Bernard d'Espagnat: On Physics and Philosophy

CHAPTER 1

BROAD OVERVIEW

1-1 A General Picture

ADMITTEDLY THE new world-view that soared in the early seventeenth century originated from Copernicus' discovery but it is not to be questioned that the change from Aristotelian to Galilean physics played an essential part in its development. Aristotle had kept close to raw data obtained through the senses. He saw that all moving bodies not subjected to any force finally stop, and he raised this observed fact to the level of a basic principle of knowledge. He observed that living beings have all sorts of different shapes, qualitatively differing from one another, and he therefore took the notion of a wide variety of fundamental forms as a guideline for his philosophy. Hence, for him, there were a great abundance and variety of concepts, all of them lying, so to speak, on the same level. Hence also he gave considerable care to detailed qualitative descriptions, counterbalanced by a marked weakness concerning anything physically quantitative. With Galileo, Descartes, etc., on the contrary, the idea that came to the forefront was that of a hierarchy of concepts. Within their approach there are basic and nonbasic ones, and the latter must be accounted for in terms of the former, so that, in the end, the description of the physical world should be entirely expressed in terms of just a few basic notions linked together by quantitative laws. And we know, of course, that within classical physics as well as in all other sciences this is the conception that finally prevailed.

The difference just sketched between the Aristotelian and the Cartesian-Galilean approaches is quite well known. But what often remains unnoticed is that, notwithstanding this difference, the approaches in question had an important feature in common. In fact, they shared the view that the basic concepts (the nonderived ones) are either obvious ones or, at least, idealizations of obvious ones; that they are familiar notions—"clear and distinct ideas" as Descartes said—whose unquestionable validity is fully guaranteed by commonsense (i.e., by God, according to the same). It is often—and rightly—stressed that Galileo, Descartes, and Newton brought mathematics into physics. But an often overlooked point is that they made use of mathematics primarily for imparting quantitative content to developments exclusively bearing on objects designated by means of familiar concepts. Descartes was bent on describing the whole of the physical world by "figures and motions" and referred to "the pipes and springs that cause the effects of the natural bodies." Newton spoke of material points, that is, (basically) idealized grains or specks. Even Pascal, in his fable of the mite, clearly took it for granted that the domain of validity of the familiar concepts extends to the whole range of conceivable scales, from the infinitely great to the infinitesimally small.

Were they right? Yes of course, in a sense. Pioneers they were and, as such, their most urgent task was to explore the ins and outs of such a natural idea. Moreover, the idea in question proved spectacularly fruitful. Still today, there are many fields of study in which it is possible to describe data and processes by the sole means of basically familiar concepts and in which this is obviously the best way to carry on fruitful research. Consider, for example, molecular biology. Molecular biologists have to do with large molecules whose behavior—for well-known reasons following from the very rules of quantum physics—practically obeys the laws of classical physics. Consequently it is possible and natural to think of them as having rigid atomic structures, fixed shapes (including hooks), and so on; in short, to reason about them as if they were component parts of a clockwork or a machine. This mode of thought opened the way to quite a host of predictions, many of which proved brilliantly successful. No wonder that many biologists are tempted to raise it to the level of an absolute; to view it as yielding *the* proper canvas for a description of "the Real itself," including thought.

All this naturally leads to a mechanistic world-view styled naïve—to be sure—within philosophical circles but stamped with commonsense and taken therefore by the majority of well-informed people to be by far the most sensible one. Think, for a moment, of an attorney, a senior executive, an engineer, or even a scientist working in some highly specialized field other than theoretical physics. Such people—most of our contemporaries indeed—have to do, all day long, with machines of all kinds, that is, with human-made devices of which the clock is the example par excellence. No wonder that they spontaneously lean toward a generalized mechanistic world-view, in spite of all that the philosophers may write and say! It is therefore fully understandable that such a type of natural philosophy should remain, so to speak, the instinctive one in the minds of both the enlightened laymen and a majority of scientists. The idea that the World—or, at least, its physical part—is of the nature of some gigantic machinery seems infinitely plausible indeed.

And still, the opposite is true! In a move that was slow at first but progressively speeded up, physics taught us, not only that the human mind is able to operate well outside the framework of familiar concepts, but also that it absolutely must do so. Of all sciences, only physics, apparently, yields this message. But it does. And the fact that it does may well be taken to constitute one of its main contributions to the development of thought.

For brevity's sake, let me illustrate this by but one example, that of particle creation in high-energy collisions. This phenomenon is explored and investigated in laboratories where large particle accelerators are available and observed in bubble chambers in which moving particles produce tracks. Two protons are accelerated. Each one has a given motion, a given velocity, and hence a given energy. They collide and they then part from one another. At that time we observe that, even though they are still in existence and did not break up, other particles have appeared, which are "really true" particles—possessing masses, electric charges, and so on—that have been *created* in the collision, at the expense of the incident protons' total energy. This, at least, is what we see. Admittedly, the phenomenon is quite in agreement with the celebrated $E=mc^2$ law expressing mass-energy equivalence. But if we insisted on describing it by the sole means of familiar concepts we would have to say that the incident particle motion was changed into particles. Now, motion is a property of objects, so that what we would thereby refer to would be nothing else than the transformation of a property of objects into objects. Such an idea lies entirely outside the realm of our familiar concepts. Within the set of the latter there are, on the one hand, objects and, on the other hand, properties of objects; and no element of either one of these subsets ever transforms into an element of the other one. The very idea of such a transformation looks just as absurd as that of changing the height of the Eiffel tower into another Eiffel tower. Or as the view that, when two taxis collide, they may both emerge undamaged, accompanied by five or six other taxis arising from the initial kinetic energy of the former. All this makes it crystal clear that contemporary physics forces upon us the use of basic concepts lying outside the realm of the familiar ones, with the sole help of which Descartes (and the other "founding fathers" of modern science) originally claimed that physics would describe the World.

Are we then faced with an enigma exceeding the powers of understanding? Quite on the contrary, theoretical physicists not only know how to deal with this creation phenomenon but also had *predicted* it, on the basis of their equations.[1] Which shows that, when applied to physics, mathematics makes it possible to really reach beyond all familiar concepts; to actually *coin* new concepts. This reminds us of Pythagoras' famous saying: "Numbers are the essence of things." A sentence to be understood, of course, as "*mathematics* are the essence—the very essence—of things."

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[1] We here refer to the work of the British physicist P.A.M. Dirac.

This, to be sure, is not the proper place for entering into a detailed account of how physics manages to describe the creation phenomenon. Already at this stage let us note, however, that it offers several ways of doing so, grounded on quite different basic concepts. The existence of this diversity should not disconcert us, but it is important that we should be aware of it, since it casts quite a serious doubt on the very possibility of univocally determining, by means of physics, a list of the truly basic notions. Which, in turn, makes it unlikely that Pythagorism is the "last word" of our story. Indeed the diversity in question is a good example of a philosophically important phenomenon—called "incomplete determination of theory by experience"—that we shall frequently have to take into consideration. With respect to the case under study, it so happens that the mathematical formalism yields not one but three distinct theories, all of them grounded on the general quantum rules, yielding essentially the same observational predictions, but widely differing concerning the ideas they call forth. They are called the "theory of the Dirac sea," "Feynman graph theory," and "quantum field theory."

We shall soon get acquainted with the two first named ones (sections 2-6 and 2-7), and shall then have the opportunity of observing how widely both depart from the Cartesian ideal of a description using only familiar concepts. But, for the time being, let us focus our attention on quantum field theory.

Unquestionably more general than the first one—Dirac's—this theory is, in a way more basic than the second one—Feynman's—which primarily appears as a powerful method of calculating, grounded, as its author himself stressed, precisely on the very rules of quantum field theory. To form a broad idea of the general guiding lines of the latter let us begin by observing that the notion of creation is not a scientific one: We do not know how to capture it, and even less quantify it. It is therefore appropriate to try and reduce it to something we can master. Now we do master the notions of a system state and changes thereof. We know how to calculate transition rates from one state to another. And the brilliant idea, the breakthrough, just came from this. It consisted in considering that the existence of a particle is a state of a certain "Something," that the existence of two particles is another state of this same "Something," and so on. Of course, the absence of a particle is also a state of this "Something." Then, the creation of a particle is nothing else than a transition from one state of this "Something" to another, and therefore we may hope to be able to treat it quantitatively. It is just as simple as that! In practice—believe it—the matter is appreciably more complex. Quantum field theory textbooks are big, fat objects, full of formulas, many of which are in no way beautiful. But by plodding through the latter it proved possible to account for observed phenomena with a precision that, in some cases, extends to the seventh decimal. Which, really, is "not too bad"!

The reader will be spared the calculations. Instead, let him or her reflect on the just described basic idea of the quantum field theory. True, the problem of the "real nature" of the "Something" that it brings—at least implicitly—into play is, as we shall see, an inordinately delicate one. However, concerning it, one point at least seems rather clear. It is that the cornerstone role tacitly attributed to it somehow suggests the presence, within the core of present-day physics, of a wholeness of some sort, radically foreign to classical physics. The point is that classical science was very much in favor of what may be adequately said to be a *multitudinist* world-view. In other words, it favored a conception of Nature in which basic Reality—matter, as it was called—was constituted of a myriad simple elements—essentially localized "atoms" or "particles"—embedded in fields, and hence interacting by means of forces decreasing when distance increased. The first two of the above mentioned theoretical approaches still are more or less compatible with such a view, although, as we shall see, they considerably weaken it by attributing to the particles behaviors that the mind cannot imagine. On the other hand, the—more general—quantum field theory is radically at variance with it. Not only is it true that, in it, the particles no longer play the role of the constitutive material of the Universe. What is more, the only "entity" that, in it, might conceivably be thought to constitute basic Reality is the "Something," of which we saw that it is fundamentally the only one of its species.

The idea that, here, is seen to come to light (though dimly as yet) is, to repeat, the notion of a wholeness of some sort. Within elementary particle physics wholeness, admittedly, remains ambiguous since while, say, manifest in one formulation, it is evanescent in the other two—in spite of the fact that all three are equivalent and proceed from the same—quantum—formalism. This perhaps explains why, when quantum mechanics appeared, the notion in question was clearly apprehended by neither the epistemologists nor even the physicists, with the perhaps unique exception of Schrödinger. But theoretical as well as experimental advances gradually made people realize that it constitutes an inherent part of the very quantum formalism and has quite specific experimental consequences.

Nowadays the common name *nonseparability* serves to designate both the just mentioned mathematical features of the formalism and the corresponding observable effects. A most important point is to be noted concerning it. It is the fact that the range of validity of the notion it designates is even wider than that of the presently accepted theory. Indeed, it has been established that in one at least of its main aspects—nonlocality—it will certainly remain true, even if the quantum formalism must, one day, be replaced by some other, more general, one. As will be seen (chapter 3), this follows from the Bell theorem and the experiments—such as Aspect's—associated with it, for the results of the latter are incompatible with some consequences of the inverse hypothesis—locality, and this quite independently of any theory whatsoever.

To be sure, scientists and even physicists go on expressing themselves in terms of particles, molecules, and so on, all words calling forth the idea of individual, localized objects depending less on one another as the distances between them grow greater. In short, they go on making use of a multitudinist language. And from their angle they are right for, as we saw, this amounts to referring to a model that is, by far, the most convenient one in an enormous variety of cases. But, by now, it appears more and more clearly that it is merely a model. With due reservations a comparison could be ventured here with Ptolemy's geocentric model, which also works quite well on specific problems. In both cases, to raise the model to the level of a description of "what really is" is scientifically illegitimate.

In this respect, let it be noted that the question "reality or just model?" never comes to light in the articles physicists write. The latter wisely remain on "secure ground," which means that their theoretical constructions, elaborate as they may be at the level of equations and methods, are left by them very much "open" regarding concepts. In fact, when they work on such constructions the condition they impose on them is just that they should be highly general models, correctly accounting for what we observe in a great variety of experiments. Consequently it is without qualms that they ground them—tacitly at least—on the basic principles of "standard" quantum mechanics, without being in the least worried by the fact that, as we shall see, some of these principles impart a fundamental role to such notions as "measurement" and "preparation of system states." Now, this fact—the occurrence of a reference to human action within the very axioms of physics—is sometimes explicitly stated. Often it is kept implicit. But in any case it implies that the theories built up in this way markedly depart from a principle that was one of the main guidelines of all classical ones. I mean the rule that basic scientific statements should be expressed in a radically objectivist language, making no reference whatsoever, be it explicit or implicit, to *us* ("operators" or "measurers").

As a consequence of all this, it becomes clearer and clearer that our senses do not reveal the "real stuff," as it truly is. Indeed, let us consider an object that is more or less on the human scale, say a stone or a speck of dust. That it is not what it looks like has been known for quite a long time. Classical physics taught us already that, while we tend to take a stone to symbolize the very notion of "fullness," it is, in fact, mainly composed of vacuum (the space between the nucleus and the electrons).

But nonseparability suggests that, strictly speaking, it does not even exist as a distinct object! That its "quantum state" is "entangled" (this is the technical word) with the state of the whole Universe. How does it then come that, to us, it seems localized? Recently, a very general argument—called "decoherence theory"—was found that partly accounts for this fact. But its nature is disconcerting enough, for, as we shall see, it amounts to proving that, for all practical purposes, we are unable to measure any one of the quantities the measurement of which would show that the stone is *not* localized. It makes it clear that all such measurements are far too complex to be performed (they would necessitate inconceivable instruments, perhaps composed of more nuclei than there are in the Universe, or, alternatively, performing times longer than the life of the latter, or other, similarly unthinkable conditions). Obviously, this view is quite the opposite of the classical, commonsense one that objects truly have the shapes and positions we see, and that they have them "by themselves," quite independently of the limitations of our own aptitudes, as well as of the size of the Universe or anything else. Were some simile requested, the best one would probably consist in comparing the quantum objects to rainbows. If you are driving, you see the rainbow moving. If you stop it stops. If you start again, so does the rainbow. In other words, its properties partly depend on you. Taken literally, quantum physics, when thought of as universal, imparts to all objects such a status relative to the sentient beings that we are. It is true that some physicists strove to revert to a more classically objective standpoint but they had such serious obstacles to circumvent that, as we shall see, the outcome of their quest has finally to be considered unsatisfactory.

To sum up, the foregoing quick survey yielded glimpses at three main points. One of them is the necessity not to keep to the set of the old, familiar concepts. Another one is the necessity of going over from multitudinism to a holistic view of whatever is meant by the word Being. And the third, related to the latter, is that trying to go on using a universal objectivist language generates difficulties that, finally, make such attempts artificial. Here the expression "objectivist language" means a language that is descriptive, that is, as already stated, not merely predictive of observational outcomes. In other words, it means a language the grammatical form of which at least makes it possible to think of what it deals with—essentially contingent, space- and time-localized data—as existing quite independently of us. All this, of course, has merely been sketched and will be developed and made precise later on.

Accordingly, the chapters immediately following this one will deal with these three points, which will be examined one after the other and in detail (with emphasis, of course on the more delicate ones). Before that, however, it is suitable that some notions in rather current use be considered. The main purpose of the following section is to make the latter precise and define words or expressions for designating them, so that we can later unambiguously refer to them. Some of the definitions in question will be supplemented by commentaries aimed at describing the contexts in which they appear.

Remark

It should be noted that within the notion that most physicists form of their science the three mentioned points do not lie at the same "obviousness level." The first one—the necessity of reaching beyond familiar concepts—is almost unanimously considered undeniable and essential. This, already, is not quite the case concerning the second point, the one relative to wholeness. In fact, while quantum field theory led to very many fruitful mathematical developments, surprisingly enough it gave rise to but few analyses explicitly bearing on its concepts. And the existing ones (such as some articles from the great physicist Erwin Schrödinger) are hardly known, even by the experts. A reason may be that, as will be shown below, a general feature such as nonlocality has no direct impact on what physicists are, as a rule, most directly interested in, namely, prediction of experimental results within their own specific field. It is therefore not surprising that, even though the Bell theorem and the corresponding experiments are by now well registered facts, nevertheless the physicists' community is still not unanimous in recognizing their full importance and bearing. Finally, with respect to the status of objects relative to us great divergences of opinions remain. True, it is rarely denied that reconciling the realist approach with the theory is difficult. But the idea remains widespread that such problems are, after all, just subtleties that the passing of time is bound to somehow remove. Being worried by them is the lot of but a minority, which, however, is numerous enough to hold international symposia and so on. The problem has many facets that lie at the core of numerous debates, and is even broader than most of the physicists engaged in such studies believe it to be. This is because—contrary to what many intuitively think—the Galilean ontology, even remodeled the Einsteinian way, is nothing like an "obvious truth" that we should have to take for granted. And in fact it is just the ambition of books such as the present one—that is, books aimed at a better philosophical understanding of present-day scientific data—to play a part in shedding light on this galaxy of questions.

1-2 Some Useful Definitions

For the above-stated purpose we shall, of course, from the next chapter on, make use of physics, that is, of essentially concrete observational data. But since we have to match such concrete material with abstract and varied human ideas, we must first allot to the latter labels making it possible to currently refer to them, without having to reiterate on every occasion the essentials of their definitions. Such is the purpose of this section, which should therefore be considered a sort of necessary parenthesis in the overall unfolding of our enterprise. It consists in alphabetically ordered definitions of words and expressions that will often occur. Following this list is a table of not so frequently used words, indicating the sections where they are defined.

Counterfactuality. See *Realism of accidents*.

Idealism (Temperate). So is to be called here Kant's conception, named by him "transcendental idealism." In it, the *thing-in-itself* notion is held to be meaningful, in spite of the fact that the said thing-in-itself is considered unknowable.

Idealism (Radical, Otherwise Known as Critical. So will be called the neo-Kantians' position, in which the *thing-in-itself* notion is rejected.

Everybody knows that idealism, in either one of its two versions, is grounded on the following remark. If objects exist of which we may acquire direct—hence sure—knowledge (it is by no means certain that there are any), these objects can only be of a mental nature: ideas, raw sense data, etc. They cannot be elements of the outside world since knowledge of the latter results from operations of the senses, and senses are likely to deceive us. Idealism claims therefore that we merely have access to representations, that is, to "phenomena," and that the only legitimate purpose of science—and of knowledge in general—is the investigation and ordering of the said representations. It is along such lines of reasoning that Kant claimed space, time, and causality are but a priori forms (of our sensibility as regards the two former and our understanding concerning the latter).

Note that phenomenalism, positivism, and pragmatism may be considered to be variants of idealism, at least in the sense that they all more or less agree with the above-stated views. Also note that Kantian idealism parts from other forms of idealism in that, according to it, raw sense data such as, say, a visual impression are neither more nor less “directly known” than external objects and are not therefore elements of “reality-in-itself” any more than the latter are. Moreover, it tends to dismiss the view that some unknown “object-in-itself” exists, corresponding to each “object for us.” As Putnam put it (Putnam 1981): “ On Kant’s view, any judgement about external or internal objects (physical things or mental entities) says that the noumenal world *as a whole* is such that this is the description that a rational being (one with our rational nature), given the information available to a being with our sense organs (a being with our sensible nature) would construct” (my emphasis).

Language (Objectivist). The (already used) expression “objectivist language” means here a language that in no way basically refers to us. More precisely, it means a language that is essentially *descriptive*, as opposed to *predictive of observations* ; a language grounded on the assumption that either the considered objects—in a wide sense of the word, that is, particles, fields, and so on—really exist, or we can *do as if* they so existed, quite independently of us. Of course the view that the objectivist language is universally valid—at least concerning nonmental issues—is derived by us from everyday life. It is, moreover, engrained in our mind by basic scientific education. Obvious pedagogical reasons induce high-school science teachers to tell or at least to suggest to their pupils that an electrical field “exists,” that atoms “exist,” and so on, just as we currently say that stones and grass exist.

It is worthwhile to note that, although the Kantian and neo-Kantian philosophers denied that knowledge has any ontological meaning, the tendency to universalize the objectivist language was in no way opposed by them. Quite on the contrary, these thinkers were among those who made great—and temporarily successful—efforts at justifying the objectivist language (in the “as if” sense, of course), and its extension to the whole field of physics.

Under these conditions the conceptual difficulties raised by the advent of quantum mechanics could not but be perceived as being particularly serious. For indeed, to be expressible in the objectivist language any theory must—at the very least—make it possible to specify what, within it, is to be taken as real, or can be treated as being real. In other words, within the mathematical formulation of the theory, at least some mathematical symbols must be interpretable as describing elements, or features, of reality. In Newtonian physics this, for example, is the case concerning the symbols representing particle positions. In classical electrodynamics it is the case as regards those representing the fields. But in quantum mechanics, specifying what is real is very far from being easy. And, in fact, this was the essence of the objection raised by Einstein against quantum mechanics. Contrary to what is often said, Einstein was not craving for a return to old classical concepts. His criticism could be expressed as a question: "What, in the theory, can be considered real or treated as if it were real? Be outspoken and let me know!" Bohr's answer to this query may be considered to be a denial of the very validity of the question; a denial justified by the fact that, as we shall see, Bohr finally interpreted quantum physics and science in general as being descriptions, not of anything like a given external reality, but merely of communicable human experience: in other words, of a "reality" (if we dare venture the term) actively constructed, not only by thought but also by our operational decisions, thus obviously parting with the objectivist language.

On the other hand, few physicists willingly accept giving up a language that, in the opinion of many of them, adequately reflects the ultimate aims of physics. And, to say the truth, for quite a long time few of them even realized that the notion of a science exclusively aimed at describing collective human experience lay at the core of Bohr's approach (even though Bohr himself took great pains to make the fact clear). The worrying question "what, then, is real?" was thus left open. It is true that it long remained in latency, so to speak, precisely because of this misunderstanding. Many physicists were, somewhat naively, convinced that the Bohrian solution was compatible with the notion of a quantum formalism correctly describing reality-in-itself. They therefore did not feel incited to think over a problem that, without having personally examined it, they thought had been solved long ago by others, in a way compatible with their own conceptions of reality. It is the belated collective realization of the occurrence of this misunderstanding that explains for the most part the present-day renewal of interest in these questions.

Multitudinism and Principle of Analysis. "To divide all the difficulties I shall examine in as many parts as possible and as needed for better solving them"—it is in this concise form that Descartes—he again!—stated a principle that, from the seventeenth century to ours, has been at the core of scientific research and may be considered one of the main sources of its success. It suggests the view that, when we have to do with a somewhat complex physical system, we should divide it by thought into simpler ones, study each one of the latter separately, take—of course—the forces connecting them duly into account, and finally make a mental synthesis of them. The fact that this procedure was very generally successful strongly suggested that, indeed, complete knowledge of the parts—and forces—ipso facto yields that of the whole, and that, therefore, the *whole* basically is a composition of *parts*. This is what will be called the *multitudinist* conception.

In section 1-1 we already had a glimpse of the fact that contemporary physics yields serious indications that multitudinism is flawed. Later we shall determine more precisely what the nature of the said flaw actually is.

Phenomenon. In this book this word is usually taken in its etymological (and somewhat restrictive) sense: the object of some possible (human) experience.

Platonism. As is well known, this venerable conception lies midway, so to speak, between idealism (it is sometimes called "objective idealism) and realism (it is also referred to as "realism of the essences").

Pythagorism. See *Realism (Einsteinian).*

Realism. As we shall see, there exist several forms of realism. But practically all the "realist" conceptions (in the philosophical sense of the word) are basically composed of two elements. The first one consists of the notion of reality-per-se—a "reality" conceived of as totally independent of our possible means of knowing it—along with the hypothesis that we do have access to the said reality, at least in the sense that "we can say something true" concerning it. At first sight this "hypothesis" looks like a mere truism (if we see an object in front of us how could it not be there, as we see it?). But the simple fact that we have dreams already convincingly shows that it is quite far from being one. In fact the hypothesis in question is one of those that, like induction and so on, are quite often intuitively assumed true (and maybe rightly so) without being scientifically provable. To try to make it plausible is, of course, quite legitimate; for example, by means of the no-miracle argument, or by referring to intersubjective agreement (both attempts will be discussed in chapter 5). But it cannot be proved correct.

The other element constitutive of (almost all) "realist" conceptions[2] (it is indeed distinct from the first one, as will appear) consists in a *representation* we build up of independent reality. A representation worked out from the phenomena, that is, from human experience.[3] Indeed, this

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[2] "Open realism" is an exception, and so is my "veiled reality" conception (see chapter 10), which is a special case of the latter.

[3] Concerning these representations a concatenation of three almost self-evident points is worth being made explicit. One of them is that obviously, being phenomena, elementary sense data (such as having the impression that a pointer has at a certain time a certain position on a dial) may (and often do) come in as parts of such a representation. Another one is that as long as we consider a representation to be valid all its elements, including these sense data qua "impressions," are to be considered valid, or "true," by definition. And the third one is that a representation is valid only if it is self-consistent, that is, if the

representation may be (and, in science, actually *is*) constructed without a reference to the reality-per-se notion being a necessary ingredient in the process. It is a posteriori—so to speak—that we identify the elements of the said representation as elements of reality. But it must be noted that the elements of experience that we preferentially select for this identification are of a varied nature and that the realists do not all select exactly the same ones. This is what gives rise to the various kinds of realism described below.

Realism of the Accidents (Alias Objectivist Realism, Alias Galilean Ontology). The "representation" element of this realism[4] primarily stems from the importance attributed by human beings to some groups of impressions, the relative stability of which they undoubtedly noted right from the very beginning of the human species. These impressions were gathered together as ideas of objects, quantities, value possessed by these quantities, sequential rules concerning these values, and so on. It is these groups of impressions that were raised to the "dignity" of representations of elements of reality. In philosophy the word "accident" was often used to designate the contingent (and possibly changing) properties of perceived things, such as their multiplicity, their forms, their positions, and their motions (in physics the two latter are often called "dynamical properties"). This is why the name "realism of the accidents" was found here adequate for labeling this realism. But another basic feature of the representation in question is the fact that it takes into account and elevates to the status of a genuine component of reality the outcome of a very general and obviously equally primitive observation: The observation of the considerable usefulness, at least for practical purposes, of the *counterfactuality* notion. Schematically, I make a counterfactual reasoning when I say to myself: "By performing such and such an operation (for example, going and seeing) I found that such and such a quantity has such and such a value. I consider that this quantity would have this value, even if I had not performed the operation in question." Counterfactuality enables us to trust the validity of some statements referring to an observation or an action that we could perform instead of the one we actually do. Now, our impression that the things are real is largely due to this trust we feel we

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consequences inferred from some of its elements by applying rules assumed in it to be valid are not at variance with some other elements composing it.

[4] One should of course carefully avoid mixing up realism of the accidents with the "realism" of the great medieval texts. In fact, these two conceptions are diametrically opposed. Realism of the accidents imparts the status of real entities to the individual objects that we perceive (and also of course, to their constituting parts), whereas medieval realism attributed this status essentially to the great general concepts, along the lines of Platonism.