THE LARGER CYBERNETICS

by R. B. Lindsay

It has not been uncommon for men who have made great contributions to special fields of science to take an interest in broader issues as they grow older and, indeed, become in a measure what we may properly call philosophers. Examples abound: Poincaré in mathematics; Planck, Einstein, and Bohr in physics; Haeckel in biology; William James in psychology—all come to mind. Here I should like to call attention to a great French scientist who followed a similar route. Some may be surprised at the mention of the name of the physicist known to all from the practical unit of electrical current: André Marie Ampère (1775–1836)—one of the founders of electromagnetism. His profound mathematical memoirs of 1820–25, amply confirmed by careful experimental research, laid the foundations of what came to be called electrodynamics and, when supplemented by the later discoveries of Michael Faraday and Joseph Henry, provided the technological basis of our modern, electrically oriented civilization.

Later in his career (in 1834) Ampère wrote a brilliant document, "Essai sur le philosophie des sciences," in which he took a particularly broad view of the philosophy of science, including social and political studies as well as the better-established natural sciences, in his discussion. It was in this memoir that Ampère first introduced the term *cybernetique* to refer to the science of government. He evidently felt that this was appropriate terminology since κγβερντεσ is the Greek for helmsman or governor, the one who controls the direction of the ship. This may be considered the beginning of the formal recognition of the science of control, though it does not appear that Ampère's definition gained much attention in the nineteenth century, nor in our own century for that matter, until Norbert Wiener resurrected the term in his book called *Cybernetics,* published in 1948, and attempted to put the subject on a more formal basis.

From the humanistic point of view, I am naturally tempted to pause here to consider the possible relation of cybernetics as the science of

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control to the motto of Phi Beta Kappa, the honorary scholastic society now approaching the bicentennial of its founding. For this motto, *Philosophia Biu Kubernates,* is usually translated: "The love of wisdom is the helmsman of life." There is little doubt that the founders of this fraternity, so celebrated in American collegiate annals, felt very strongly the appropriateness of the motto. And on the whole, down through the past two centuries it has seemed to have a meaning for those who, by devotion to academic studies, have convinced themselves that such studies can lead to that wisdom which serves as the best guide to the conduct of life. It is true that in some academic quarters today doubts seem to be arising about the validity of the motto.

Transfer and Transformation of Energy

However, it is not my intention here to dwell further on Phi Beta Kappa, its significance and problems. What I wish to do is to emphasize that the fundamental idea of helmsmanship or control is one of the vital factors in the whole of human experience. From the standpoint of the scientist the reason for this is simple. It has to do with the prime position in the interpretation of human experience of the concept of energy, the most important idea in the whole of science. Representing in its simplest form the notion of constancy in the midst of change, it has come to pervade all aspects of life. There is nothing in our experience which cannot ultimately be described in terms of the transfer of energy from one place to another and for the transformation of energy from one form to another.

An illustration or two will remind you of this important scientific generalization. When you start the engine in your car, you are initiating a transformation of chemical energy (the rapid combustion of a gas mixture) into thermal or heat energy and thus in turn into the mechanical energy of the pistons in the cylinders. This energy of motion, however, does not remain localized in the engine but is transferred by the crankshaft to the rear wheels, thus enabling them to move and make the car go. The details may be complicated but the fundamental idea is simple.

A second illustration is provided by the processes going on inside our bodies as we digest our meals. We avoid details but merely emphasize that in substance what happens in metabolism is the transformation of the energy of chemical reaction, in which certain substances are changed into other substances which are then conveyed mechanically by the blood to the various parts of the body, where they provide for the so-called life of the cells. A large part of this chemical energy is converted into heat to keep our bodies warm; some into the mechanical energy of bodily movement, which, as it ceases, is transformed ultimately into heat. There is of course the additional complication of the conversion of some of the energy into electrical energy in the muscles and nerves. But the fundamental idea behind the whole business is that of the transformation into that random form of energy that we call heat. It is exemplified by the popular admonition that you must watch your *calories,* for the calorie is the standard physical unit of heat.

Appropriately enough, the first evaluation of the important numerical constant governing the transformation of heat into work and work into heat (the so-called mechanical equivalent of heat) was made not by a physical scientist but by a physician, Julius Robert Mayer, one of the scientific immortals of the nineteenth century and one of the founders of thermodynamics, the greatest physical theory ever concocted by the mind of man.

There seems to be no reason to doubt that not only is the physical behavior of human beings describable in terms of energy, but that the same is true of mental and emotional behavior commonly ascribed to the nervous system. It is not necessary to give further examples from the inorganic realm: they are all around us in terms of the various engines and other devices which, as we say, do the work of the world. In sum, all that goes on in the civilization that man has invented, including all the activities of living things, can be described most simply in terms of the transfer and transformation of energy.

Control of Energy Changes

It takes little reflection to convince oneself that life itself could never have developed nor could civilization have been invented without the *control* of all the energy changes involved. The study of such control is the province of cybernetics. Let us consider a couple of simple illustrations. One of the most important devices for the transformation of heat into mechanical energy or work was and still is, for that matter, the steam engine. An early problem of some technical difficulty involved in such an engine was to keep it running smoothly in spite of variations in the load on it. Without attention to this matter, if the device being driven by the engine demanded energy at too great a rate, the engine would stall; on the other hand, if the load dropped to nothing, the engine would race. Obviously some kind of control was needed. At first this was taken care of manually. A human being was deputed to control the flow of steam into the cylinder by somehow keeping track of the variations in the load. This was a clumsy kind of control. It was obvious that someone would think of something more clever than that. This happened when James Watt, the canny Scot, invented what he quite appropriately called a governor, a device attached to the engine which employs a small amount of the energy being transformed by the engine for controlling the rate of this transformation. The details are not important. What is significant is that the governor used a little of the engine's energy to ascertain when the load demanded more or less power and communicated the relevant message to the throttle, telling it in effect to let in more or less steam as needed. This is a process known in cybernetics as feedback. Watt was one of the first applied cyberneticians and, though he did not use the modern terminology, evidently had a very firm grasp of the basic principle of feedback control.

To return to your car which you have now put into motion, thanks to the transformation of energy you have initiated, your prime necessity is to steer it properly and control its speed. These are cybernetic activities in which you use a very small amount of energy, namely, that in your eye motions and the motions of your hands and feet to control the relatively large amount of energy involved in the motion of the car. You are indeed the steersman and, in modern parlance, a cybernetician.

Another familiar example is the operation of the simple thermostat which regulates the temperature of our living spaces. This ingenious device utilizes a very small portion of the heat energy of the room to inform the burner in the heater in the basement to transform more chemical energy into heat in order to raise the temperature of the room or to stop the transformation in order to bring the temperature down. Here is again a process of feedback control or the control of relatively large amounts of energy transformation by the use of a relatively minute amount.

Even more important is the vital feedback control in our bodies, without the presence of which human life would become impossible. Everyone must have heard of homeostasis, a word made famous by the late Dr. Walter B. Cannon of the Harvard Medical School in his book *The Wisdom of the Body*. It means among other things the regulation of bodily temperature by an elaborate control system in which a small amount of energy (i.e., heat loss or gain) in the skin sends a message to the thalamus, which in turn induces mechanical energy increase in skeletal muscle or in the blood vessel endings in the skin. The details of the process are complicated, but the fundamental basis for the automatic body regulation of temperature is again feedback control or an example of cybernetics: the wise governor that the process of evolution has developed for enabling so-called warm-blooded animals to face the thermal vicissitudes of their environment.

Still another example of cybernetic control is involved in speech communication in human beings. Think of the enormous amount of energy transformation that can be brought about by the utterance of a single word! Examples are unnecessary! Without such communication there could have been no development of human civilization as we know it. What is worth emphasizing is the relatively small amount of speech energy needed to control the transformation of enormous amounts. If I were presenting the contents of this essay orally to an audience, my voice would need to provide speech energy only at the rate of about 1/10,000 of a watt. This would be the power being dissipated as the mechanical power in the sound radiated from my mouth as a speaker. Let us suppose you can buy energy from the electric power company at about five cents per kilowatt hour. It is simple arithmetic to figure out that I should have to keep on talking at that pace for over one thousand years in order to provide a nickel's worth of energy or enough to keep a three hundred–watt lamp going for a bit over three hours. You have always suspected that talk is cheap. This simple calculation should convince anyone!

Nature—the Great Cybernetician

The point here is that Nature, the name we give to the content of our experience which we interpret as being independent of ourselves, also seems to exert control over the transformation of energy. Nature is indeed in the last analysis the great cybernetician. Its control is exercised in terms of the two great principles of thermodynamics, already mentioned as the science which deals with energy. The first principle, established by Mayer and confirmed by the Englishmen Joule and others, says that the total energy in the universe of our experience is constant. All we can do is to transfer or transform it; we can never change its total amount.

Application of this fundamental principle is indeed part of the accumulated wisdom of our race. In fact the authors of the sacred writings of the Judeo-Christian tradition included it in the scriptures. For in the third chapter of the Book of Genesis, we learn of God admonishing the sinners in the Garden and saying: "In the sweat of thy face shalt thou eat bread." This is the first law of thermodynamics. The clever ones have indeed through the ages tried to arrange matters so that someone else's sweat was required, but that does not invalidate the principle that someone has to sweat to provide subsistence for the race and that, in our universe, on net balance you do not get something for nothing, or as some modern wit has put it, you cannot win! Other clever ones have tried to extract work out of so-called perpetual motion machines but have never succeeded. Here is one of Nature's means of control over the transformation of energy; there seems to be little we can do except put up with it. As Mayer liked to phrase it: *ex nihilo nil fit.*

As a matter of fact, one of the best expressions of the first law of thermodynamics is the famous essay of Ralph Waldo Emerson, *Compensation.* The shrewd Yankee moralist was keenly aware of that inscrutable duality of human experience involved in the fact that there is never a gain without a compensatory loss, never a plus without a minus, never a good without a connected evil. It may be objected that this is an unnecessarily pessimistic view of experience, but I think it is just as valid for the optimist. All he can truthfully say is that for every minus there is a plus, while a pessimist merely says that for every plus there is a minus. As Emerson himself might have said, it comes to the same thing in the end.

But now I must emphasize that the first law of thermodynamics, the principle of the conservation of energy, is not the only natural control in our environment; not the only grip that Nature has on all our energy transactions, whether in the marketplace, the home, or even the racetrack. Nature appears to have another trick up its sleeve, in many ways a cruel trick. It reinforces its control over energy transformation by relentlessly arranging that every time any energy transformation takes place under natural conditions the chance of the repetition of the transformation is reduced by a measurable amount. Every time an engine goes through a cycle there is an inevitable degradation of the availability of energy to repeat this process. Every time you light up a cigarette you decrease by a certain amount the chance of lighting another one. This is the principle of the increase of entropy, the measure (introduced by the German physicist Rudolf Clausius) of the steady decrease in the *availability* of the constant amount of energy in our universe. This is the second law of thermodynamics: Nature's ultimate control, the cybernetics of the universe. It leads to the conclusion that the ultimate end of our universe is the heat death, in which, though the total amount of energy remains the same, no part of it is in a condition for further transformation. Nothing further can happen so far as energy transformation is concerned.

It must be emphasized that the heat death as a conclusion from the second law of thermodynamics is based on the extension of the principles of thermodynamics to the whole universe. Clausius was content with nothing less. In his famous 1885 memoir he expressed the principles in the simple form:

> Die Energie der Welt ist constant.
> Die Entropie der Welt strebt einem Maximum zu.

In this extension of thermodynamics to the universe we part company with the orthodox thermodynamics of the chemists and engineers, who insist on restricting the application of the principles to closed or isolated systems (or to those which, if open, can effectively be closed by considering finite portions of the environment). The attitude is understandable, since by this restriction they are able to calculate energy and entropy changes in specific systems of practical interest. The extrapolation to the whole universe seems to be a dangerous one from the standpoint of strict logical clarity. Nevertheless it is a tempting procedure, and many physicists have found illumination in it. This point of view rests heavily on Ludwig Boltzmann's interpretation of entropy as proportional to the logarithm of the statistical probability, which in turn is the number of ways in which a given system can be distributed over the possible energy states available to it. On this view the second law merely means that the total state of the universe tends to move toward a state of greater probability, a kind of tautology. Some have sought to rephrase this by introducing a concept of order and saying that the natural tendency of the universe is to move from order to disorder. This has been criticized on the ground that the concept of order is difficult to define precisely so as to make it fit logically all cases. Fortunately for the cybernetic implications of thermodynamics as applied to the universe, we do not really need to use the order-disorder notion. All we need to do is to say that the second law implies the steady increase in entropy in the universe, meaning thereby the corresponding degradation of the availability of energy for further transformation.

This means that it will do no good affixing stickers to our cars with the slogan: "Save America from Entropy." Here is a war we cannot win. All experience teaches us that the steady decrease in the availability of energy for new transformations is an irresistible and irrevocable one. All experience shows that this transition, which for the individual living organism we call the downhill march to death, is the fate of each one of us. The second law assures us that it is the fate of our universe as a whole.

The Thermodynamic Imperative

To prevent unhealthy concern, a few words of encouragement are in order. The first relates to the time scale. Relative to the time range of human history, the degenerative process described by the second law is a slow one; it is just as well to relax. Lots can happen before the final heat death. In fact some astronomers consider that the sun on which all life on earth depends may in due course become a supernova and blow up. In this case our paltry little planet may wind up its independent existence with a bang, even though the universe rolls on serenely with its steady entropy increase toward the eventual end as T. S. Eliot's whimper, an appropriate one-word metaphor for the heat death.

C. P. Snow has complained that humanists have been content to remain ignorant of the second law of thermodynamics. He seems to have overlooked Eliot and, somewhat more surprisingly, the Victorian poet A. C. Swinburne, the final stanzas of whose "Garden of Proserpine" constitute one of the best versions of the heat death implied by the second law we could ask for:

> Then sun nor star shall waken
> Nor any change of light
> Nor sound of waters shaken
> Nor any sound or sight
>
> Nor wintry leaves nor vernal
> Nor days nor things diurnal
> Only the sleep eternal
> In an eternal night.

How much more appealing this is than Clausius's statement quoted above! We can be fairly sure that many modern poets have tried to express the same thing that Swinburne did in his somewhat jingly verse. At any rate, Swinburne's verse has the merit of being intelligible, whereas in most modern poetry you need a computer to extract the signal from the noise.

Another silver lining in the apocalyptic gloom of the second law is that life itself constitutes what may legitimately be called a fight against the increase in entropy. For life is a local consumption of entropy in the midst of the sea of its production. This is true in the sense that the production and maintenance of a living cell represent the local increase in the availability of energy for transformation. It does not mean that the living cell contravenes the second law, for in its environment the entropy still tends to increase irreversibly. But it does mean that life constitutes a local consumption of entropy in the same sense as the operation of the domestic mechanical refrigerator, which makes heat flow from a cold to a warmer region in the face of the natural tendency for heat to flow the other way. Locally, the refrigeration process consumes entropy, though there is still an overall production of entropy represented practically in the monthly electric power bill.

More important still, life in the form of human beings has through thousands of years waged a relentless struggle to build a civilization which represents an attempt to increase the availability of energy for transformation or, as some would prefer to put it, to fashion order out of disorder. Even though the second law guarantees that the struggle will not avail and that we must all go down ultimately to defeat, the challenge to fight on is still there. To me it conveys the distinct suggestion that we as individuals should endeavor to consume as much entropy as possible to increase the order in our environment. This is the thermodynamic imperative, possibly not unworthy to rank alongside the categorical imperative of Kant or even the Golden Rule.

The relevance of the thermodynamic imperative is particularly great at this late twentieth-century period of social disorder and threatened educational disruption. We think here not merely of the urge to destroy the visible material signs of the civilization which has been painfully built up over the ages, but the denial by many people that rational thinking has any part to play in our confrontation with the hard facts of human experience. Now rational thought as represented not only by science but also by philosophy, religion, and indeed all the humanities, constitutes the crux of man's endeavor to associate meaning with his experience and establish order in it. The denigration of rational thinking in our education of the young would constitute an abdication of our fight against the second law. Man's lot has been and is a hard one. We shall not make it easier by abandoning the only way in which we can cope even in limited fashion with Nature's ultimate cybernetic control.