheses, and by testing our theories to see whether reality conforms to our notions.

This line of reasoning leads us to the conclusion that the objectivity of science depends wholly upon the ability of different observers to agree about their data and their processes of thought. About quantitative measurements and deductive reasoning there is usually little dispute. Qualitative experiences like color, or inductive and theoretical types of reasoning, leave great room for disagreement. Usually they can be reduced to scientific treatment only if the subjective color can by agreement be translated into some quantitative measurement such as a wavelength, only if the reasoning can be rendered quantitative by use of a calculus of probability. It nevertheless remains a basic fact of human existence that the subjectivity of the individual personality cannot be escaped. We differ in our genes, each of us possessing a genotype unique throughout all past and future human history (unless we happen to possess an identical twin). To the extent that our genes endow us with similar, though not identical, sensory capacities and nervous systems, we may make similar scientific observations, and we may agree to ignore the existence of the variables in our natures that prevent us from ever making exactly the same measurements as someone else or arriving at exactly the same conclusions. But it is perilous to forget our genetic individuality and our own uniqueness of experience. These form the basis of the ineradicable subjectivity of science. In the last analysis science is the common fund of agreement between individual interpretations of nature. What science has done is to refine and extend the methods of attaining agreement. It has not banished the place of the individual observer, experimenter, or theoretician, whose work is perhaps subjective quite as much as objective.

These considerations may seem so obvious as not to require the emphasis just given them. Yet I believe not. Somehow there has crept into our writings about the nature and methods of science a dictum that science is objective while the humanistic studies are subjective, that science stands outside the nature of man. What a profound mistake! Science is ultimately as subjective as all other human knowledge, since it resides in the mind and the senses of the unique individual person. It is constrained by the present evolutionary state of man, by the limitations of his senses and the even more significant limitations of his powers of reason. All that can be claimed for science is that it focuses upon those primary observations about which human observers (most of them) can agree, and that it emphasizes those methods of reasoning which, from empirical results or the successful fulfillment of predictions, most often lead to mental constructs and conceptual schemes that satisfy all the requirements of the known phenomena.

Science, Integrity, and Intellectual Freedom

From a consideration that science is a human activity, inescapably subjective, and a product of biological evolution, it is possible to derive a genuine ethical basis of science. J. Bronowski, in an essay entitled "The Sense of Human Dignity" (*1*, p. 63), has sketched a treatment that serves well for a beginning. The values and duties which are the concern of ethics are social, he affirms. The duties of men hold a society together, he says; and "the problem of values arises only when men try to fit together their need to be social animals with their need to be free men." Philosophy must deal with both the social and individual aspects of value. Most philosophical systems have found this very difficult to do. Thus dialectical materialism swings far to the side of social values and leaves little scope for individual freedom. Positivism and analytic philosophy, as typified by Bertrand Russell and Wittgenstein, on the other hand, emphasize the values of the individual.

Hence, continues Bronowski, because the unit of the positivist or the analyst is one individual man, "positivists and analysts alike believe that the words *is* and *ought* belong to different worlds, so that sentences constructed with *is* usually have a verifiable meaning, but sentences constructed with *ought* never have" (*1*, p. 72).

The issue, then, is simply whether verification can indeed be assumed to be carried out by one man. Bronowski concludes, and I find it impossible to deny, that in the practice of science this supposition is sheer nonsense. Verification depends completely on the existence of records that may be consulted, of instruments that may be used, of concepts that must be understood and be properly utilized. In all these ways, knowledge is a social construct, science a collective human enterprise, and verification is no procedure of the naked, unlettered, resourceless man but an application of the collective tools of the trade and the practiced logic of science to the matter at hand. It is a fallacy to assume that one can test what is true and what is false unaided. But then it must follow that all verification, all science, depends upon communication with others and reliance upon others. Thus we come straight to the *ought* of science, for we must be able to trust the word of others. A full and true report is the hallmark of the scientist, a report as accurate and faithful as he can make it in every detail. The process of verification depends upon the ability of another scientist, of any other scientist who wishes to, to repeat a procedure and to confirm an observation.

Neither the philosophy of dialectical materialism nor that of the individualist accords with the basic nature of man and of scientific truth. The extreme social position leaves no room for the conscience of man and the exercise of intellectual freedom because the community dictates what is right and what a man *ought* to do. Yet the positivist's position is also faulty because "how a man *ought* to behave is a social question, which always involves several people; and if he accepts no evidence and no judgment except his own, he has no tools with which to frame an answer" (*1*, p. 72). Again, "All this knowledge, all our knowledge, has been built up communally; there would be no astrophysics, there would be no history, there would not even be language, if man were a solitary animal" (*1*, p. 73).

"What follows?" asks Bronowski, and answers (*1*, p. 73): "It follows that we must be able to rely on other people; we must be able to trust their word. That is, it follows that there is a principle which binds society together, because without it the individual would be helpless to tell the true from the false. This principle is truthfulness. If we accept truth as a criterion, then we have also to make it the cement to hold society together." Whence he derives the social axiom:

"We OUGHT to act in such a way that what IS true can be verified to be so."

So Bronowski. If his reasoning be accepted, and to me it seems unarguable, we must conclude that the cement of society is nothing less than the basic ethical tenet of science itself. The very possibility of verification, the assurance that one's own conclusions are not dreams, hallucinations, or delusions rests upon confirmation by others, by "competent" observers whom we trust to tell the truth.

The scientist's integrity. Ethics rests upon moral integrity. Science rests upon the scientist's integrity. This is so implicit in all of our science that it is rarely expressed and may be overlooked by novice or layman. Bronowski mentions examples of what happens when this basic moral commandment is violated by a scientist. Lysenko is held up to scorn throughout the world and eventually is deposed (*2*). Kammerer commits suicide (*3*). It is very interesting that both of these notorious examples, and others less well known, such as that of Tower, a quondam professor of biology at the University of Chicago, have related to attempts to "prove" or bolster the theory of the inheritance of acquired characteristics. The singular attractiveness of this theory for violators of scientific integrity is no doubt owing to its social significance, since if true it would offer a quick and easy way for man to control the direction of human evolution and would lessen the obdurate qualities of genes modifiable only by mutation in uncontrollable directions.

It is not so generally recognized by these superficial evolutionary philosophers that, if true, the inheritance of characters produced through modifications of the environment would call in question the value of all evolutionary gains, since the modified characters would themselves have no real genetic permanence and would shift and vary with every change of environment. They also do not recognize one of the most essential aspects of heredity, the protection of the genetic nature against vicissitudes. The reason why death is so necessary a part of life is that the ground must be cleared for fresh life. The reason why the genotype must remain unmodifiable by ordinary environmental causes is because the course of life for every individual involves the cumulative effects of injury, disease, and senescence. The new generation must indeed start *fresh*—that is, free from all the disabilities incurred during life by its parents and remoter ancestors. Evolution through the action of natural selection upon mutations, most of which are harmful and nonadaptive, while only a rare exemplar among them is possibly advantageous, is a process slow in the extreme. But it preserves the gains of the past, and it permits every generation to be born anew, unburdened by decrepitude, to try out its varieties of genotypes in each niche of the environment.

The loss of scientific integrity through deliberate charlatanry or deception is less common than the violation of scholarly honesty through plagiarism. The theft of another man's ideas and the claim that another's discovery is one's own may do no injury to the body of scientific knowledge, if the substance of what is stolen be true. It may even do no harm to the original discoverer, who may be dead or in no need of further credit to advance his own career. It is nevertheless a canker in the spirit of the thief and does damage to the fabric of science by rendering less trustworthy the witness of the scientist.

Plagiarism shades into unacknowledged borrowing. Which of us in fact can render exactly the sources of all his ideas? Psychologists have now amply demonstrated the ease with which self-deception enters into the forgetfulness of borrowed benefits. The wintry wind of man's ingratitude blows only on the donor of benefits forgot. Around the self-deluded recipient blow only the mildest, gentlest zephyrs of spring. The newer patterns of scientific publication and support of research have multiplied a thousandfold the opportunities for the scientist's self-deception. Editors of scientific journals today customarily rely upon referees for opinions regarding the merit of manuscripts submitted for publication. The enormous expansion of scientific activity and the development of hundreds of new specialties have made this referee system necessary. The best referee is of course some other scientist who is working closely on the same scientific problems but is not associated with the author in the actual work —in other words, a competitor, since we must not forget that scientists are people who must earn a living, and since compensation and repute follow productivity and publication. Natural selection is at work among scientists, too! What is most alarming about the workings of the referee system is not the occasional overt lapse of honesty on the part of some referee who suppresses prompt publication of a rival's work while he harvests the fruit by quickly repeating it—perhaps even extending it—and rushing into publication with his own account. What is far more dangerous, I believe, because it is far more insidious and widespread, is the inevitable subconscious germination in the mind of any referee of the ideas he has obtained from the unpublished work of another person. If we are frank with ourselves, none of us can really state where most of the seminal ideas that lead us to a particular theory or line of investigation have been derived. Darwin frankly acknowledged the ideas of Malthus which led him to the Theory of Natural Selection; but although he was one of the most honest of men, and one who was deeply troubled when Alfred Russel Wallace sent him in 1858 the brief paper setting forth his own parallel derivation of Darwin's theory, Darwin nevertheless never made the slightest acknowledgment of the idea of natural selection which he had surely read in the work of Edward Blyth in 1835 and 1837 (*4*). We may guess that Darwin's reasoning at the time went rather as follows:

Blyth's conception is that natural selection leads to a restriction of hereditary variation in populations. Through elimination of the more variable specimens in a species, nature keeps the species true to type and prevents it from becoming maladapted to its environment. Blyth's Natural Selection is not an evolutionary force at all, but instead is a force for maintenance of the status quo.

Yet it is very hard to understand why, when the full significance of the action of natural selection dawned upon Darwin, he did not reexamine the ideas of Edward Blyth. It should have been perfectly evident to him that the very same force that would eliminate variation and maintain the status quo of the species in a stationary environment would operate quite differently in a changing environment. Will we then ever know the extent to which Darwin was really indebted to Blyth, or how the ideas he probably rejected as invalid actually prepared the way for his reception of Malthus's thoughts in 1838?

The conscientious referee of unpublished scientific manuscripts is similarly a gleaner in the harvest fields of others. The only possible way to avoid taking an unfair advantage would be to refuse to referee any manuscripts that might conceivably have a relationship to one's own research work. The consequences for editors left with piles of unevaluated manuscripts might become desperate, were there not, as I believe, a reasonable solution in the possibility that the role of referee could be limited to scientists who have ceased to do active experimental work themselves. What with the increasing life span and the large number of retired but mentally vigorous older scientists, the supply of competent referees would perhaps be sufficient. To be sure, the criticism may be raised that the older scientific men cannot properly evaluate the significance and merit of really revolutionary new ideas and lines of work. Neither, for the most part, can the young! A combination of older referees in the field and younger ones knowledgeable but not working in the same specialty might solve this difficulty.

What has been said about referees applies with even greater force to the scientists who sit on panels that judge the merit of research proposals made to government agencies or to foundations. The amount of confidential information directly applicable to a man's own line of work acquired in this way in the course of several years staggers the imagination. The most conscientious man in the world cannot forget all this, although he too easily forgets when and where a particular idea came to him. This information consists not only of reports of what has been done in the recent past but of what is still unpublished. It includes also the plans and protocols of work still to be performed, the truly germinal ideas that may occupy a scientist for years to come. After serving for some years on such panels I have reached the conclusion that this form of exposure is most unwise. One simply cannot any longer distinguish between what one properly knows, on the basis of published scientific information, and what one has gleaned from privileged documents. The end of this road is self-deception on the one hand, or conscious deception on the other, since in time scientists who must make research proposals learn that it is better not to reveal what they really intend to do, or to set down in plain language their choicest formulations of experimental planning, but instead write up as the program of their future work what they have in fact already performed. Again, the integrity of science is seriously compromised.

Science and intellectual freedom. The first commandment in the ethical basis of science is complete truthfulness, and the second is like unto it:

> Thou shalt neither covet thy neighbor's ideas nor steal his experiments.

The third is somewhat different. It requires fearlessness in the defense of intellectual freedom, for science cannot prosper where there is constraint upon daring thinking, where society dictates what experiments may be conducted, or where the statement of one's conclusions may lead to loss of livelihood, imprisonment, or even death.

This is a hard ethic to live by. It brought Giordano Bruno to the stake in 1600. The recantation of Galileo was an easier way; the timidity of Descartes and Leibniz, who left unpublished their more daring scientific thoughts, was understandably human but even less in the interest of science or, ultimately, of the society that felt itself threatened. Whether in the conflict of science with religion, or with political doctrine (as in Nazi Germany), or with social dogma (as in the Marxist countries), scientists must be willing to withstand attack and vilification, ostracism and punishment, or science will wither away and society itself, in the end, be the loser.

From the beginning the inveterate foe of scientific inquiry has been authority—the authority of tradition, of religion, or of the state—since science can accept no dogma within the sphere of its investigations. No doors must be barred to its inquiries, except by reason of its own limitations. It is the essence of the scientific mind not only to be curious but likewise to be skeptical and critical—to maintain suspended judgment until the facts are in, to be willing always, in the light of fresh knowledge, to change one's conclusions. Not even the "laws" of science are irrevocable decrees. They are mere summaries of observed phenomena, ever subject to revision. These laws and concepts remain testable and challengeable. Science is thus wholly dependent upon freedom—freedom of inquiry and freedom of opinion.

But what is the value of science to man, that it should merit freedom? There are those, indeed, who say that science has value only in serving our material wants. To quote one of them: "Science is a social phenomenon, and like every other social phenomenon is limited by the injury or benefit it confers on the community. . . . The idea of free and unfettered science . . . is absurd." Those were the words of Adolf Hitler, as reported by Hermann Rauschning (*5*). In Soviet states a similar view is held officially; and in the Western democracies, likewise, not a few scientists as well as laymen have upheld a similar opinion. The British biologist John R. Baker has pointed out that this view shades through others, such as the admission that scientists work best if they enjoy their work, and the supposition that science has value in broadening the outlook and purging the mind of pettiness, to the view that a positive and primary value of science lies in its creative aspect "as an end in itself, like music, art, and literature" (*6*). "Science aims at knowledge, not utility," says Albert Szent-Györgyi (*7*); and Alexander von Humboldt wrote in his masterpiece, *Cosmos*, that "other interests, besides the material wants of life, occupy the minds of men" (*8*).

It is readily demonstrated that the social usefulness of the conclusions of science can rarely be predicted when the work is planned or even after the basic discoveries have been made. John R. Baker, in his book *Science and the Planned State*, has cited numerous examples that show the impracticability of too narrowly planned a program of scientific research. The sphere of investigation must be determined by the investigator's choice rather than by compulsion—by perception of a problem to be solved rather than by a dogma to be accepted blindly. Science must be free to question and investigate any matter within the scope of its methods and to hold and state whatever conclusions are reached on the basis of the evidence—or it will perish. But science is represented only by the individual scientists. These persons must acknowledge the moral imperative to defend the freedom of science at any cost to themselves. Every Darwin needs a Thomas Henry Huxley. Every Lysenko demands his martyred Vavilov, his hundreds of displaced geneticists before he is finally deposed. Modern science, from its very beginnings near the end of the 16th century, became immediately concerned with a major political issue, the freedom of the scientist to pursue the truth wherever it might lead him, even though that conclusion might be highly disturbing to settled religious beliefs or social conventions and practice. The pyre of Bruno and the ordeal of Galileo led directly in spirit to the attacks on Charles Darwin 250 years later and to latter-day instances of the social suppression of scientific findings. The distortion of genetics by racists in Nazi Germany finds a counterpart in the United States. Mendelian genetics in the U.S.S.R. and the nutritive qualities of oleomargarine in Wisconsin share a similar fate. The third commandment then reads:

> Thou shalt defend the freedom of scientific investigation and the freedom of publication of scientific opinion with thy life, if need be.

Science and communication. Inasmuch as science is intrinsically a social activity and not a solitary pleasure, another primary aspect of the ethics of science is the communication to the world at large, and to other scientists in particular, of what one observes and what one concludes. Both the international scope of scientific activity and the cumulative nature of scientific knowledge lay upon the individual scientist an overwhelming debt to his colleagues and his forerunners. The least he can do in return, unless he is an ingrate, is freely to make his own contributions a part of the swelling flood of scientific information available to all the world.

There are at least five distinct obligations his indebtedness places upon each scientist. The first of these is the obligation to publish his methods and his results so clearly and in such detail that another may confirm and extend his work. The pettiness and jealousy that lead some scientists, in their effort to stay ahead of the ruck, to withhold some significant step of procedure or some result essential to full understanding of the stated conclusions have no place in the realm of science. In other instances it is sheer laziness or procrastination that is at fault. Whatever the only-too-human reason, science suffers.

A second obligation that is far more frequently neglected is the obligation to see that one's contributions are properly abstracted and indexed, and thus made readily available to workers everywhere. Many scientists ignore this obligation completely. Yet, as the sheer volume of scientific publication passes a half-million and soon a million articles a year, it is obviously insufficient to add one's own leaflet to the mountains of paper cramming the scientific libraries of the world. The need to have scientific findings abstracted and indexed has been fully recognized by such international bodies as the International Council of Scientific Unions: its Abstracting Board has urged every author to prepare an abstract in concise, informative style, to be printed at the head of each scientific paper; and the editors of most scientific journals have now made this a requirement for acceptance and publication of a paper. Nevertheless, few authors prepare their abstracts without a reminder, and few heed the requirements for a concise, informative summary that will permit proper indexing of the major items treated in the paper.

A third obligation is that of writing critical reviews, which will be true syntheses of the knowledge accumulating in some field. I firmly believe that there is no scientific activity today more necessary and at the same time less frequently well done than this one. I have said elsewhere (*9*):

> To be sure, the scientist seeks for facts —or better, he starts with observations. . . . But I would say that the real scientist, if not the scholar in general, is no quarryman, but is precisely and exactly a builder—a builder of facts and observations into conceptual schemes and intellectual models that attempt to present the realities of nature. It is the defect and very imperfection of the scientist that so often he fails to build a coherent and beautiful structure of his work . . .
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> The creativity of scientific writing lies precisely here. The task of the writer of a critical review and synthesis . . . is not only indispensable to scientific advance —it surely constitutes the essence of the scientific endeavor to be no mere quarryman but in some measure a creator of truth and understanding. The aesthetic element that makes scientist akin to poet and artist is expressed primarily in this broader activity.
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> The critical nature of the critical review grows from our constant forgetfulness of all this. The young scientist is taught carefully and methodically to be a quarryman or a bricklayer. He learns to use his tools well but not to enlarge his perspective, develop his critical powers, or enhance his skill in communication. The older scientist is too often overwhelmed by detail, or forced by the competition of the professional game to stick to the processes of "original research" and "training." The vastness of the scientific literature makes the search for general comprehension and perception of new relationships and possibilities every day more arduous. The editor of the critical review journal finds every year a growing reluctance on the part of the best qualified scientists to devote the necessary time and energy to this task. Often it falls by default to the journeyman of modest talent, a compiler rather than critic and creator, who enriches the scientific literature with a fresh molehill in which later compilers may burrow.

All this need not be so, but it will remain so without a deeper sense of the obligation of the scientist to synthesize and present his broadest understanding of his own field of knowledge. Tomorrow's science stands on the shoulders of those who have done so, no less than on the shoulders of the great discoverers.

A fourth obligation is communication to the general public of the great new revelations of science, the important advances, the noble syntheses of scientific knowledge. There have always been a few eminent scientists who did not scorn to do this: Thomas Henry Huxley, John Tyndall, and Louis Pasteur set the pattern in the 19th century, and in our own time there have indeed been many who followed their precedent. Yet there seems to be a growing tendency to turn this obligation over to professional science writers who, however good, should not replace the direct, personal, and authoritative appeal of the scientist to the general public. As our culture and civilization become day by day more completely based on scientific discovery and technological application, as human exploration becomes ever more restricted to the endless frontiers of science, every citizen must know whereby he lives and whereupon he leans. A democracy rests secure only upon a basis of enlightened citizens who have imbibed the spirit of science and who comprehend its nature as well as its fruits. In fulfilling the requirement of our age for the public understanding of science the scientist must shirk no duty.

A final obligation in the total purview of scientific communication is the obligation to transmit the best and fullest of our scientific knowledge to each succeeding generation. It is well said that genetic transmission of human characteristics and powers is now far overshadowed by cultural inheritance. The transmission of knowledge is the role of the teacher, and the obligation of the scientist to teach is his last and highest obligation to the society that gives him opportunity to achieve his goals.

To every scientist—to some sooner, to some only late—there comes the realization that one lifetime is too short and that other hands and other minds must carry on and complete the work. Only a few scientists are therefore content to limit their entire energies to exploration and discovery. Research is one end, but the other must be the training of the new generation of scientists, the transmission of knowledge and skill, of insight and wisdom. The latter task is no less necessary, no less worthy. From the beginnings of human history, the exponentially accelerating growth of human power . . . has required each generation to instruct and inform the next.

This is the challenge that faces every teacher of a science as he steps into the classroom or guides the early efforts of an individual student. Here, in this sea of fresh faces—here, amidst the stumblings and fumblings—may be the Newton or Einstein, the Mendel or Darwin of tomorrow. For few—so very few—men are self-taught. The teacher cannot supply the potentialities of his students, but he is needed to see that the potentialities will unfold, and unfold fully. His is not only the task of passing on the great tradition of the past, with its skills and accumulated knowledge; he must also provide breadth and perspective, self-criticism and judgment, in order that a well-balanced scientist may grow to full stature and continue the search.

Of all the resources of a nation, its greatest are its boys and girls, its young men and women. Like other material resources, these can be squandered or dissipated. They are potential greatness, but they are only potentialities. Science creates knowledge and knowledge generates power, but knowledge resides only in the minds of men who first must learn and be taught, and power is tyranny unless it be guided by insight and wisdom, justice and mercy. The greatest of men have been teachers, and the teacher is greatest among men (*10*).

The Social and Ethical Responsibilities of Scientists

The scientist escapes lightly—instead of ten commandments only four: to cherish complete truthfulness; to avoid self-aggrandizement at the expense of one's fellow-scientist; fearlessly to defend the freedom of scientific inquiry and opinion; and fully to communicate one's findings through primary publication, synthesis, and instruction. Out of these grow the social and ethical responsibilities of scientists that in the past 20 years have begun to loom ever larger in our ken.

These may be considered under the three heads of proclamation of benefits, warning of risks, and discussion of quandaries. The first of these, the advertisement of the benefits of science, seems to be sufficiently promoted in these days when science is so well supported by government and private agencies and when grants are justified on the basis of social benefits. Every bit of pure research is heralded as a step in the conquest of nuclear or thermonuclear power, space exploration, elimination of cancer and heart disease, or similar dramatic accomplishments. The ethical problem here is merely that of keeping a check-rein on the imagination and of maintaining truthfulness. But the truth itself is so staggering that it is quite enough to bemuse the public.

Since 1945 more and more scientists have become engaged in warning of the great risks to the very future of man of certain scientific developments. First the atomic bomb and then the hydrogen bomb brought swift realization of the possibility of the destruction of all civilization and even the extinction of all human life were a nuclear war to break out. The atomic scientists, conscience-stricken, united to secure civilian control of nuclear energy. Albert Einstein and Bertrand Russell issued an appeal to scientists to warn the world of the tragic consequences of overoptimism and of an unbridled arms race. Joined by a dozen notable scientists, they initiated the "Pugwash" Conferences on Science and World Affairs in 1957. In these conferences scientists of East and West sat down together to talk, in objective scientific terms, of the military and political problems of the world and their resolution. It was not that the scientists at all felt themselves to be more highly qualified than diplomats and statesmen, economists or lawyers, to find solutions of the most difficult and delicate problems of international relations. They acted on two grounds only: that they understood the desperate nature of the situation about which the world must be warned in time; and that they hoped discussions by persons accustomed to argue in objective, scientific terms might pave the way for better understanding and more fruitful negotiation on the part of officials. In the ensuing discussions of the effects of fallout from nuclear weapons tests on persons now living and on the generations yet unborn, scientists played a very important role. In no small measure, I believe, historians of the future will recognize how great a part was played by the scientists in bringing about the partial nuclear weapons test ban. Scientists are now deeply involved in politics, and naturally enough often on both sides of the argument, for although they may agree upon the basic scientific facts which are relevant to the issue, there are rarely enough established facts to clinch the argument and there is always room for differences of opinion in interpreting the facts. In these matters the ethic of the matter requires the scientist to state his opinion on matters of social concern, but at the same time to distinguish clearly between what he states to be fact and what opinion he holds. Moreover, his opinion about matters within his technical sphere of competence is an "informed" opinion; his opinion about other matters, even other scientific matters, is that of a layman. He must in all honesty make clear to the public in what capacity he speaks.

Nuclear war is only one of the dire misfortunes that are poised above the head of modern man. The unrestricted and appalling rate of population increase in most countries of the world, if projected just a few decades into the future, staggers the imagination with its consequences. Effective control of the birth rate is the only conceivable answer to effective reduction by modern health measures of the death rate. This is the world problem second in importance at the present time, and must engage the conscience of the scientist.

The problem of the future is the ethical problem of the control of man over his own biological evolution. The powers of evolution now rest in his hands. The geneticist can define the means and prognosticate the future with some accuracy. Yet here we enter the third great arena of ethical discussion, passing beyond the benefits of science and the certain risks to the nebulous realm of quandaries. Man must choose goals, and a choice of goals involves us in weighing values—even whole systems of values. The scientist cannot make the choice of goals for his people, and neither can he measure and weigh values with accuracy and objectivity. There is nonetheless an important duty he must perform, because he and he alone may see clearly enough the nature of the alternative choices, including laissez faire, which is no less a choice than any other. It is the social duty and function of the scientist in this arena of discussion to inform and to demand of the people, and of their leaders too, a discussion and consideration of all those impending problems that grow out of scientific discovery and the amplification of human power. Science is no longer—can never be again—the ivory tower of the recluse, the refuge of the asocial man. Science has found its social basis and has eagerly grasped for social support, and it has thereby acquired social responsibilities and a realization of its own fundamental ethical principles. The scientist is a man, through his science doing good and evil to other men, and receiving from them blame and praise, recrimination and money. Science is not only to know, it is to do, and in the doing it has found its soul.

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Preserving Vegetation in Parks and Wilderness

This fragile natural resource is endangered by the lack of trained specialists and the lack of clear objectives.

Edward C. Stone

Federal efforts to preserve natural vegetation go back to 1872, when Yellowstone National Park was carved out of the public domain; state efforts go back to 1885, when the New York Adirondack Forest Preserve was established (*1*). All efforts, however, have been largely unsuccessful because of a failure to appreciate fully that vegetation is a living, dynamic complex and cannot be preserved in the sense in which a building or an archeological site can be preserved. Even the most uniform vegetation is a mosaic created by local variations in the environment and by prior events such as fire, drought, and insect infestation. When a mature plant dies, hundreds of seedlings spring up to take its place, some or all of which may be of different species. Which seedlings survive, and for how long, depends upon their relative growth potential, what effect the dead plant had on its environment before it died, and what kind of environment resulted when it died. Vegetation can only be preserved by controlling the complicated successional forces that have created it and that, if unchecked, will in turn destroy it.

The very efforts made to preserve a natural system of vegetation may bring on unplanned and undesired changes in it. That steps taken to preserve animal wildlife may have this effect is well known to the general public. By 1930 there were overpopulations of elk and bison in Yellowstone National Park, of mule deer in Zion National Park, and of deer and elk in Rocky Mountain National Park, all brought about by control of predators in and around the parks (*2*). Recognition of the problem led to a reconsideration of these practices, and today, although hampered by a lack of basic data and a restrictive budget, specialists in wildlife preservation are employed in the national parks to plan and apply sounder regulatory methods. While not so dramatic and not so widely publicized as imbalances in wildlife populations, drastic changes in the composition of many of the plant communities in the national parks have occurred during the last 50 years under fire-protection policies and heavy concentrations of use. In a number of cases these changes have progressed so far that even the once dominant plants in a wide variety of plant communities have been replaced, and now trees and shrubs occupy slopes and meadows once clothed in grass and sedge (*3*).

There are two federal agencies largely responsible for the management of national wildlands, each by charter concerned with conservation of this resource but each with different primary objectives. The Forest Service was organized in 1905 within the Department of Agriculture to manage the forest reserves—later renamed national forests—to secure favorable watershed conditions and to furnish a continuous supply of timber. Shortly thereafter, however, the Forest Service recognized

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