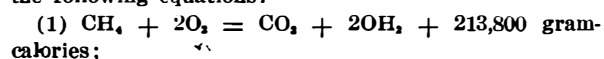


Is the Organism a Thermodynamic Mechanism—I*

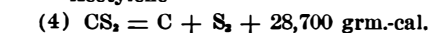
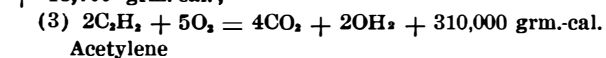
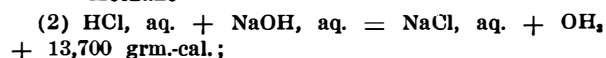
A Consideration of Certain Organic and Inorganic Systems in Relation to Physical Laws

By James Johnstone, D.Sc., University, Liverpool

LET us consider the chemical reactions represented by the following equations:



Methane



Carbon disulphide

The first two reactions are typical examples of processes which occur commonly in organic and inorganic systems. The first represents an oxidation, and the second a neutralization. When methane burns completely in oxygen carbon dioxide and water are formed, and a certain quantity of heat is evolved. When very dilute hydrochloric acid is added to very dilute caustic soda a neutral salt, also in dilute solution, is formed. If quantities of each of the reacting substances equal to the molecular weights, in grams, represented by the formulæ take part in the chemical changes, quantities of heat represented by the numbers given on the right-hand sides of the equations are evolved. The reactions are *exothermic*. In most chemical changes the "intrinsic energy" contained in the substances before they react is greater than is the intrinsic energy contained in the products formed by the reaction, and the balance of energy appears as evolved heat. The 213,800 gram-calories of equation (1) are the heat of combustion of a gram-molecular weight of methane; and the 13,700 gram-calories of equation (2) are the heat of neutralization of gram-molecular weights of hydrochloric acid and sodium hydrate.

Equations (3) and (4) represent also exothermic reactions. In the first of these acetylene burns completely in oxygen; and in the second one carbon disulphide is decomposed into its elements. When acetylene burns in this way 310,000 gram-calories of heat are evolved; and when carbon disulphide is decomposed completely 28,700 gram-calories are evolved. Now, if we calculate, from known data, the heats of combustion of the carbon and hydrogen contained in a gram-molecular weight of acetylene we shall find that it is only 256,900 gram-calories; therefore the balance of 53,100 gram-calories must be absorbed when carbon and hydrogen are synthesized as acetylene. Also when carbon and sulphur are synthesized to form carbon disulphide 28,700 gram-calories, the heat of dissociation of the compound must also be absorbed. These reactions, the combination of carbon and hydrogen to form acetylene, and carbon and sulphur to form carbon disulphide, are therefore *endothermic* reactions. In them the intrinsic energy of the final product is greater than the intrinsic energy of the initial substances.

The difference between the two kinds of chemical change—exothermic and endothermic changes—is fundamental. Nearly all substances which react with each other do so with the evolution of heat. A few reactions occur in which heat is neither evolved nor absorbed, but these are of an altogether special kind. A few reactions also occur in which heat is absorbed. These, also, are special chemical changes; they are not numerous; and the products resulting from them are unstable as a rule.

Considering further the above reactions two things are to be noted. First, exothermic reactions occur of themselves. Immediately caustic soda is added to hydrochloric acid neutralization begins. Methane and oxygen do not react at ordinary temperatures (or they react "infinitely slowly") but an infinitesimal amount of energy starts the reaction which then proceeds until it has been completed. Endothermic reactions, on the contrary, do not occur of themselves: carbon and hydrogen will not react by themselves to form acetylene, nor will carbon and sulphur to form carbon disulphide. These reactions will not occur, as does the explosion of a methane-oxygen mixture, when an infinitesimal "stimulus" is applied. In order that they may take place a compensatory energy-transformation must be set up, and in this compensating reaction an amount of energy equal to that absorbed in the endothermic change is supplied. I have emphasized the above sentence in order that the reader may appreciate the importance that it has for our later discussion.

The second thing to notice is that the equations show that chemical reactions are *directed changes*. In all

exothermic reactions, that is, in the vast majority, heat is evolved. If the reaction takes place of itself, that is, apart from intelligent ordering of the conditions under which it occurs, this heat is dissipated: it is conducted away, or radiated, and it raises the temperature of its physical surroundings to an infinitesimal degree, so that it can no longer be recovered or made use of to produce further transformations. In all physical or chemical changes of this category the heat so produced becomes *unavailable*; and the products of the changes, if they are chemical changes, possess less intrinsic energy than did the original substances. Thinking about chemical changes in general we see, then, that each one that takes place exothermically reduces the probability of the occurrence of further exothermic changes, since in it some part of the available energy of the universe has become unavailable. Every such chemical reaction tends towards stability, since the products are less likely to react with each other, or with other substances, than were the original substances.

The opposite tendency is exhibited by endothermic changes, for in such the products of the reaction possess a greater quantity of intrinsic energy than did the original substances. The reaction tends towards instability, for the substance which is formed endothermically is more likely to react (it is often explosive) than were the substances from which it was formed. In the preparation of an endothermic substance some heat is certainly dissipated, since we cannot avoid the loss of heat by conduction and radiation, and we cannot, as a rule, control perfectly the progress of the reaction. But the general result of the change is that energy remains in the available form, and can be made use of in the production of other energy-transformations.

We may now generalize these statements. All physico-chemical changes whatever, organic or inorganic, exothermic or endothermic, are said to conform to the two laws of thermodynamics. The first law states that the energy of an isolated system is constant, that is, by no conceivable change occurring within the system can the sum of potential and kinetic energy contained in it be diminished or augmented. If we couple the law of conservation of energy with the law of conservation of matter (in modern views the latter is, of course, contained in the former), we arrive at the conclusion that nothing in the universe can be created, nor can anything be destroyed. But the second law of thermodynamics states that something which is characteristic of an isolated physico-chemical system, its sum of entropy, tends continually to become augmented. Our only isolated system is the universe, and the most general statement of the second law is that the sum of entropy of the universe tends continually to a maximum.

We cannot discuss here the shadowy mathematical concept called entropy, but we may state the second law (partially, but correctly for our purpose) in saying that something is irretrievably destroyed in every physico-chemical reaction that occurs. This something is available energy. Energy, potential or kinetic, that is, energy of position or the energy of motion of entities possessing mass, which can be made use of in producing or setting up transformations, or natural phenomena, is available energy. The heat energy of one part of a system which is at a higher temperature than another part, for instance, the energy of steam in a boiler in relation to the energy of the condenser water is available. Energy which cannot be utilized to set up transformations—to do work—is unavailable; such is, for instance, the heat energy of the ocean in relation to the engines of a ship traversing it. In order that some of the energy of a system may be available some part of it must be at a higher potential than another part. If there are no differences of potential the energy is unavailable. Now, in all natural changes, or phenomena, or energy-transformations, there is an ever-present tendency for some fraction of the total energy manifested in the change to become converted into low-temperature heat. Such heat becomes conducted or radiated into the earth or into space, becomes uniformly diffused, and so becomes unavailable. This occurs in endothermic and exothermic processes. In the imaginary world of mathematical physics natural phenomena may occur in systems with perfectly elastic or perfectly rigid parts, where there is no friction, and where heat is either perfectly conducted or

perfectly insulated. But in the real world all natural processes are such as involve friction and loss of heat. In all of them some energy becomes unavailable. All of them are *irreversible* processes, that is, processes which cannot be retraced. With every such irreversible process some part of the available energy of the universe becomes unavailable. With every natural phenomenon that occurs the number of phenomena that may occur in the future becomes appreciably less. "Every irreversible transformation leaves an indelible imprint *somewhere or other* on the progress of events in the universe considered as a whole."

Thus there is a *tendency or direction* in the progress of inorganic happening. Energy is continually being degraded, continually passes from the available into the unavailable form. With every such transformation the number of things that may happen in our universe in the future becomes less. The universe tends toward a limit which is the cessation of all phenomena—universal physical death. There is nothing fanciful or metaphysical in this conclusion. It is a sound deduction from the results of physical science. It is the plain outcome of our experience.

And yet it is perfectly clear that we cannot extend it, *a priori*, to the universe as a whole. We must extend universally the law of the conservation of energy—it is unthinkable that it cannot apply to all that exists. If we imagine, literally, that the sum of available energy in the universe was infinite, then the fall of available energy is asymptotic to time considered as the independent variable. But we must also regard time as infinite, that is, we must think of the universe as having, literally, no beginning and no end. Obviously, we are only juggling with words in these statements. Infinite time is really time that has as great a duration as we please to conceive. Then in the lapses of duration that lie in the past of our universe the limit to the fall of available energy must have been attained if the second law be universally true. But we look out upon a universe which is still the theatre of inorganic phenomena. The second law cannot, then, be universally true, like the first law is universally true. But it is true of all that comes within our experience.

Thus we come to an *impasse*, for two aspects of our experience seem to be flatly contradictory to each other. On the one hand the results of experimental physics show us a universe in which there is a progressive degradation of energy, that is, an energetic system which had a beginning and will come to an end. On the other hand experience also shows us a universe in which natural phenomena still occur, and for which we can postulate any past duration, however great. Now there appears to be *only* one way out from this deadlock; somewhere or other in the universe *there must be a restoration of available energy*. This is the explanation suggested by Boltzmann, and we may usefully consider it here, since it suggests at once a manner of regarding the activities of the organism which indicates that a theory of life may, after all, be possible.

Let us consider, then, a volume of a "perfect" gas equal to, say, one tenth of a liter. Let this gas be contained in a vessel made of some perfectly non-conducting material, and let the vessel have a partition, also made of non-conducting material, dividing it into two chambers. Let the gas in the two chambers be at unequal temperatures, T_1 and T_2 , T_1 being greater than T_2 . Now let the partition be withdrawn so that the gases mix. In a few minutes thermal equilibrium will be established and the temperature of the mixture will be, everywhere, sensibly the same.

A perfect gas consists of a very large number of molecules moving in straight lines at very high velocities. These molecules incessantly collide with each other, and since they are perfectly elastic no energy is lost in the collisions. They must be moving in every conceivable direction and (within a certain range) at different velocities. But there is, at a definite temperature and pressure, a certain mean molecular velocity toward which the greater number of the molecules approximate. Some are moving at higher, and others at lower velocities than the mean one, and these velocities other than the mean deviate from the later in such a way that they can be represented by a "frequency distribution" with the mode at the mean. For two gases differing only in their temperature the squares of the mean velocities are proportional to the absolute temperatures, that is, $V_1^2 : V_2^2 = T_1 : T_2$.

Since the molecules of the gas are moving with dif-

*From *Science Progress*.

ferent velocities, and in every conceivable direction, the result of their collisions must be that molecules moving with speeds above the mean will tend, owing to collisions with molecules moving with speeds below the mean, to lose some of their velocity. When the two gases at different temperatures are allowed to mix the molecules of the hotter one will communicate to the molecules of the cooler one some of their velocity of movement. Thus the temperature of the cooler gas must increase while that of the hotter one must decrease. This is a progressive change requiring some time (a matter of minutes). At each momentary phase of the progressive change there is a new distribution of the molecules and of their directions and velocities of movement. Every such phase is, of course, a dynamical consequence of the preceding phase. When thermal equilibrium has been attained the mixture of molecules has a new mean molecular velocity with individual deviations from the mean represented by a new frequency distribution.

Now it can be shown that if, at the moment at which thermal equilibrium is attained, the direction of motion of each molecule were to be reversed, the series of changes through which the mixture had passed would also be reversed. It would gradually become separated into two masses of gas, each of them characterized by its original temperature. Instead of having a gas at uniform temperature in every region we should have a gas separated into two parts, in thermal contact with each other but having different temperatures. The progressive change from two masses of gas at unequal temperatures to one mass of gas at uniform temperature would be reversed. The series of momentary phases leading from inequality to equality of temperature would be exactly followed, but in inverse order.

It is important to note here that the second law of thermodynamics would apparently be "violated." Heat would flow, of itself, from a body at low, to a body at high temperature. But if this were to happen, perpetual motion would be possible, whereas we know (at least it is our experience) that it is impossible. Therefore we must conclude that heat cannot flow, of itself, from a body at lower to another body at higher temperature, and we seem to be justified in concluding that this imaginary simultaneous reversal of motion of all the molecules of a gas cannot take place.

Yet it may conceivably take place. At any instant many of the molecules in a deciliter of gas must be approaching each other in the same straight line, and with the same velocity. As the result of such collisions the direction of motion of these molecules must be reversed, the magnitude of their motions remaining unchanged. The number of such molecules as collide "end on" is continually changing; sometimes there are relatively many, sometimes few. The probability of any fraction of all the molecules so colliding can be calculated, and also the probability that all the molecules should collide end on, so leading to a reversal of the physical history of the gas. The calculation has been made by Boltzmann. It is possible that this simultaneous reversal of motion of all the molecules in a

deciliter of perfect gas may occur, but in order to witness it we might have to observe the gas for a lapse of time represented (in centuries) by unity followed by a thousand millions of ciphers! The chance is thus very small. It is about equal to the chance that all the houses in London might catch fire, independently of each other, on the same day, or that all the men in London might commit suicide, independently of each other, on the same day. An insurance office would certainly disregard such risks. They would say that it was "practically impossible." So we must say that it is "practically impossible" that heat should flow, of itself, from a colder to a hotter body; that perpetual motion is a practical impossibility; and that it is also practically impossible that the second law of thermodynamics does not apply to all physical and chemical transformations. We say, therefore, that all natural phenomena have the same tendency—toward degradation of energy, or augmentation of entropy—and much of our power of so ordering naturally occurring events, or of forecasting future events, depends on our confident assumption that this tendency will continue to hold true. It is almost certain that the second law of thermodynamics will be valid in all our future experience as it has been valid in all our past.

"Almost certain," we say, but not logically capable of demonstration—not inevitable. The first law—that of conservation—is *a priori* certain, that is, it is unthinkable that it should not be universally true. But the second law is only a probability—a very great probability if we like. Now let us regard the deciliter of gas of our example as a "model," in a kind of way, of the universe. Like the universe we may describe it as a "collection of isolated mass points, devoid of rotatory inertia, moving in accordance with Newton's laws, and attracting or repelling each other with forces which are continuous or discontinuous functions of the distance between them." If, then, we extend the general conclusions deducible from the kinetic gas-theory to the Universe itself, we might consider whether heat may flow, of itself, from colder to hotter regions—in general, whether there may not be, somewhere, a restoration of available energy. The possible form of such a speculative process would depend on the cosmology we adopt; obviously we cannot consider it in detail now. But clearly this restoration of available energy may occur in the universe, and the probability that it does so occur is of the same order as that in Boltzmann's estimate.

The probability is, as we have seen, unimaginably small. But the universe is as unimaginably great. What do we mean by saying that the universe has infinite extension and duration? We do not mean that it has, literally, no boundaries; nor that it had no beginning and will have no end. To say as much is to play with pseudo-ideas. When we say that the universe has infinite extension we mean that no matter how great, in finite numbers, it may be conceived to be, it can still be conceived as greater; and so also with its duration. That is to say, we can make the universe as big as we like, or as old as we like, while still re-

garding the dimensions we ascribe to it as such as are capable of mathematical treatment. Its extension and duration are "infinite" in the sense that we speak of infinitesimally small magnitudes in the theory of the differential calculus. The radius of the earth, the distance of the earth from the nearest fixed star, and its distance to stars of no parallax are to be regarded as infinitesimals of the $(n-1)$ st, $(n-2)$ nd, and $(n-3)$ rd orders. The duration of a man's life, the age of the habitable earth, the age of the solar system, may also be so regarded. It does not matter now that the probability of a restorative of available energy is incredibly small. We can suppose the duration of the universe to be as much greater as we wish.

The universe that we know is the material universe in which there are energy-transformations. We may regard it as an infinitesimally small part of all that exists—the entire universe, let us say, in short. Its duration we may also regard as an infinitesimally small part of the duration of the entire universe. The latter is physically dead: the sum of its entropy has attained its maximum value. But here and there in it are regions of the magnitude of our known stellar universe—individual universes, Boltzmann calls them—but infinitesimal in their extension when compared with the entire universe. In these individual universes, for moments when compared with the duration of the entire universe, but for eternal eras (Aeonon) when compared with a human lifetime, the second law of thermodynamics becomes reversed, just as it does in our imaginary deciliter of gas. Physical inertia is "normal," that is, it is the most probable condition of a dynamical system in the general sense. But in small regions of the entire universe, and for infinitesimal periods of duration, the improbable condition may obtain. It does occur in regions of a deciliter of gas, if we take these regions small enough. Here and there there are certainly small groups of molecules, in which, for a very small time, the mean linear velocity, and therefore the temperature, is greater than in adjacent regions.

Such a universe, one in which there was physical activity, as there is in our universe, would be passing from an improbable toward a more probable phase. The most probable phase would be that in which entropy had attained its maximum value; the least probable phase would be that of zero entropy. The phase of physical activity would be preceded by a phase of restoration of available energy, that is, a passage from the most probable to the least probable condition. Time would have a double sign. The passage from the improbable toward the probable conditions would occur in our time, that is, from the past to the future. But in the period of restoration of available energy the scale of time would be reversed, and the passage from the most probable to the least probable phase would occur in time which moved from the future back into the past. Conscious organisms in such a phase of an individual universe would possess knowledge of the future but not of the past.

(To be concluded.)

Limits of Experimental Investigation

By Our Berlin Correspondent

THE problem as to where the limits accessible to experimental investigation are reached has ever been one appealing to the human mind. While it would be premature to answer the question in an absolute manner, assigning to scientific work a boundary never to be exceeded, the limits corresponding to the present state of science can be ascertained with a high degree of accuracy.

The lowest temperature obtainable by artificial means, until 20 years ago, was -87 deg. Cent., liquid carbonic acid being used for its production. When then Prof. Linde, by the construction of his refrigerating machine, opened up new fields to cold storage scientists succeeded in working at temperatures as low as -190 to -200 deg. Cent. Since hydrogen does not boil above a temperature of, say, -253 deg. Cent. the use of this liquefied gas allowed even lower temperatures to be reached, while helium, the boiling point of which lies at -269 deg. Cent., quite recently enabled Dr. Kamerlingh-Onnes nearly to reach the temperature of absolute zero.

As pointed out by Prof. Kurt Arndt, in a lecture held at the Society of German Chemists, the temperature of the electric arc forms a counterpart to this lowest temperature reached by artificial means. It is true that the temperature of the electric arc is anything but uniform, 3,000 to 4,000 deg. Cent. being recorded at some places, while others only show temperatures as low as 1,000 deg. Cent. Whenever constant temperatures are to be used for purposes of scientific investigation, they must therefore be produced by means of electric radiators. Thin nickel wires traversed by

electric currents will be sufficient in this connection up to 1,000 degrees, while Heraeus' platinum furnaces are used above this limit, and iridium metal (which, it is true, cannot be drawn out into wires or hammered,) between 1,500 and 2,000 deg. Cent. Since the melting point of tungsten is as high as 3,000 deg. Cent., its use allows even higher temperatures to be reached, though on account of its sensitiveness to atmospheric oxygen, this element must be kept in the vacuum. The highest temperatures (up to 2,700 deg. Cent.) therefore are preferably produced by the aid of carbon resistances, used in connection with several types of electric furnaces.

The most varied instruments are used to gauge the low and high temperatures thus produced. Degrees of cold can be determined with mercury thermometers only as far as -38 deg. Cent., which is the freezing point of mercury. Liquid thermometers, filled with liquids, such as pentane, will suffice down to temperatures of, say, -100 deg. Cent., when pentane becomes plastic. Resistance thermometers, designed by William Siemens (and based on the increasing electrical conductivity of platinum with decreasing temperatures) serve for the measuring of temperatures still lower. The relation between temperature and the resistance of platinum being known, temperatures above $-1,000$ deg. Cent. can be gaged by this means. Thermo-electric pyrometers (based on the production of electric currents by heating the contact between certain metals and metal alloys) are used in determining temperatures between 500 and 1,500 degrees, while optical pyrometers—in connection with which the surface brightness of incandescent bodies is determined by an optical process—must be resorted to in the case of tempera-

tures even higher than 1,500 degrees. The greater the brightness of an incandescent body, the higher, of course, will be its temperature.

As regards, next, the measuring of time, stop watches will be sufficient for intervals of, say, one-fifth of a second as a minimum. Any more rapid phenomena must be allowed to record themselves of their own accord. In the case, for instance, of explosive phenomena, the pressure of explosion is made to displace a minute mirror, whence a reflected beam of light falls on a revolving drum coated with photographic paper. The displacement of the mirror, as produced by the pressure of explosion, is thus recorded photographically, intervals of, say, 1-50,000 second being gauged in this way.

While ordinary chemical scales, of course, insure an accuracy of 1-10 milligramme, extra-sensitive weighing machines, such as those used in comparing standards of weight, allow differences as small as 1-500 milligramme to be ascertained.

Especially sensitive, however, are the processes used in determining lengths, the interferometer allowing the three-hundredth part of a millionth of a millimeter to be gaged, a length far too small to be conceived by the human mind. The ultra-microscope, finally, enables the one hundred-thousandth part of a millimeter to be visualized in gold solutions.

Owing to the Demands for the by-products of coke ovens in Germany for use in making explosives the production of coke has been very greatly increased; and to create a market for the additional amount of coke the Government is encouraging manufacturers and railways to mix coke with their coal.