III.5 · Matter, Energy, Information

Unpublished until now, this essay was written in 1969. It takes up the ancient concept of form, in order to interpret the contemporary concept of information and to develop a unified concept encompassing both biology, as understood cybernetically, and physics, as the theory of decidable alternatives. The problem of the subjectivity of information is encountered along the way ("for whom is this event information?"). The objectification of the meaning of information, roughly analogous to measurement theory in physics, reduces information to the flow of information; i.e., to temporality. Thus, here, too, the transition is made from the subjective to the temporal point of view.

The line of argument begins once again with the development of physics toward unity (section a). Sections b and c discuss the concept of information especially in terms of its objective utilization in biology. We leave the domain of biology, however, without having contributed to the material problems of this science, since further clarification of the concept must first be sought in physics. The economic intermezzo (section d) represents a dilettante's calisthenics; I merely ask the professional economist to consider the layman's question of how it is that an almost universal yardstick for value can at all exist in the economic domain. The road into physics (section e) leads only to conjectures that cannot be tested until elementary physics has been explicitly constructed. The conjunction, in accordance with III.3, of matter, i.e. motion, i.e. form, with consciousness (section f) then leads to the threshold of what in our tradition is referred to as "philosophy of the spirit."

a) Matter and Energy

Historically speaking, matter is, to begin with, the conceptual opposite of form. A cupboard, a tree are made of wood. Wood is their "matter." The name of the term "matter" is in fact taken from this example: *materia* = *hyle,* which means wood. But the cupboard isn't simply wood, it is a wooden cupboard. "Cupboard" is what it is intrinsically; cupboard is its *eidos,* its essence, its form. But a cupboard must be made of something; a cupboard without matter is a mere thought abstracted from reality. On the contrary, this cupboard made of wood is a real whole of form and matter, a *synholon;* form and matter are "grown together" in it, it is something concrete.

In the realm of the concrete, then, no form exists without matter. Nor can there be matter without form. Wood not fashioned into furniture exists, to be sure—e.g., wood which is the matter of a tree. Wood also exists that is not (i.e., that is no longer) the matter of a living tree —this pile of firewood, for example. But wood is itself a form. Form and matter are relative terms. What is matter relative to cupboard and tree—namely, wood—is form relative to earth and water (in the language of the ancients), or relative to organic molecules (in modern language). All wood consists of "earth and water," or of carbon, nitrogen, hydrogen, etc. According to Aristotle, a first matter *(prima materia, prote hyle)* that is no longer the form relative to another matter is merely a philosophical principle that neither exists concretely nor can be known, since whatever we know is form.

Modern physics, however, takes up another ancient philosophical tradition, that of atomism. According to this doctrine, a set, final form of first (and therefore true) matter does exist—namely, the space-filling extendedness of the indivisible smallest bodies, the atoms. In this conception matter is no longer a relative term in the relation matter-form, which can be exhibited only by means of something concrete; rather, it designates what truly exists in itself. An atom is an atom regardless of what larger body it is a part of. Continuum theories of matter also conceive of what is extended in space—i.e., matter—as existing in itself. Thus matter becomes the only true existent in that monistic conception which rightly bears the name "materialism." In a dualistic conception such as Descartes', matter becomes the term that represents the opposite of consciousness. But consciousness is not a term that occurs in physics (or in natural science, as one said later, when "physics" was reduced in scope), it is not a physical object. The existent in physics, it appears, is matter.

In the nineteenth century, a new term paired with matter arose—namely, energy. At first, energy was force become substance. This connection is important for our present theme. Already in the seventeenth century, physics was forced to introduce force as a second, problematic entity alongside matter. Physics is the science of the motion of matter. Motion is subject to laws. The laws prescribe how matter moves in given circumstances. But the circumstances are characterized in terms of the presence of causes of possible motion (or, in accordance with the law of inertia, causes of possible changes in motion), and these causes are termed "forces." Forces as individual entities were suspect in the seventeenth century as "occult qualities." One tried to reduce them to the essence of matter, to its filling out of space or—put in popular language—to pressure and collision. From this point of view, force as the cause of motion resides in matter itself; and from these reflections the concept of "living force" or, as we now say, "kinetic energy" finally developed. But pressure and collision turned out to be an unsatisfactory model for the movement of one body by another. Potential energy had to be placed alongside kinetic energy; it is the force-potential (capacity to exercise force) that does not manifest itself as motion.

We note: energy is the capacity for moving matter. This capacity is turned into substance as a result of the Law of the Conservation of Energy. Energy can be quantitatively measured, and it turns out that its quantity, just like the quantity of matter, is conserved in time. (Robert Mayer thought of the energy law as the quantitative formulation of the rule *causa aequat effectum.*) If something is conserved, one regards it as a substance, as a substrate that remains itself in the world of changing appearances. Thus it seemed in the nineteenth century that physics dealt with two substances, matter and energy, the latter more often referred to as force in popular philosophical writings.

Relativity theory has, in a certain sense, taught us the identity of the two substances. In contemporary terminology, conservation of matter is called conservation of mass; and energy and mass are relativistically equivalent. The group-theoretical viewpoint (Noether's theorem) allows us to understand the reason for this "unity of substance." To every continuous real parameter of the symmetry group of the equation of motion corresponds a conserved quantity. The energy is the conserved quantity corresponding to translation in time; i.e., to the homogeneity of time. If time plays as fundamental a role in physics as I assume it does, it seems plausible that a particular conserved quantity would correspond to it; this is why already Kant had related the conservation of substance to the homogeneity of time.[1]

But the real significance of the unity of substance shows only in elementary particle physics. Group theory at first tells us merely that in every physical theory characterized in terms of an equation of motion, the conserved quantities defined by the symmetry group of that equation must exist; thus for every equation of motion invariant with respect to translation in time, an energy must exist. But the idea of the general energy law was, from the beginning, that all forms of

[1]Cf. IV.2.

energy were comparable among, and could at least in principle be transformed into, one another. It follows that something like a universal equation of motion embracing all kinds of energy would have to exist. Heisenberg's unified field theory constitutes an attempt in this direction. It does lead to a unified substance that Heisenberg rightly calls "energy"; the elementary particles are merely its different quasi-stationary states.

What are the essential properties of this substance? Its quantity can be measured. The elementary particles and everything constituted by them are its possible forms of appearance, which represent the solutions of the basic equation of motion. The law itself, which we will not examine in detail now, admits of a fundamental interpretation. We arrived at substance through the identification of two entities—i.e., matter and energy—that at first were conceptually clearly distinct. Matter was introduced as the stuff of which things consist—i.e., as the "substance," in the sense in which we are using the term. Energy was introduced as that which can move matter, its quantitative measure being at the same time a measure of the "quantity of movement" it produces. (The latter is defined as the square of the velocity vector multiplied by the mass that executes the motion—a circumstance we do not find surprising nowadays since it follows from rotational symmetry.) When matter and energy are identified now, one must say that matter *is* at the same time the capacity to move matter. This is just what the basic law of motion—in the hypothetical form of Heisenberg's nonlinear operator equation, for example—in fact expresses.

The meaning of the unity of substance can be stated more trenchantly, if at first in purely symbolic form, by starting not from matter but from energy—or, actually, from time. Starting from matter, we have been saying that matter is the substance of things. Energy is the capacity to move matter. If matter and energy are identical, then matter is the capacity to move itself. A dualism of substance and movement remains. Why does substance move at all, and why is it at the same time its own capacity to move itself? If we start from time as the fundamental concept of all physics, we can say: All there is, in the final analysis, is time. To be time, it must be change; i.e., movement. (The foregoing "i.e." is formally a verbal definition; only a theory that deduces space can justify the nature of "movement" as spatial motion.) Only insofar as movement does not remain identical with itself is it truly movement; it must therefore at the same time be the capacity to change; i.e., to move itself. Movement must therefore have the double aspect of that which moves and that which is moved.

b) Information and Probability

In the sense of traditional physics, information is neither matter nor energy. Rather, the concept of information brings into play the two older antipoles of matter—namely, form and consciousness.

Information can be defined as the quantity of form. I will discuss this with reference to one of the usual quantitative definitions. Let E be a formally possible event, and p its probability. Then

$$I = -\log_2 p$$

is the information obtained when E occurs. If, for example, $p = \frac{1}{2}$, then $I = 1$ or, as one says, 1 bit; if $p = (\frac{1}{2})^n$, then $I = n$. The less probable an event is, the more information it furnishes. This introduction of the concept of information makes sense provided one already understands the concept of probability.

It would be wrong to argue that probability, being a conjecture, is subjective, and that information, therefore, is evidently "(not matter but) consciousness." Every concept is "subjective" as thought, even the concept of a thing or of matter; it is at the same time "objective" insofar as it is "true." A concept is true, broadly speaking, if it can occur in true propositions on its object. A proposition may be called true if it can at least be verified intersubjectively. In this sense, probability is certainly an objective, true concept, assuming that probability judgments can be tested empirically. The sense in which this is possible was discussed in the justification of probability theory in terms of the logic of temporal propositions,[2] where probability appears as the prediction or, to be more mathematically precise, as the expectation value of a relative frequency.

The information of an event can also be defined as the number of completely undecided simple alternatives that are decided by the occurrence of the event. A simple alternative is said to be "completely undecided" if neither one of its two possible answers is more probable than the other. One can define the quantitative measure of the form of an object as the number of simple alternatives that must be decided in order to describe this form. In this sense, the information contained

[2]Cf. II.5.c.

in an object measures exactly its amount of form. The information "contained" in an object is the information represented by the appearance, in the field of vision of an observer, of an object whose identity has been recognized.

Thus, information measures form. At the same time, however, information cannot—at least in this preliminary, still primitive conception—be defined except in relation to a consciousness. In a sense, this is true of every concept, but here something more is meant, for even the concept of objective probability is subject-related. As an example, allow me to discuss the casting of two good dice. Two observers A and B are asked to predict the probability p that the sum of the spots on the upturned faces is 2. A's prediction is to be made prior to the throw, B's only after he already knows the number of spots showing on the first die. A therefore predicts $p = 1/36$; B predicts $p = 1/6$ if the first die shows 1 and $p = 0$ if it does not. Both predict correctly (as can be verified objectively); their values for p differ merely because the event they predict is a sample out of two different statistical ensembles. The value of an objective probability, in other words, depends on the prior knowledge. The information of the event "total number of spots = 2" is less for B, who already knows "number of spots on first die = 1," than for A.

This example shows, first of all, that one must take "probability" and "information" as objective and, at the same time, as subject-related concepts; their conceptual meaning is the quantification of "knowledge," and knowledge is always the knowledge someone has of something. Information measures, in particular, the increase in knowledge gained as the result of an event, and this must obviously depend on one's prior knowledge. That information measures knowledge does not contradict the thesis that information measures the amount of form since, in ancient philosophy, form *(eidos)* is precisely what can be known. But how can we assert that the amount of form in an object depends on prior knowledge? After all, form is supposed to be what can be known objectively, it is an objective property of something. With this question we enter upon a very lengthy investigation.

It is easy to "objectify" our example. Prior knowledge here refers to one part of the formally possible contingent properties of the pair of dice. In conformity with the question asked by the dice players, one defines the objective amount of information in the pair of dice in terms of what can be registered upon looking after the dice have been cast, and what is therefore based on a prior knowledge that is acquainted with the formally possible outcomes (i.e., that knows: this is a good pair of dice), but not with any contingent facts concerning the dice. In this sense, the objective information of the event "spots add up to 2" equals $\log_2 36$. Thus, the amount of information in every measurement of a quantity described in advance as formally possible can be objectively stated.

But this does not exhaust the amount of form in the two dice. Only for a dice player do the two dice carry the information just discussed. His prior knowledge is extensive: he knows what a game of dice is, that the two wooden cubes are dice as understood in this game, what the number symbols on the faces say, etc. He must know all this to be able to recognize what he sees *as* the number of spots on two dice. The information is an information for the dice player only by virtue of a semantics in which a great deal of knowledge—i.e., a great deal of *other* information—has already been invested. A large part of this "semantic information" can also be considered as the "form of the dice." How much form, now, does the pair of dice contain in the end?

In looking for an answer to this question, an obvious approach is to investigate the dice physically; and then there is no stopping before the atomic level is reached. The amount of information in each die must then be $N \cdot i$, where N is the number of elementary particles of which the die consists, and i the formally possible amount of information of the individual elementary particle. At this point we are confronted with difficult questions concerning the foundations of physics, which we will refer to explicitly only in section e. Let me now say merely that this information remains "virtual," since, in practice, no experiment can ever exhaust it. How is it possible to single out actual or actualizable information in this practically unlimited reservoir of virtual information?

The concept, as subjective knowledge, corresponds to the form, which is known objectively. We therefore expect to be able to measure the information of an object to the extent that we can subsume it under a particular concept. Subsumed under the concept "pair of dice in a game of dice," the two dice contain exactly $\log_2 36$ bits of information. Subsumed under the concept "game," they contain additional information—for example, the information that they are a pair specifically of dice. The measure of this information clearly depends on the prior knowledge of how many different games there are. To every concept belongs a prior knowledge that constitutes its semantic information. (An extreme case would be the concept "structure made up of elementary particles.")

If we wish to make these reflections more precise, we would have to try developing an "objectification of semantics." Consider a reliably functioning instrument that reads off and stores or processes that information concerning an object which falls under a particular concept. This would constitute an objectified operational definition of that concept. An example would be a measuring instrument; quantum measurement theory, which replaces the observer by an instrument, is a model for the objectification of semantics. Of course, to assure a clear-cut formulation of the question the measuring instrument itself must also be subsumed under particular concepts in this theory. Here lies the reason for the necessity, emphasized by Bohr, of classical concepts in the description of measuring instruments. Naturally, it is possible, by "shifting the cut," to observe the measuring instrument in turn by means of a meta-measuring instrument; the "classical" nature of the concepts of measurement is then intended as a guarantee that nothing new will result from such an iteration in the objectification of the semantics.

If one wishes to eliminate the *ultima ratio* of the observer, then one can try to have an apparatus not only store the measurement results, but evaluate them as well. Here we enter the theory of control systems. The most significant example of a "fully automated" control system is genetics. Organisms control their own growth by means of the genetic information stored in the DNA molecules; they reproduce this information and thereby themselves, and, assuming the Darwinian hypothesis to be correct, have produced with this system even the contemporary form of the system itself. Let us first consider only the cybernetics of reproduction, leaving aside that of evolution.

One can, in principle, easily calculate the amount of information contained in the DNA chain of molecules: every molecule is known to contain 2 bits, a chain of n molecules thus contains 2n bits. Theoretically speaking, this is the information corresponding to the concept "genetic constitution." A much larger amount of information would of course correspond to the concept "chain of atoms," which admits arbitrary atoms as components in the chain; most of that information is already contained in the employment of the concept "DNA chain," which excludes all other possible atomic combinations. Furthermore, in a particular case we can ascertain that we are dealing with a DNA chain only by doing a chemical analysis; but contemporary genetics utilizes the information invested in its conceptualizations for presupposing without further ado that DNA is indeed the carrier of the genetic constitution. It was in this sense that we were entitled to use the term "genetic constitution" in the definition of the amount of information.

With regard to this definition, we said above that we were speaking "theoretically." After all, we are interested just now in the objectification of semantics. But in the reality of organic life, the DNA molecule carries 2 bits only if a mechanism exists for transforming this information into the growth of somatic structures in the organism—into the production, as a first step, of certain proteins. It is known that the mechanism for the production of proteins already involves a certain loss in information as compared with the theoretical value of 2n bits per chain. We see from this that it is only the semantics (the objectified semantics of the production mechanism for albumen, in this instance) which determines the amount of information.

We now generalize and formulate, in two theses, the relation between information and objectified semantics with which we have just become acquainted:

1. *Information is only what can be understood.* "Understood" can be interpreted here in as objective a sense as the DNA information has been "understood" by the mechanism for the production of proteins, when it transforms this information into protein structures. The structures produced are themselves information. In fact, the meaning of the objectification of semantics lies in enabling us to calculate the amount of information contained in the semantics. The first thesis can now be further developed:

2. *Information is only what produces information.* It should be pointed out that virtual information, which is capable of producing information, must be distinguished from actual information, which actually produces information.

The second thesis presents the flow of information in the form of a closed system: information exists only when, and in the degree that, information is produced—i.e., when and insofar as information flows. In this form also we talked of energy, at the end of section a, as the amount of movement: movement exists only insofar as it is moved (insofar as it changes). There I referred to this way of speaking as "purely symbolic." What it lacked for a precise formulation was the connection between movement and information, the question that now confronts us. Can energy and information, too, be identified?

But we must first attend to a few further reflections.

c) Information Flow and Natural Law

How much information is contained in the objectified semantics of a given amount of information? How many bits are needed to understand one bit?

One is tempted to give two very dissimilar answers, both of which I will illustrate in connection with genetic information. Let the genetic information be 2n bits for some particular animal species; how many bits are contained in the objectified semantics of the life of this species?

First answer: as many bits as correspond to the quantity of form contained in an entire organism—a very large number, that is. A single DNA "alphabet"-triple in the chromosome of a newly formed cell produces many—say, m—albumen molecules identical in structure, whose information content must therefore be multiplied by m. These proteins cooperate in constructing the cell, whose metabolism no doubt produces additional bits. And in a multicellular organism the average information of the single cell must be multiplied by the number of cells. The difficulty with this answer is its failure to articulate the concept governing the calculation of the information in the organism.

Second answer: exactly 2n bits. For the organism develops from its genetic endowment and transmits these same 2n bits (apart from mutations) to its offspring. These bits are necessary and sufficient for the definition of the species; they are therefore the true amount of information in the organism. Anyone who completely understands the laws governing the functioning of an organism ought to be able to derive its form and functions simply from a knowledge of the DNA chain in the nucleus of any one of its cells. He would know, therefore, that the huge amount of information arrived at by the first answer is redundant and reducible to 2n bits. Only the second answer subsumes the organism under the concept of a living being, which is of course appropriate to it; the first answer subsumes the organism under the concept of a physical object. The excess information in the first answer is simply the information contained in the concept of a living being.

One can argue against the second answer by saying that the individual has many characteristics that are determined not by its genetic endowment but by the conditions of growth, by the vicissitudes of life, and perhaps by pure (quantum theoretical) chance. One could mediate between the first and second answers by distinguishing between species-specific information in the sense of the second answer, and individual-specific information, freeing the latter, too, of its redundancy by referring to the relations governed by natural law. In the case of man, dependent as he is on learning, the information we called "individual" includes historical information, which is actually "superindividual." This last remark leads us to the question of progress, which we do not wish to raise here.

If we confine ourselves, for the time being, to a specific information, we must still ask how, under this aspect, the first answer is related to the second. If viewed separately, both answers interpret the theses of the preceding section in too narrow a sense; i.e., both fail to take the theses seriously. The first answer interprets thesis 2, "Information is only what produces information," in the purely external sense that the genetic information does indeed produce the rich information of the phenotype, without considering to what extent the phenotype is a "semantics" of the genetic information. The second answer, in asserting that the same amount of information is contained in the phenotype as in the genotype, takes thesis 1, "Information is only what can be understood," literally by interpreting the phenotype exclusively as a new representation of the genotype. The first answer loses sight of the understanding, the second of the production of information; but the two theses had been intended in the sense that the production of information *is* the understanding. It seems that both answers forget we are dealing with the flow of information, not with static information.

To clarify the situation further, let us consider the concept of natural law, which plays an essential part in the second answer. By virtue of the laws of nature, the answer says, the information of the phenotype is identical with that of the genotype. We are to interpret this "identity" as "understanding." What is the structure of a natural law? Let us examine the basic laws of physics.

According to Newton's law of motion, the change in the velocity of a body is proportional to the force acting on it. Let us assume, for the sake of simplicity, that the force is given ("fixed environment = external force"); the body we take as a point mass. The law describes the change in the state of the body as being determined by the state itself. The state designates those properties of the body which, rather than being implied by its essence (here its essence as a point mass), are freely assignable ("contingent"). It is the form of the law itself that specifies what properties are contingent. The state ("phase") of a point mass is characterized by its position and velocity. The contingent information concerning a point mass consists of the specification of its phase. Only if the accuracy with which position and velocity are measured is known can the actual value of the information be calculated; these problems I wish to omit here. The information always refers to a particular time; e.g., the present. The phase of the point mass differs at another time. It appears, therefore, that the complete trajectory of a point mass during an interval of time contains a lot more information than its phase at a time (again omitting problems relating to the accuracy of time measurements). The point mass continuously produces, so to speak, new information. If an apparatus external to the point mass is available for storing it, this information is not lost; *in* the point mass it does disappear, however, to be replaced by new information. For one who knows the law of motion and the external force, the new information is nothing but a necessary consequence of the old; the two are equivalent. The new information is merely the form that the old information takes on at another instant.

We can thus say, in a purely formal manner: The contingent information of a point mass at a time produces another information equivalent to it at all other times, and is thus understood. This description is formal because the point mass is so simplified a system as not to give rise to the processes characteristic of the phenomenon of understanding. Not only does the description leave aside the consciousness of a possible observer, it even omits mention of an apparatus or process that "objectifies" or "objectively simulates" the understanding in the manner of a measuring instrument or an organism. On the other hand, the point mass exhibits in its greatest possible simplicity the structure of a law-governed information flow, on which all complicated "processes of understanding" are in turn based.

To understand the basis of physics, it is important to remember that the elementary laws predict probabilities. Old information is lost when a radium atom decays, and the new information is not equivalent to the old. It seems as if the elementary event in physics presupposes not the conservation of information but its change. "Understanding," however, presupposes conservation; i.e., a sufficient degree of the deterministic causality characteristic of classical physics. For this reason, as well as because of the irreversible processes required for storage, understanding can arise only in sufficiently large composite systems.

The cybernetics of understanding is not our present theme; cf. essay

III.4. The central issue concerning understanding is the "cybernetics of truth," which is merely hinted at in the essay just cited.

d) Digression on Economic Goods and Money

How many bits are there in one dollar? I will discuss this semi-playful question as an exercise in the application of the concept of information.[3]

Not unlike length, mass, energy, and information, money is a universal measure for very different kinds of things. The scientist is inclined to see a degree of arbitrariness in this measure ("I pay as much as I like to pay"). But the remarkable fact remains that this seemingly arbitrary measure has prevailed quite universally in human society. If one asks Darwinistically for the survival value of money, one will find that here, too, the answer involves objective structures from which the monetary value of economic goods deviates empirically, just as the empirical greylag goose deviates from the greylag goose of the zoologist, which conforms to an objective ecological niche. In the case of money this structure will not be something like a specific species or niche, but a feature essential to the entire economic realm. The question "How many bits are there in one dollar?" formulates the hypothesis that, in the last analysis, money measures information. According to this hypothesis, the universality of money could be explained in terms of the universality of information.

The conception of economic goods as exchangeable commodities leads to the creation of a measure for this exchange value—i.e., money. How is it that one can find a common measure of exchange for goods so diverse as bread, fur, bricks, and a boat trip—which, furthermore, have such diverse value with respect to the subjective needs and subjective preferences of different people? What is it that the exchange value really measures? It seems to be something that all goods have in common. What can be had without effort has no exchange value—even if it is necessary to life, such as the air we breathe, or water (in water-rich regions). The idea therefore arose that it is the labor required to produce a good that constitutes its value. This idea formed the basis of classical economic theory as developed by Smith and Ricardo, and it later became the basis of Marx's economic teach-

[3] I leave aside the trivial answer, $1 = 8 bits, which follows from the fact that a coin that existed in the early nineteenth century was worth one-eighth of a dollar and was called a bit.

ings; but contemporary economic science no longer accepts it. Let me first explain what it would mean if this idea were correct.

What is the labor expended on a good? One might measure it in terms of the time required to produce it. The relevant time is, of course, not the empirical time required for the production of a particular good—the worker might have been clumsy and excessively slow, or there might have been some other deviation from the rule. What is intended, rather, is the socially necessary time, the time in which the good is normally produced in a free and competitive market. Under given conditions of production, this time establishes itself in law-like fashion.

But what is labor, what is production? A good is manufactured—a cupboard, say. Its matter does not have to be produced, the wood was already in existence; production consists of shaping it into the form of a cupboard. The amount of labor required to produce it is the work required to give the wood the form that makes it a cupboard. The "degree of processing" of the product is therefore measurable in terms of its amount of form, its information. And the information is the one belonging to it by virtue of its falling under the concept of a cupboard. Now "wood" itself is also a form. And the raw material wood does indeed have a value that, in accordance with the theory we are discussing, is measured in terms of the human labor required to grow the wood as a tree, to cut it down as timber, and to transport it to the furniture factory. In this wood inheres the information that belongs to it insofar as it falls under the concept of timber, etc.

Human labor is therefore the production of information. If one assumes that a worker produces a constant flow of information—i.e., the same amount of information per unit of time—then the working time becomes a measure of the information being created; and if money measures the socially necessary working time, it is thus information that it measures.

While showing up some of the weak points of the labor theory of value, these reflections also contribute to the clarification of the basic idea. Consider a few obvious counter-examples to the theory. A cupboard that takes a carpenter a good deal of time to manufacture is worth far less than a drawing that Picasso dashes off in a minute on the back of a menu, or than a diamond that a South African farmer accidentally finds on his property. In neither case is the empirical time of labor a meaningful yardstick of value. The socially required time might come closer: Picasso had to work for a lifetime so as to today be capable of producing this drawing in a minute; in the case of diamonds, it is not the time expended on its chance discovery that counts, but the expectation value of the time a systematic search would require. It is not everyone, however, but only a great painter who acquires the capability illustrated in the Picasso example; and it is profitable to spend a lot of time looking not for an arbitrary mineral but only for one that has the natural properties of diamond (hardness, crystal structure, transparency, etc.). Fashion, too, plays a role. The value of jewels and of fur fluctuates—and is Picasso's drawing really so overwhelmingly superior to the drawings of hundreds of his contemporaries who earn much less?

Let us first discuss the problem of fashion. There is no doubt that the price frequently cannot be correlated with an objective yardstick. One could try to use the subjective valuation of an economic good by a sufficiently large number of people as a measure of its value, and thus construct a purely "subjectivist" theory that discards objective valuations. But the theory we are looking for sticks to the idea that values are based on objective matters of fact, just as the behavior of the greylag goose is objectively based (and therefore self-reproducing) on the dovetailing of its genetic endowment with the ecological niche. In the economic domain, these matters of fact are demand and performance, the thesis being that the performance which satisfies a demand defines the concept enabling one to measure the information of the good produced by this performance. The "theoretical price" of the good would then be a measure of this information. Fluctuations of the empirical price about the theoretical value would normally be the "healthy" play of the actual about the established value. A fashion would be the irrelevant or possibly "erroneous" ("ill") deviation of the established value from its "healthy" or "average" value.[4]

The theory we have in mind, it appears, searches for the "truth" of the value of a good. That is why the case for it can be made more convincing the more primitive and non-exchangeable the demands and performances under consideration are. Even then, however, it will be possible to construct the theory only if a sufficiently subtle concept of information is available. The inescapable problems faced by this theory construction can best be seen in our two extreme examples.

Let us valuate the diamond merely according to the utility it has by virtue of its hardness. Its price will depend on its usefulness and scarcity. The scarcity governs the amount of work required to discover the

[4]Cf. III.4c.

diamond—*provided* one wants to discover it at all. Scarcity is the improbability of being discovered, i.e., a large amount of information; in this sense, "scarcity value" *is* information. *Whether* one wants to have the diamond, or for what price one would still want to have it, depends on its utility. Does utility admit of a measure in the language of information theory? As the hardest crystal there is, the diamond cuts all other materials. Thus, one single diamond, without being used up, contributes to the shaping of many objects (glass panes, for example); it therefore produces much information. If information is only what produces information, the diamond as this concrete hard crystal contains much information, which is defined in terms of a concept referring to human labor. The reader will be keenly aware of the distance separating these few sentences from a thorough analysis of the actual technical and economic process; I wanted merely to indicate the direction in which the investigation would have to be continued.

The "collector's value" of a painting is even more problematical. Its discussion would require a theory of the information value contained in human culture. The "objective" estimate of the value of art work requires familiarity with the "truth of art." The discrepancy between the social valuation as expressed in the price, and the "true value," which posterity sometimes perceives more clearly, is part of the historicity of culture itself; i.e., part of the constituents of the phenomenon. An adequate economic theory of these valuations is therefore not to be expected. Our approach can at least explain why it must be so, and it can thereby help us to assess the scope of certain concepts on the basis of their meaning. Here lie the limits of information itself: the probabilities defined on the basis of natural law, which this concept presupposes, lose their meaning when it comes to the uniqueness of historical events. Conversely, though, an information theory of value will be meaningful in all cases in which money may be regarded as a true measure of value.

This was a digression, an exercise. Let us return to physics.

e) Form as Substance

I begin with a terminological point. In the "exact" sciences, the term designating an entity is often confused with the term designating its quantitative measure. We are here distinguishing between the three entities matter, movement, and form, and their three quantitative measures, mass, energy, and information. In section a—putting it now in precise terms—we identified matter and movement as substance by relying on Einstein's identification of mass and energy, and by regarding both of these as quantities of substance. "Movement" was taken in its active mode; i.e., not as the actual process of being moved but potentially, as that which moves. The connection between the potential and the actual was not discussed, and the thesis that movement is the production of movement therefore remained "symbolic." At the end of section b we discovered the similar structure that showed information to be the production of information, and we announced that we would use this structure to explicate the thesis concerning movement. We now do so in the form of the hypothesis that substance *is* information.

This hypothesis entails the following theses: Substance is form. More specifically: Matter is form; movement is form. Mass is information; energy is information.

The theory of "ur-alternatives"[5] attempts to carry out this hypothesis. I will now discuss the theory from this point of view; prior acquaintance with II.5e is assumed.

I begin with an obvious objection. How can substance be form? Form, after all, is the form of a substance. Is form then the form of a form? Or, more peculiar still, is substance the substance of a substance? I note first that we have defined the concept of substance as matter = "energy" so narrowly that certainly not all forms can be substance in that narrow sense. "Substance is form" is not an equivalence but a predication: substance is subsumed by form. Thus, in our way of talking, substance is not the substance of a substance, but form can be the form of a form. From the point of view of ancient philosophy it is quite natural that this should be so. "Cupboard" is the form of wood, but wood, too, is a form. Our "substance" corresponds to "first matter" (not to *ousia*). On the level of reflection attained by Aristotle, first matter cannot be further predicated. In the less well developed science of the seventeenth century, first matter is characterized by a "first form" (extension in space). How should we conceive of this today?

First matter cannot be characterized other than in terms of the form one can find in it. What characterizes it as matter in this sentence is the "can": according to Aristotle, matter is the possibility of form. The "in it" in the sentence is therefore a pleonasm: first matter is not a

[5]Cf. II.5e.

something "in which" a form can be found; this would be true only if it were a form still different somehow from the form "in it." Rather, it *is* the possibility of finding form. What can be found is *eo ipse* form.

How can form be characterized in terms as general as possible? Whether a particular form is or is not there constitutes an alternative. To distinguish among many different forms we must decide a multiplicity of simple alternatives. In general we can therefore say: Wherever a particular form is found empirically, a number of simple alternatives are being decided empirically. Formulated as the basic hypothesis of "ur-alternatives," we say that all forms "consist of" combinations of "final" simple alternatives.

In the spirit of the axiomatic construction of quantum theory and of the theory of ur-alternatives, we try to base all postulates and axioms on the analysis of such terms as "decision," "prediction," "probability," and on a fundamental assumption concerning symmetry. The latter is meant to follow from the notion that every decision is a decision among ur-alternatives, and that for every given finite number of ur-alternatives a deviation from the symmetry of its state space would imply the decision of an additional ur-alternative, contrary to the assumption of a given definite number. What this program is worth can be discovered only upon its completion. I will now assume it to be successful, in order to discuss it as a model of the thesis that substance is form, and of the consequences of this thesis.

Matter is form. Today we understand matter in terms of elementary particles. These are to be constructed in terms of ur-alternatives. Ur-alternatives are the final elements of possible forms; decided ur-alternatives are the final elements of actual forms. The simplest example of form is spatial structure. The theory must therefore deduce the possibility of spatial structure, and does this by reducing space to the quantum mechanical state space of the isolated simple alternative. State space is in turn structured by the probability function, whose meaning rests on the possibility of counting relative frequencies; i.e., on the repetition of the same experiment with many identical simple alternatives. Spatial structure, then, really does consist of many ur-alternatives; actual spatial structure consists of many simultaneously decided ur-alternatives, whose actual frequencies are proportional to the computed probabilities.

Mass is information. In the force-free approximation (and I have not as yet mastered the theory of interactions), the information of an event is simply the number of ur-alternatives in it. In the case of the simplest model of a particle with mass, the rest mass of the particle is the number of ur-alternatives required for the construction of the particle at rest; thus, it is simply the information invested in the particle. The mass of a moving particle is larger, and contains proportionately more ur-alternatives.

Energy is information. The relativistic equivalence of mass and energy enables us to transfer to energy all we have said about mass. The formal relation is simplest in the case of kinetic energy. A free ur-object has a constant energy, the smallest possible cosmic energy quantum E_0. A "naked neutrino" with the energy $E = n \cdot E_0$ is simply the superposition of n parallel ur-objects, n being the information of the neutrino.

Movement is form. The flow characteristic of form (information is only what produces information; movement moves itself) only now becomes apparent. The stepwise clarification proceeds as follows:

To begin with, the free ur-object is assumed to be in motion (its state vector contains the factor e^{-iE_0t}). Why? This is in fact the solution of the most general SU_2-symmetric equation of motion; but why, in the absence of external forces, do we not set $E_0 = 0$? (If the number of ur-objects is indefinite, this is not a mere matter of convention.) A first answer is given by the argument for the "weak law of inertia": interaction can be understood (at least in the case of localizable particles) only if particles move even in the absence of interaction. The weak law of inertia seems to be a precondition for the possibility of interaction. Objects without interaction would not be observable, they would be objects for nobody. In our present way of putting it: information that does not produce information would be information for nobody.

Secondly, the law of inertia in its "strong" form (i.e., with the factor being precisely e^{-iE_0t}) is a consequence of the action of the universe as a whole on an individual ur-object. Therefore, only this theory fully satisfies the Aristotelian-Machian postulate of no motion without a cause. "Cause" is meant in the traditional sense of an effectual thing (not of an abstract fact, such as the prior motion of the moving object). Mach accepts the causal paradox of the law of inertia and wishes merely to specify the reference system, which defines uniformity of motion, in terms comformable to his philosophy; i.e., in terms of perceptible things. In locating the cause of motion in the structure of the universe, our theory does more. We can also put it this way: the ur-object is the simplest form; at the same time, it is the quantum of movement. It is form because it is form (through interaction) for something else, it is form in a universe in which it moves something else. It is itself moved as a form in the universe by which it is moved.

The universe appears in this theory as the totality of forms. In its basic conception, the theory thus carries out the radical objectification of semantics. Form is understood only by the form it produces. In this sense, understanding is a part of the great process of self-movement. Whether this is a merely metaphorical or a rigorous expression will be discussed in section f.

The finiteness of the universe is a central problem of the theory. I do not as yet see through this matter, but would like to conjecture as follows. Form occurs in this theory only as form that is knowable in principle. Who is it who knows here, who is the subject? It is man, in a sense, since this is a theory made by men for men; what man in principle cannot know does not occur in the theory. But the theory objectifies semantics; should it then not also describe knowing in terms of measuring devices; i.e., by means of physical objects? Let us first stick to man, so as not to lose all sense of direction.

How much information can men have? Only a finite amount, at any given time. Is there an upper limit on the amount of additional information that could be acquired? Not as far as we know. If the universe is the totality of knowable forms, it must at any given time be finite. But the universe can acquire an additional finite amount of information in a finite time interval. Invoking the objectification of semantics, I interpret this growth in the amount of knowable form as the expansion of the universe. The growth of space, in this sense, *is* the openness of the future.

f) Mind and Form

As we conceive of it, movement always appears as self-moving, form as forming, form also as knowable, and knowledge as form. Is this a theory that objectifies consciousness, or are our formulations obtained in an underhand way?

In the mechanistic world view, the idea that matter can think is an empty postulate. The explanatory power of that view depends on the explicit specification of the defining properties of matter (extension in space, impenetrability); all that could ever be derived from it is the movement of matter thus defined. In our view, however, matter is nothing but the possibility of the empirical decision of alternatives. This presupposes a subject who decides. If this subject can know itself and express this knowledge in terms of empirically decidable alternatives, one must assume that it itself is a part of the universe that is the totality of these alternatives. One can say: We have presupposed knowledge and need assume no more than that knowledge can know itself.

The uniformity of all ur-alternatives now implies that all substance is in principle of the nature of knowledge that knows itself. It will be up to a "cybernetics of truth" to describe how "virtual knowledge" can become actual—an immense task, to be sure. The limits of human knowledge must be specified not only with respect to man's organic life (to which the feelings and pressures of our embedment in the environment can be attributed); one must also show in what sense human knowledge knows not only objects but also the knowledge of other men; i.e., in what sense subjective knowledge is trans-subjective. And one must at least ask how the finite human knowledge known to us is limited at its apex. If the essence of substance is form, and form is mind, then it is not a matter of course that mind is limited to man. The Neoplatonist doctrine that the ideas know themselves seems natural in this context.

For all these questions, however, the conceptions of our approach no longer suffice. Objectifiable forms are static, they can be repeated; the concepts of probability and information are of this kind. In its historical development, knowledge transcends this static quality. The cybernetics of truth would have to describe the process of objectification; and in the objectifying delineation of the possibility of its own method, it would then come up against the limits of that method, which are the limits of objectification itself. From the point of view of transcendental philosophy, the idea of the objectification of a final subject confuses the empirical with the transcendental. It is of the nature of meditation not to objectify. God is not the totality of forms, but their ground.