Ernest H. Hutten

SYMMETRY PHYSICS AND INFORMATION THEORY

There are three main issues I wish to discuss here. First, I want to point out the changing pattern of scientific explanation in physics. Briefly speaking, the model of Nature underlying the explanatory schemes has become more realistic. Communication is substituted for causality, or information flow for the simple energy flow described by the equation of motion. The second point I want to make is to explain modern symmetry physics in terms of information theory. Finally, last and not least, my third issue is to show how this new conception of scientific method can help us to understand the human (or life or social) sciences.

I

There are at least four definite stages that can be discerned in the development of physics. We have classical physics, relativity theory, quantum mechanics and, finally, the symmetry physics of the so-called elementary particles. Our concepts must be adequate for the level of organization of the phenomena to be described. Thus, isolated and permanent particles require only causality—one-sided action or energy flow—for describing the only process they can carry out, i.e. movement in space and time. This is the basic, simple picture of Newtonian mechanics, the mechanistic world view. All explanation depends upon the possibility of creating an order or pattern in our experiences of natural phenomena: this is the essence of active experimentation. We must be able to find constant features in the ever-changing flight of phenomena; or, we must postulate certain constancies and then see whether or not they are satisfied by experiment. Thus, we invent *conservation laws*: we have the conservation of energy, of momentum, etc. This, then, is the simplest order we can introduce on the lowest level of organisation of the phenomena.

It is not even sufficient for the whole of classical physics. We need the concept of field—that is, we require a system of quantities characterized not only by energy but also by order, by relationships between the constituents of the system expressed by the variables, or parameters, of the system as a whole. The electromagnetic field and the gravitational field are the examples. This is the stage of relativity theory. Then we have at once to consider the level of organisation of the system, not only its energy. This level is indicated by the *potential information content*, or 'instruction,' that the system contains. *Invariance*—rather than simple constancy of certain properties of a single particle or of an assembly of particles—becomes a necessary concept. Invariance under a Lorentz transformation is no longer a single or directly observable property. Rather it is a second-order property which depends on carrying out a mathematical transformation and necessarily involves the presence of the relativistic observer. The field may be regarded as a higher level of organisation compared to the assembly of non-interacting particles. The levels of organisation are then described as levels of the logical hierarchy: invariants under a transformation are entities that are logically higher than simple properties. What is invariant are certain correlations between events, not the events themselves.

What is important, too, is the fact that an observer is needed. It is true that the observer does not interfere with the events; but he must 'translate' the events into another reference frame and judge them accordingly. Thus, the invariance of the space-time interval, or the co-variance of the field quantities, etc. are established.

This procedure brings with it a slight restriction in the range and effectiveness of causal action. Causality is no longer a chain by which all events can be connected, a universal pattern-making device. There are, in principle, events that cannot be so connected, segments on the world line which are causally indeterminate. Instead of a chain, we have short fibres of causality. A kind of lack of knowledge, or 'uncertainty,' seems to creep in into the world picture. The causal action, moreover, is no longer mechanical: it is a light signal. And a light signal is not a mere energy flow; it is 'organized,' it possesses an entropy, it has a degree of order since it is capable of modulation. Therefore, although perhaps only in a weak mode, the conception of order and of system is needed on the level of relativity theory. The restriction in relativistic causality is due both to the finite speed of light and to the need of having an observer present. It is consequent on making the process of measurement more realistic. In Newtonian mechanics, measurement is a totally idealized process; physical interaction with the measuring device is excluded, or neglected, and the speed of causal action is implicitly taken to be infinite. The understanding that we must remain within the finite domain brings us nearer to the idea of information, rather than causality, as describing the processes of Nature.

A light signal becomes the carrier of action in relativity theory. The light signal conveys a message; it represents both energy and order. Thus we see emerging a new pattern linking events together, other than simple, mechanical causality. It is communication between observers rather than energy flow between space-time points that provides this link.

With quantum mechanics we arrive at the next stage. The act of measurement is now included in the physical situation instead of being only formally acknowledged, as in relativity theory; and the observer becomes a necessary participant in the physical process. This restricts further the causal description. Causality becomes statistical though the uncertainty principle strictly limits the margin within which natural processes can occur. Randomization remains within the limits set by the quantum of action h. Far from knowing less or less certainly the results of an experiment, we now know more exactly the actual situation since we can specify the interaction with the instrument and the limits of observational error. This has nothing to do with any 'subjective' or 'personal' interference by the experimenter as has so often been wrongly asserted. What is important, however, is to notice that both relativity theory and quantum mechanics—the classical, macroscopic and the microscopic theories—require us to introduce the observer as an essential agent in the acquisition of knowledge. We have interaction rather than one-sided action. We see that the concept of *communication* is slowly displacing the concept of mechanical causality.

Let me mention briefly that there always had been some difficulties about causality even in classical physics. Laplace's *Superman* and Maxwell's *Daemon* may help us to see that it was never quite possible to banish the human observer from the scene of action. Magical omniscience was needed in order to keep up a programme of so-called objective or observer-free physics. Man is the very condition of knowledge and he cannot be asymptotically eliminated as in the physics of the 19th century.

Quantum mechanics, however, also shows another new idea to emerge: that is, *symmetry*. Pauli's Principle and his theory of the electron spin introduces the symmetry properties of the wave functions belonging to an energy state of the atom. Inside the atom, an electron is characterized by four quantum numbers alone and we cannot speak of its space-time motion in the ordinary way. Only the transition probabilities given by the $\psi\psi^*$ have physical significance. In other words, ordinary dynamics and causality are reduced, almost given up in fact, in favour of the new conception of symmetry. We can obtain a great deal of information about the atom by considering only the symmetry properties of its wave functions, e.g. the energy levels. The Schroedinger equation is a kind of equation of motion, but its significance lies no longer in its dynamical aspect. This has almost vanished in comparison, say, with Newton's equation of motion or even with Maxwell's equations. We still need the Hamiltonian in order to determine actual energies; but the structure of the atom as a system is completely specified by symmetry.

Thermodynamics, although a product of the 19th century, has always offered an alternative approach to that of particle mechanics. This had not been recognised for a long time even though, historically, thermodynamics provided the starting point for quantum theory. Instead of seeing a process as a collision of particles in space-time, thermodynamics describes it as a sequence of transformations from one state to another of a closed system. At once, the dynamical picture of motion is banished in favour of a more 'abstract' cycle of transformations.

So we arrive at the present stage of elementary particle theory, that is, of symmetry physics proper. Let us remember here that the particle physicist has only one kind of experiment he can perform. He scatters a beam of 'organised energy,' or particles, off another such beam and then counts the numbers that fly away in a given direction. Thus he tries to assign spin, iso-spin, etc. to the different endproducts. A symmetry operation is then, in the first instance, an operation which leaves transition probabilities in such a collision invariant. No change can be expected to occur when we rotate the laboratory in space. Or, the invariance with respect to the transformation of rotation is connected with the conservation of angular momentum. We are considering symmetry operations because only such operations are associated with conservation laws and can yield quantum numbers. Without the conservation of angular momentum, it would be impossible to infer from scattering experiments a unique spin for each particle. Thus each symmetry operation gives us an invariance which, in turn, is associated with conservation of a property. Our assumptions concerning symmetry can so be tested by experiment.

It seems reasonable, therefore, to say that symmetry represents a logically higher level than invariance. Constancy, invariance, and symmetry operation are three successive levels in the logical hierarchy of description; the entities of one level become the objects of operations on the next level. Similar interpretations have been given by Wu and by Wigner. If I understand Wigner correctly, however, he distinguishes between geometric and dynamic principles of invariance. These two seem to represent different logical levels. The geometric invariance, though it gives a structure to the laws of nature, is formulated in terms of the events themselves. Thus, timedisplacement invariance is the correlation between events when these depend only on the time-intervals, not on the exact time at which the first event takes place. The dynamic invariance, however, is formulated in terms of the laws of nature, based on the existence of specific types of interaction. Every interaction possesses a dynamic invariance group, e.g. the gauge group for electromagnetic interactions. Without going into more detail, what is certain is that the symmetry operations of elementary particles which are dynamically invariant do represent a higher logical level. The symmetry does not concern the particles themselves; nor is it the characteristic of a single transformation: it belongs to the group of transformations.

We can see this too from the fact that in elementary particle theory symmetries are all-powerful and have replaced dynamics. Within the special theory of relativity, certainly, the equations of motion (or Maxwell's equations) remain as a necessary part of the description; and even in the general theory they are needed although dynamics and geometry have become united.

With the disappearance of dynamics and of the equations of motion causality (in the ordinary sense of the word) also disappears. This is perhaps not so astonishing if we remember the historical origin of the concept of causality. It arose with atomism, that is, with the idea that simple, imperishable and immutable particles are the ultimate constituents of Nature which act upon each other according to the law of causality, the necessary connexion between cause and effect. Let me remind you here, for future reference, that the original Greek word for cause is αἰτία, or 'blood guilt,' and that the necessity of the connexion reflects the moral law of revenge, as carried out by the Erinyes. The impersonal law of 'objective' causality has arisen from a very personal, 'subjective' experience; and this origin has left its traces even in modern physics, e.g. the futile discussions about determinism.

The symmetry physicist has found about 100 particles which are reduced to about ten sets of multiplets through the application of the group concept. CPT—charge conjugation, parity and time-reversal—are the basic symmetries. It must be clear, however, that the symmetries are not properties of the actual particles or resonances. Charge conjugation, for example, is concerned with the invariance of a 'strong' reaction with respect to electric charge. This is expressed as the symmetry of the group of rotations in isotopic-spin space, which of course is not ordinary space. Invariance of a reflexion in the mirror gives us the conservation of a new quantum number, parity. Again, this is not a property of the actual particles (or resonances) which would exist in ordinary space. The existence of a right-handed, or left-handed, molecule—as in sugar chemistry—does not establish the conservation, or lack of it, of parity. It is always with respect to an operation carried out in a fictitious space that symmetry properties are specified.

The higher logical level of description in symmetry physics corresponds then not only to a more complex level of organisation of the phenomena but is also more 'abstract,' in the sense that it is farther removed from actual experience. More intermediate steps are needed to connect the symmetry group operation with observation.

It is, however, important to see that conservation, invariance and symmetry are related to one another. Invariance with respect to time allows us to deduce the conservation of energy. Invariance with respect to space, i.e. the group of rotations, leads to the conservation of angular momentum, or spin, etc.

We can then arrange the baryons (heavy particles) of ordinary spin $J = 1/2$ and positive parity into an octet given by the unitary symmetry group SU(3). This will serve as a convenient illustration. We have eight quantum numbers, i.e. three components of the isotopic spin, three components of the hypercharge, and two new spins called U and V. The hypercharge Y is related to other parameters, i.e. $Y = S + B$ (strangeness plus baryon number), the third component of the isotopic spin $I_z = Q - Y/2$ (charge minus half hypercharge). The net result is that we have a diagram, an eightfold hexagon, for what we consider physical quantities, such as the neutron, proton, sigma, lambda and xi particles. For particles of spin 3/2 a decuplet was needed and a previously missing particle, Ω_-, was so predicted and found.

The success of the symmetry group approach in predicting a new particle (or resonance) was very great. The success has been even greater when the symmetries were shown to fail occasionally. The break-through came when Yang, Lee and Wu showed the violation of parity in β-decay. Since then, one or the other of the symmetries has been found to be broken in a specific situation and for a certain kind of nuclear interaction. This can briefly be summarized by speaking of the seven possible transformations P,C,T, CP, CT, PT and CPT. All these symmetries seem to be slightly defective except the combined operation CPT. There has been recently the suggestion, however, that the T-operation (time-reversal) may not always be obeyed since the CP-symmetry fails in the decay of K-mesons. If the CP-operation can be shown to fail, then the T-operation must also do so in order to keep the combined CPT-operation invariant. This over-all symmetry is required in order to satisfy the postulates of the special theory of relativity.

Nature, on the level of elementary particles, shows a slight asymmetry. It is the approximate character of physical symmetries that surprises us most and gives us the most valuable information.

Some general remarks about symmetry may be in place here. Symmetry is similarity applied to one system; that is, parts of the system—either geometric shapes or dynamic relationships—repeat and resemble each other. Thus an over-all pattern is established. A star or a crystal are examples. Every system, physical or organic, shows some symmetry with respect to a centre or line of symmetry. There is only one exception, the system of independent particles flying at random in space: in other words, if there are no relations whatever between the constituents of the system.

Relationships within the system determine its symmetry character. The system is made up of units—e.g. the unit cell of the crystal—which repeats and produces the pattern. Atomism without symmetry would be impossible. The symmetry characterizes the system as a whole: it is an indicator of cohesion and stability.

Living systems all show symmetry. This suggests that symmetry, making for stability, makes a living system viable, gives it integration. If we look at evolution, we see this process as growth and differentiation—increase in size and increase in functional specialisation. The latter process makes necessary to de-differentiate first to some extent—and also to stop growth temporarily at least—so that a new level of differentiation can be achieved. Higher symmetries so correspond to higher levels of integration (and differentiation). A small asymmetry, therefore, is needed for any process to go on so that a little instability can exist. Complete symmetry is static. The meaning of the small amount of asymmetry we find in physics and elsewhere is, I think, clear: it allows both stability and processes to exist and continue, i.e. dynamics—as, indeed, we require.

II

An experiment is designed to provide information. In a scattering experiment, a source of particles is prepared in states of definite mass, momentum, spin and charge and the detector records these values again after the interaction has occurred. It is necessary to prepare the information source so that it becomes a system of high degree of order; otherwise the signals we receive from it cannot be distinguished from noise. This is the more necessary when the phenomena studied are below or beyond the size which would allow direct observation, e.g. in the microscopic realm. All scientific research is therefore a competition between achieving as much order as possible before beginning the work and still leaving as much surprise as possible as result of it. We have therefore to put into the experiment a great deal of information in order to extract new information from it. Or, to put it into more technical terms, the source must possess internal structure so that the message transmitted from it has a sufficient degree of redundancy. A completely redundant message is certain but contains no information. A completely random message contains more (potential) information than any other but cannot be distinguished from background noise. Thus, our effort is directed toward preparing a source, e.g. a system of particles, that achieves a workable compromise.

Take the orbital motion according to celestial mechanics as example. We choose angle-variables for describing it; they become parameters that can be dismissed from the equation since they correspond to the constant momenta in the motion. We have a source, then, the outcome of some judiciously chosen observations, which yields values of variables that can be manipulated. If these variables were completely random, the source would produce indecipherable noise. Since there are links between successive values of the variables, we have some degree of redundancy and we can interpolate missing values or extrapolate beyond those observed. Thus we can code the signals into a message. We can assign definite symbols to certain sequences of the source. The simplest sequences will consist, of course, of constants.

Coding depends on our decision. We want to achieve as high a rate of information transmission as possible with the smallest possible error. But we must code in accord with the statistical structure of the source. Thus, in planetary motion, we choose a coordinate system in which the angular momentum is constant. We code the observations in terms of the constancies we can impose upon them. Without imposing conservation laws on mechanical phenomena, for example, we would not be able to describe and predict them; we would not have sufficient order for our purpose. We prepare the source of information so that such constancies can be imposed and signals emitted by it can be coded into a coherent message.

The constancy of certain properties of a system of independent particles characterises the simplest, physical, source of information. The system is not highly organized and there remains a great deal of random motion that is compatible with the constraints imposed on it. From our point of view, we can regard a purely mechanical system as representing the lowest level of organization. Invariance, then, imposes more restrictions and thus enhances the degree of redundancy. We have to say, too, that the higher degree of organization also gives rise to a level of information higher than that assumed for constancy. We have a multiple message, i.e. one message superposed on another. For invariance contains constancy within it. Finally, symmetry would seem to represent the highest level containing invariance within it. Symmetry requires to construct a system with the greatest number of constraints. It must so represent the level of strongest organization, or the greatest degree of order, or display a maximum of redundancy. There is then a hierarchy of messages that can be transmitted simultaneously. This reflects the method of scientific theory construction we employ: abstraction and generalization. A new level of abstraction in our concepts allows us to enlarge the range of generalization, e.g. relativity mechanics includes Newtonian mechanics; and so we achieve a greater degree of integration of our knowledge.

Redundancy is then accounted for in terms of the constraints upon the freedom of choice we allow in the transmission of a signal from the source. A message must be interesting and this implies we must know a priori that it contains information and how to organize it. If there is no structure or internal order in the message, it produces too large a flow of information. Indeed, all observation makes us eliminate stimuli in favour of a few perceptions that can be organized. We select evidence in accord with some theory in terms of which a particular hypothesis is formulated; otherwise the one would not be relevant to the other. We know these organized modes a priori, i.e. from previous experience; and by matching our prior knowledge against the new perception we correct and improve it. Only because we have prior knowledge, and redundancy, can we predict and extrapolate.

There is always a fund of pre-existing knowledge, as Aristotle already remarked, and we build upon it. We look for an increase in knowledge rather than start from total ignorance. Comprehension rather than apprehension is the aim. Thus, it is not the amount of information we are interested in so much as its value. The value of a message lies precisely in its deviation from what is previously known. The greatest deviation will be obtained if we take as standard the most highly organized, or completely redundant, message. This is the deviation from symmetry we find in present-day physics.

The amount of (potential) information is a measure of the surprise value of its content. The value of information, in the sense used here, is then only a measure of the surprise relative to a standard. The redundancy is: $R = 1 - H/H_m$, where H is the actual amount and H_m the maximum of possible information, i.e. when all the symbols are equally probable. The value would then be $\Delta = R - H = 1 - H/H_m - H \cong 1 - H$, that is, simply the complementary information (in %).

Information is, too, a measure of the degree of organisation of the system, or of its complexity, or of its structure. Hence, the high degree of complexity of the symmetry group of operations allows us to say that any deviation from redundancy is more valuable on this than on any lower level. If we were to find an instance which looks like a violation of conservation in a simple, mechanical system, we can always re-arrange the components in order to keep conservation. It is a simple, bookkeeping operation. We have enough freedom to overcome any lack of conservation. This will be more difficult on the level of invariance since more parameters and relationships are involved and, moreover, the constancies on the lower level are affected. If invariance under the Lorentz-transformation would not hold for some motion, space and time measurements could not be universal and energy would not always be conserved. On the higher level of symmetry, then, a violation, however small, will be of the greatest consequence. Indeed, the violation of symmetry schemes leads to the discovery of new types of interaction.

The more abstract (i.e. removed from direct experience) the entities, the more complex the organization, the higher the degree of order, the more redundancy is needed. It is easy to overcome noise when the entities are directly observable. High redundancy is needed also for the reason that a great deal of information has been fed into the system in order to construct it at this high level. We require lower levels of organisation in order to build up the system to a higher level and, with them, we have relationships and linkages that must exist before the higher level is reached. The levels of integration of the nervous system which Sherrington described illustrate this method. Symmetry seems to be a universal characteristic of highly organized systems. It is the deviation from symmetry, however, that conveys new information.

This is true even when the symmetry concerns actual entities, i.e. atoms, in a crystal. A crystal represents a highly redundant information source; we need to know only the unit cell to know everything about it. Thus it is easy to grow a crystal from the melt since we need only very little (potential) information, or instruction, that is, a small nucleus of solid material, to do so. What is important, however, are the asymmetries, the lattice defects of the crystal; for they determine to a large extent the actual properties of the crystal. For such a low-level system the deviation must be large to have an effect; for a high-level system a small deviation is already powerful.

Lower-level systems require less stringent conditions in order to yield interesting information. This can be seen when we compare the symmetry group scheme with the Periodic Table of the elements. With the help of SU(3) a new elementary particle (or resonance) was predicted. With the help of the Periodic Table new elements were predicted. Both have served as schemes of classification, though on very different levels. The Periodic Table only requires fairly loose relations of similarity (for certain properties) to be satisfied; and irregularities and variations can be, and have been, accommodated without shaking the Periodic System. The group scheme is based on the strict relation of symmetry and only very small deviations in prediction, e.g. of the mass, are tolerated. If we consider even grosser, or more concrete, systems of classification, as in evolution, we see that they allow a very wide tolerance without becoming useless.

In order to have information it is necessary to have uncertainty; and uncertainty necessarily involves an observer or experimenter to evaluate it, to make a decision whether or not to accept a result. This is quite outside the causal scheme which we may symbolize as: $(x)\ \mathrm{Cause}\ (y) =_{\mathrm{df}} (x,y)\ (fx \longrightarrow gy)$. Error and uncertainty remain external to the scheme and have to be evaluated separately. In information theory uncertainty is at its very origin. This may be symbolized with the help of quantum mechanics which is based upon uncertainty. Using Dirac notation we may write: $(x)\ \mathrm{Info}\ (y) =_{\mathrm{df}} \langle x|C|u\rangle\langle u|T|v\rangle\langle v|D|y\rangle$. The conditions to be imposed on the operations of coding C, transmission T, and decoding D must be similar to those imposed on the quantum-mechanical operators which, through their non-commutativity, show the underlying, fundamental uncertainty of the process of receiving y when x is being sent.

It would be interesting to re-write and work out in detail the main theorems of information theory in the Dirac notation. This is too technical a task to attempt here. There is, however, one main point still to be made. Coding and decoding necessarily involve an observer or experimenter. Reception of a message is a decision problem. We can extract information from a message only by following a rule. It is no longer a so-called impersonal, universal law necessarily connecting events, that provides the pattern of scientific explanation. Instead, we have rules that we follow if we want to decrease our uncertainty, increase our information, and explain a natural phenomenon. The rules are of course not arbitrary though they have to be chosen by us in conformity with observation and common consent. The scientist's task is to increase our knowledge; and he does so by imposing some conceptual scheme on the phenomena, creating order, and then extracting information from it. The rules are non-referential in the sense that we always deal with messages, not entities. Scientific theorizing is a problem of communication.

III

The pattern of explanation which symmetry physics requires is then the following. Science is an activity, not a collection of statements; and this includes the need for choice and decision. Constancy, invariance and symmetry represent operations: we follow rules and do not discover or construct entities. The first step in interdisciplinary understanding, that is, in understanding how the physical and the human sciences are related—the most urgent problem today—is to recognise that scientific method has changed even in physics.

Method is abstracted from the actual theories and practice of physics; it provides the interpretation of our activities that, at any given time, we accept as adequate. Classical physics is thus linked to deterministic causality, relativity theory to restricted causality, quantum mechanics to statistical causality and symmetry physics to information. The model of a natural process underlying the successive theories has changed and so have the systems we experiment on, from the low level of organization characterized by constancy, through invariance, to the level of symmetry. Correspondingly, instead of simple energy flow, or causality, we have information flow, energy plus order. A new dimension—order and organisation—has to be employed in our explanations which hitherto had been neglected. Information, moreover, requires the scientist to participate in the process by which knowledge is increased.

The earliest conception of scientific knowledge we have was given to us by the Pre-Socratic philosophers in terms of atomism and causality. They were looking for imperishable entities and the forces between them, existing forever but hidden, like gold in the ground, ready to be discovered. It is a very natural attitude to have but prevents us from understanding the science of today. We tend to slip back into this attitude since our earliest 'concrete' experiences as infants arise from contact, from touch and from the sensation of pushing external objects around. This gives us the first experience of causality and sets the distinction between what we feel to be inside and outside our skins that we take as the basis for 'reality'. The thing-language of ordinary life embodies this attitude. We so construct an ontology, have 'ultimate' building-blocks of 'reality' like atoms and forces making them move—though today's elementary particles are obviously no longer very suitable for this purpose. From this early experience arises, too, the idea of Nature—the mother goddess—which we explore and whose reaction to our efforts is shown by causality.

On this basis we slowly developed our conception of natural law which, today, is represented by the universal statement of a material implication describing the causal mechanism. A cause is no more than the set of antecedent conditions (given suitable boundary conditions). The explanation comes by logically deriving a particular statement, the hypothesis, from the universal law and then finding the evidence for it. More specifically, we have a mathematical expression and try to fit a set of numerical data to it. If we interpret the law in this manner, we have to acknowledge that it is a contrary-to-fact conditional. No set of data can then validate our hypotheses or theories. We can do so only by assuming an ideal world, a model, to which the implication applies; even then we have to avoid the paradoxes of confirmation, etc. At best, we have an empty form—$(x)(fx \rightarrow gx)$—which may be used, it has been said, as an inference licence. We are able to maintain a so-called 'objective' attitude only at the cost of an enormous idealization.

Modern physics has progressively abandoned this idealization in which the actual process of experimenting, the interaction of phenomenon and apparatus, is neglected. We must take as basic the flow of information from a source prepared, coded, transmitted and decoded by the scientist. Thus laws become rules according to which we carry out experiments. Previous knowledge is used to give order and organisation to an information source; the (potential) information content of a natural phenomenon can then be extracted. New information is generated through the interaction of the phenomenon and the experimenter, when the scientist deciphers the message and finds out whether and how the original order has been changed. This leads to the discovery of new relations and structures, to new forces, etc. In the simplest instance, a new planet is discovered through the observed deviation of the orbit of a known planet calculated according to the theory of gravitation.

Nature is not the clockwork suggested by Newtonian mechanics nor the world machine into which the 19th century industrialization made us believe; after all, we are right now in the middle of the second industrial revolution, and so it seems reasonable to change our ideas a little. There is no 'ultimate' reality that exists independently of ourselves, untouched by human hands and untouchable, a kind of *Ding an sich.* This false objectivity was incurred by the justified rejection of anthropomorphism in physics that naturally arises from the origin of our conceptions in early experiences. The illusion of universality and necessity of the natural law comes about through the logical form and the idealization of the underlying mechanism. But the stages physics has passed through have demonstrated that this rejection went too far and that we now need to re-interpret the structure and methods of science.

Thus we need non-referential rules—rather than causal laws—to explain what goes on in a modern physics laboratory. It is no longer the question of finding entities of one sort or another and determining the paths they travel—it is a question of a system having order and organization. No more ontology: no Museum of Stuffed Animals which the scientist has to classify and about which he has to come to the decision whether they belong to a 'real' species or not. We must follow the way in which in mathematics we generate numbers, e.g. by Cantor's diagonal procedure, and settle the dispute between formalism and intuitionism about what kind of entities numbers are. The rules may also be expressed as universal statements—like the causal law—but their use is different: they represent a procedure for generating information and the universality merely indicates the possibility of using the rule indefinitely.

Here we can see how the human and the physical sciences can come together. The relevance of the concept of information is that it allows us to do away with the causal scheme and mythical entities and to substitute instead a pattern that is characterized by order as well as energy and includes the human being as participant in a process. Thus we are enabled to interpret phenomena in terms of meaning, according to the significance to the sender or receiver or both. The causal scheme is based on the dynamics of particles, on space-time movement. The universal law is an equation of motion that allows us to predict the later position, say, of a particle, from the knowledge of an earlier position. This does not suffice for explaining life phenomena, e.g. human behaviour. Actions are the units of human behaviour, not mere movements.

No scientist or philosopher today would maintain that psychology is no more than physics applied to human beings instead of atoms. New and different concepts are needed to describe human behaviour, and so ideas like conditioned reflex, learning, reinforcement, etc, have made their appearance. The net result is a behaviourism which, however refined, restricts the human being to physical manifestations as the only sign of his being alive. It is not enough to introduce new concepts: the whole explanatory scheme has to be changed. Keeping to the causal scheme necessarily, though in a subtle way, makes human behaviour inexplicable. Thus we have mythical entities like mind and body and a 'paramechanical' causation between them. This brings about a *physikomorphism* in psychology which is as untenable as the anthropomorphism in physics. Many years ago Bertrand Russell remarked that the 'law of causality... like much that passes muster among philosophers, is a relic of a bygone age, surviving, like the monarchy, only because it is erroneously supposed to do no harm.'

Causality has been a very successful notion in physics and in science in general; but even in physics, with the demise of atomism, it has come to an end. In physics, we have instead communication—the transmission of information—as a pattern for explanation. This brings us much nearer to the motivational explanation in psychology. For a motive must not be regarded as a sort of 'internal' cause: it represents potential information, or instruction. Inner experience, conscious or unconscious, thus becomes accessible to theorizing without having to specify what is 'real' or not and what kind of push-pull mechanism may relate mental to physical phenomena. Motives are not antecedent conditions, but dispositions to act; unlike causes, they do not necessitate movements. They anticipate a change in affect of which we may, or may not, be aware and according to which we may act or not, depending on circumstances. The motive remains alive and may be known, or not, to the person from his inner experience. Imprinting, i.e. infantile experiences, the first stages in the development of affective relationships with other people, are often a very powerful source of motivation.

How do we come to know about motives? It cannot be my task here, nor do I want, to give a detailed account of psychological theory; I do, however, claim that a motivational explanation is as valid as the causal explanation ever was. For we gain knowledge about other people not merely through perceiving their behaviour from the outside. We attribute motives rather than infer causes since we know them from our own experience, since we know others to be similar to ourselves, since we can understand other people by putting ourselves in their place. We must remember here that the idea of physical causation is rooted, historically and individually, in our experience of motivation, when we feel ourselves as agents changing the environment. In short, we can give reasons for actions—not causes for movements—that entitle us to accept, or reject, a given explanation. Human beings are motivated to follow certain rules in order to carry out an action. This explanatory scheme is in accord with our interpretation of 'motive' as instruction.

Events, causes and laws are terms that apply to the physical world (within limits), actions, motives and rules describe human affairs. Then we can banish at once the false dichotomies that have beset the theory of knowledge for so long: subjective/objective, private/public, real/imagined, caused/free—in brief, the problems of the relation of mind to body, or matter to life, and of free will. We escape the consequences of a false categorization which arises when we impose the causal scheme on life phenomena. Epiphenomenalism, interactionism, and parallelism—the three main philosophical accounts—come about naturally when causality is supposed to link two objects in space-time. They are 'shadow and substance' theories which hail back to the religious concept of the soul. Preformation versus epigenesis, in the theory of evolution, is an issue that embodies a similar mistake, that is, of taking the gene either as the complete organism shrunk to microscopic size or as a complete blueprint. The gene, however, is a template, an instruction that works itself out in response to the environment. We have rules rather than laws, motives rather than causes: laws generate entities—causes and effects of various kinds; rules generate information.

We must broaden the concept of explanation beyond deduction and prediction, superseding the causal scheme and the equation of motion on which it is based, and arrive at a more comprehensive pattern of explanation. All explanation is originally an attempt to answer the question 'why?'. Gradually, with the mechanization of the world picture, the question was changed to 'how' and, finally, to the mere statement of 'that' —no mechanism can any longer be specified. Conditions, initially given, are related to later conditions. Thus, we have a universal scheme but it is vacuous. Explanation, however, is not given by a formalism; its power lies in the real changes that it leads us to make in our environment, in the direction it gives to our activities.

This scheme became useless in physics since the act of measurement, and with it the experimenter, had to be brought into it. In effect, the causal law is used more or less like a rule though the pragmatics of the situation is tacitly neglected in favour of the semantics. No knowledge can accrue unless there is an interaction between the external and the internal world, between the processes of perception and conceptualisation, and so on. Here, again, the term 'knowledge' has played havoc with our explanations as if we could ever start from total ignorance or formulate an 'absolute' criterion of knowledge. This is the basic flaw in traditional epistemology. Knowledge is past information; and we can only increase our information, decrease ignorance and uncertainty, relative to the information already at hand.

We validate a procedure rather than confirm a universal statement; we give reasons rather than determine causes. What else could we do? Explanation must derive from testing, from the basic human motive of control over the environment, of acting in accord with what has been called the 'reality principle.' Thus we have a purpose, follow a rule. But the rules require a certain consistency, form a set, provide integration with past knowledge, correspondence with previous theory as well as prediction. We need no mythical induction or philosophical theory of confirmation—the technique of validation of a statement by evidence is mathematical as it has always been. We have statistical inference, decision-making under conditions of uncertainty, which can be applied equally to numerical and non-numerical statements, to many instances and to the single case. We follow established rules or generate new rules; and the rules tell us what has been done or what to do and so provide us with reasons. An explanation must justify our activity before it can formally validate a result of it.

This is the great change in methodology that symmetry physics, and modern science in general, has brought about. We do not explain the workings of an impersonal Nature existing independently of ourselves but the scientific activity of human beings. Science, as Bacon said, 'is not so much a lesson to be learnt as a task to be done.' Communication between scientists rather than causality is the basic process. The human being can never be left out for he is the agent who creates science. 'Subjective' knowledge—to put it into conventional terms—is as important as are the 'objective' data obtained by observation from outside which anyway bear the human imprint, since perception is loaded by conceptualisation before it gives us the datum. In physics, knowledge about, e.g. atoms, is almost sufficient, though not quite, since we must consider, marginally, the process by which the human experimenter obtains this knowledge. In psychology, the understanding which comes from our 'subjective' experience, from the recognition of the humanity we have in common, is the basic requirement; and knowledge and self-knowledge are inextricably mixed.

Information theory allows us to treat both knowledge and understanding in our explanatory schemes and to construct a theory of science, or metascience, that is more adequate than the traditional epistemology. This may be only methodology. But methodology is important since it expresses our view of how the world works and reflects the attitude we adopt towards other people and ourselves.

REFERENCES

Symmetry physics:

W. Frazer, *Elementary Particles*, Prentice-Hall, New York, 1966.
E. H. Hutten, *The Ideas of Physics*, London, 1967.
A. Salam, *Math. Journal*, 1968.
E. Wigner, *Scientific American*, 1967.
E. Wu, *Am. J. of Physics*.

Information theory:

F. Bonsack, *Information, thermodynamique, vie et pensée*, Paris, 1961.
E. H. Hutten, *Scientia* 56, 1-10, 1962; 58, 1-8, 1964; 60, 3-9, 1966.
A. Moles, *Information Theory and Esthetic Perception*, Illinois, 1966.

Mind-Body problem:

E. H. Hutten, *Methods* 5, 187-202, 1954; *B. J. Phil. Sci.* 7, 73-85, 1956; *Rationalist Ann.*, 1960; *American Imago* 18, 269-277, 1961; *Rationalist Ann.*, 1965.
V. Somenzi, *G. Critico Fil. Ital.*, III, IV, 1967; *De Homine*, No. 15/16.

Methodology:

P. Bridgman, *How Things Are*, Harvard, 1959.
R. de Charms, *Personal Causation*, Acad. P., New York, 1968.
E. H. Hutten, *The Language of Modern Physics*, London, 1959; *The Origins of Science*, London, 1962.
A. R. Louch, *Explanation and Human Action*, Blackwell, Oxford, 1966.
R. S. Peters, *The Concept of Motivation*, Routledge, London, 1958.
H. Rickman, *Understanding and the Human Sciences*, Heinemann, London, 1967.
Bertrand Russell, *Mysticism and Logic*.
I. Scheffler, *Science and Subjectivity*, New York, 1967.
J. Tucker, *Proc. Aristotelian Soc.*, Feb. 1970.