energy physics. It makes a difference in a scattering experiment what the target is.

With a suitable interpretation of the probability concept, any probability distribution can itself be interpreted as a *statistical law*. It then says with what probability a result will occur if a certain experiment is repeated. The law-like character is particularly evident for transition probabilities of stationary Markoff processes. The special cases of probability 1 and 0 suggest anew the old view that probability-free physical laws, if they are valid, are *necessarily* valid. Such necessity has been claimed particularly for *causal laws*. On the other hand, already David Hume had argued in great detail that necessity, if it can be found at all, can be found only in the experiencing subject and not in the physical processes themselves. Indeed, from an empiricist point of view, the idea that the world could be different from what it is in some respects but not in others is wholly fictitious. For us, then, there is only one world, and the necessity of its laws as distinct from singular propositions may just be falsely suggested by the fact that the latter but not the former, occur in numerous similar variations.

The laws of physics (and presumably of all natural science) can be ordered in a *hierarchy*. Some laws are reducible to (or explained by) others. At the bottom of the hierarchy there are the 'degenerate' cases where laws explain singular facts. In general, the reducing laws are the more comprehensive, in the sense that they introduce more detailed descriptions of already known systems or even of entirely new ones. The direction of the reduction is roughly determined by the composition of matter and by the decrease of the governing forces with increasing distance. The final goal is the reduction of all forces known by experience to as few fundamental interactions as possible. This completion of the hierarchy of its laws could eventually lead to the unity of physics.

"The age in which we live is the age in which we are discovering the fundamental laws of nature" (Feynman 1965, p. 172). However, it may very well be that this age will soon come to an end – even without the fundamental laws. There is growing interest, even on the part of the physicists, for detailed investigation into more and more *complex systems*. The exploration of the hierarchy of natural laws has at least shown how little we know about the world if we know its fundamental laws. Contingencies pervade the derived laws, and their explanatory power decreases with increasing complexity in the systems to which they are applied.

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ERHARD SCHEIBE

Natural Science

Natural science is in this article understood in the post-medieval sense where, almost by definition, questions about intentionality and teleology are excluded. Furthermore, the term is here restricted to those areas of contemporary natural science where physics is regarded as the basic discipline. Ontological questions pertaining to biology and ecology are excluded, too.

Before presenting the central issues around which ontology and natural science meet, some words are needed about the general relationship between philosophy and science. There are, first of all, epistemologies which rule out ontological considerations in the natural sciences (e.g. conventionalism and instrumentalism). But this holds of some ontologies, too. Ontologies saying that nature is an assemblage of unstructured particulars effectively turn the philosophy of the natural sciences into a branch of (say) the philosophy of language, since all structure, then, is linguistic structure. Ontologies affirming that all change is illusion, of course, also render illusory the content of the natural

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If one accepts, however, that ontology and natural science are relevant to each other, then three epistemological options seem to be available. One may claim (a) that philosophers can decide about the true ontology without any help from scientists, (b) that scientists can make this decision without any help from philosophers, or (c) that some kind of co-operation is required. Arguments concerning these positions will not be dealt with here. Whatever the true context of justification looks like, ontology and natural science will be taken in what follows to be overlapping disciplines.

The meeting-place for ontology and natural science contains three main areas which we shall call

1. The Stuff of Nature,
2. Space and Time,
and
3. The Causal Connection.

The relationships between issues classified separately under the three groups will here be hinted at only.

The Stuff of Nature. The issue as to what the world is ultimately made of may itself be broken down into five subsidiary questions:

1.1 Is there only one stuff of nature?
1.2 Does everything that exists exist actually?
1.3 Is the stuff of nature definite or indefinite?
1.4 Is the stuff a substance or something else?
1.5 In what way can different kinds of stuff be brought together in space?

1.1 Most ontological positions with regard to the question 'What is the stuff of nature?' were delineated already by the pre-Socratics. Thales (*c.* 624–545 BC), in particular, began to ask questions about the world's origin or original principle (ἀρχή) and its nature (φύσις). Thales, Anaximander (*c.* 610–547/6 BC), and Anaximenes (fl. *c.* 546/45 BC) all claimed that there is but one ultimate stuff. Later, Empedocles (*c.* 490–430 BC) argued that there is a plurality of such ultimate stuffs, and Anaxagoras (*c.* 500–428/7 BC) held that there are infinitely many. This dispute, *the problem of one and many*, has been casting its shadow over natural science ever since. The corpuscularism of Newtonian mechanics tended originally towards the view that there is one kind of atom only; the chemical atomism of John Dalton (1766–1844), however, led 19th-century atomists to adopt a belief in many substances, though never in infinitely many. In modern physics, the theory of general relativity has given new impetus to the belief that there is only one ultimate stuff, an energy field. But the theory itself is only about gravitational interaction. It takes into account neither electromagnetic interaction nor weak and strong interactions, though there have been several attempts to create an all-embracing one-stuff theory (the latest being the theory of superstrings).

1.2 Is everything that exists actual, or does existence have two modalities: actuality and potentiality? Aristotle's ontology recognizes two kinds of ultimate stuff: first, an undifferentiated prime matter which exists only potentially; second, the four fundamental stuffs of the world: earth, water, air, and fire, which exist in actuality. Post-medieval physics has mainly worked only with actual entities, but there are two notable exceptions, one within general relativity and one within quantum mechanics (QM).

The famous equivalence formula ($E=mc^2$) of relativity theory has made it possible to regard mass (formerly a property of particles) as a kind or *form of energy* beside the other forms (kinetic, electromagnetic, etc.). Even particles in themselves may thereby be regarded as merely forms of energy. Everything becomes energy, but there is never any energy without a specific form. Energy in itself has therefore only potential existence. In QM it has been proposed (even by Werner Heisenberg) that some states of affairs, e.g. the orbit of an electron, should be regarded not as actualities but as potentialities.

1.3 The actuality-potentiality problem should not be confused with the definite-indefinite problem. Mostly, it is taken for granted that what (actually) exists has to be of a definite kind and has to have definite properties. Anaximander's *apeiron*, however, may be interpreted as a fundamental stuff which does not have any definite properties. '*Apeiron*' can mean both infinite and indefinite.

Anaximander's idea has made an unexpected return in the discussions about the interpretation of QM. The dominant interpretation is the so-called Copenhagen interpretation of Niels Bohr (1885–1962) and Heisenberg. Today, however, we must distinguish two interpretations of this interpretation: the epistemological and the ontological one. Heisenberg's uncertainty principle implies that it is impossible simultaneously to measure both position and momentum exactly. According to the epistemological interpretation, Bohr and Heisenberg merely made the positivist point that it is meaningless to speak about what one cannot measure, and so that it is meaningless to ask for the position of an entity when its momentum is being measured and vice versa. According to the ontological interpretation, they claimed that the sub-atomic world *is* such that its entities have neither a definite momentum nor a definite position when no measurements are being made. Before measurements there are neither waves nor particles, there is only something 'indefinite'.

1.4. A fourth ontological discussion concerns the problem of whether the ultimate stuff is substance(s) or process(es) or something else. Most pre-Socratic philosophers – their differences notwithstanding – shared the view that the world ultimately consists of some kind(s) of substance(s). Their chief opponent was Heraclitus (*c*. 540–*c*. 480 BC). According to his view the ultimate stuff is fire, i.e. a ceaseless flux, not a substance retaining its identity through time.

Natural science has mostly been dominated by the view that the ultimate stuff of reality is substantial. Ontologically, both particles and classical (Maxwellian) fields have to be regarded as substances. (Even though a classical field may have to originate from a source particle, it can later on exist in and of itself, retain its identity through time, and be a bearer of properties.) The view that the world is ultimately a process has mostly been defended by philosophers (such as Hegel and A. N. Whitehead), not by physicists. However, parts of modern physics, in particular special relativity, have fostered a third view, a view of a kind which was unknown among philosophers up until David Hume. The world, it is argued (e.g. by Bertrand Russell), is a four-dimensional manifold of *events*. 'Event' should here be taken as a fundamental category not reducible to a change in or state of any substance. There are three main positions with regard to the fourth problem now presented. It might therefore be called the *Substance-Process-Event problem*.

1.5 Still another 'stuff problem' concerns the question how different kinds of substances can be brought together in space. This is often, especially in relation to Aristotle and the Stoics, called the *problem of mixture*. In corpuscular ontologies atoms cannot penetrate each other. In such ontologies, therefore, a mixture of different kinds of substances is necessarily a spatial mosaic – a blend or a juxtaposition – of substances. If, however, we regard fields, e.g. the classical Maxwellian electromagnetic waves, as substances, then we find substances which can mutually penetrate. Two such fields which meet do not collide; they just exist in one and the same place. In the space they jointly occupy, their field strengths are superposed. The fields make up a true mixture, a state of affairs which is regarded by corpuscularism as impossible.

Superposition of fields exemplifies a specific kind of true mixture. Another kind is found in pre-Daltonian chemistry, which assumed the existence of true mixtures in which the substances mixed not merely interpenetrated but were in fact also synthesized into a new kind of substance. In the field case we have quantitative superposition of a property which inheres in all the mixed substances. In the kind of chemistry referred to, we have either emergent properties (i.e. the coming into being of new properties which do not inhere in the unmixed substances) or cases where a property of one of the substances involved dominates the properties of the others (as when, phenomenologically, sugar in a liquid makes the whole liquid sweet).

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A very special ontology of substances and mixtures was put forward by Anaxagoras. According to him, every bit of the world is a true mixture of all the different kinds of substances there are in the world. Today, parts of QM and features of the holograph have been used in attempts (D. Bohm, G. F. Chew) to look at the world along Anaxagorian lines. Electromagnetic interference patterns out of which holographs can be made have such a structure that the *whole* holograph can be created out of any *part* of the wave pattern. In a sense, here, every part can be said to contain the whole.

Space and Time. 2.1 With the advent of classical physics in the 16th and 17th century, especially in Newtonian mechanics, there became predominant a *container conception of space*. Space came to be regarded as an empty receptacle containing substances within it. Of course, space cannot be any ordinary container, in that it cannot be limited by anything outside itself, but the containment relation is none the less preserved. Such a space is not an aggregate of smaller spaces; rather, sub-volumes of space exist only as parts of space.

The container conception of space was from the start under attack from two opposing flanks. One was René Descartes's identification of spatial extension and matter, which implies that space and material substance are one and the same. This is an example of a *prime stuff conception of space*. Space itself may be regarded as the fundamental stuff of the world. On the other flank, Leibniz proposed a *relational conception of space*, according to which space is merely a system of relations between fundamental particulars of some kind. Different philosophers have proposed different kinds of fundamental particulars, material as well as spiritual, as a substratum for relational space.

All the three conceptions of space here mentioned have both forerunners in ancient philosophy and are live alternatives within physics today. It should be said, however, that they were not worked out very well before modern times. For instance, it is unclear whether the famous 'void' of Democritus (*c.* 460–*c.* 370 BC) is to be regarded as a substance or as a container space. Titus Lucretius Carus (*c.* 99–55 BC), though, put forward a container conception of space, and Theophrastus (*c.* 372–*c.* 287 BC, Aristotle's successor) a relational conception. To most ancients and medievals, space and time were rather unimportant problems because spatial and temporal relations were regarded as accidental, not essential, characteristics of substances.

In modern times, it has been quite the other way round. Space and time have been deemed important ever since, in the Renaissance, the idea of space as an infinite container began to stir the minds. Today, due to general relativity, there has even been a revival of the prime stuff conception of space. The space-time of this theory has been interpreted (for example by J. A. Wheeler) not as a container whose structure is affected by the masses and fields contained in it; but on the contrary: masses and fields have been regarded as fashioned out of curved empty space.

The last remark shows that the prime stuff conception is sometimes regarded as compatible with the idea of a (structured) void, although in many varieties (e.g. Descartes's ontology) the stuff assumed necessarily excludes a void. The container conception, of course, allows empty space, but it does not entail it. Space may be filled as a contingent fact. According to the aether hypothesis – propounded from Christiaan Huygens (1629–95) to James Clerk Maxwell (1831–79) – container space is filled with an aetherial substance.

In the ontology of time, too, there is an analogue to the controversy between relational and container conceptions of space. Time is in one camp regarded as a system of relations between changes, and in another as something which contains and makes changes possible. According to the latter view, there can be a flow of time even in an otherwise absolutely static world, something which is impossible according to the relational conception. After general relativity there is even a prime stuff conception of (space-) time. Thus there is a three-cornered opposition between a container conception, a relational conception, and a prime stuff conception, with regard to time as well as to space.

2.2 For many materialist philosophers, e.g. the Epicureans, Pierre Gassendi, and John Locke, space is *independent* in the sense that there may be space without things or any other kinds of entities, but there cannot be things if there is no space. Things, or matter generally, are dependent for their existence on space, but space is not dependent for its existence on anything else. In relational conceptions, space is by definition dependent, but in prime stuff conceptions space is almost by definition independent. As was just said, many of those who have a container conception are materialists and claim that space is independent. Two proponents of dependence, however, are Sir Isaac Newton and Kant. Space was Newton's bridge between science and theology. He argued that space is dependent on God, that space is "God's sensorium". According to Kant, on the other hand, space and time are dependent on a "transcendental ego".

2.3 *The singularity problem*. Most natural scientists and philosophers have merely taken it for granted that there is precisely one space and one time. Kant tried to prove that this is necessarily the case. Today, quantum mechanics has given rise to speculations about many spaces. According to the 'many worlds interpretation' (Everett-Wheeler-Graham), the wave function of QM should not be seen as describing different possibilities, but as describing different actual worlds, and so as referring to many different space-times.

2.4 The *container-relationality-prime stuff problem*, the *independence-dependence problem*, as well as the *singularity problem*, are all conceptually distinct from the problem whether space and time are *absolute or relative*. The last issue is as much about motion as about space. To claim, as Newton did, that space is absolute is to claim that space is such that things in it can move not only in relation to each other but also in relation to space itself. To claim, as Ernst Mach (1838–1916) did, that space is relative, is to claim that all motion is necessarily motion between kinds of things. This claim, it is worth noting, is not identical with Leibniz's that space is relational, nor does it in itself imply that space has a relativistic metric. Albert Einstein's (1879–1955) theories are not entailed by Mach's position.

2.5 Two developments in mathematics have deeply affected the old questions as to the *shape, structure*, and *extension* of space and time: the discovery of the non-Euclidean geometries and the development of topology. Questions not dreamt of before have arisen and old ones have taken on a new character. For instance, in some non-Euclidean (spherical) geometries every straight line will, if extended far enough, come back to itself. The question whether space is finite or infinite here loses its meaning. Such a space is closed but unlimited. Also, quite new properties – like intrinsic shape and intrinsic curvature – have entered the discussion.

2.6 Whether Newtonian space and time are independent or not has been a matter of some controversy, but it is quite clear that this space is a container which is singular, absolute, infinite, and Euclidean. Indeed it has still more characteristics: it is *non-causal, homogeneous, isotropic*, and *continuous*.

It seemed more or less self-evident that an empty container space can have no causal efficacy, which means that Newtonian space is non-causal. In general relativity, matters are not that simple. Of course, when the latter theory is interpreted so that space becomes the prime stuff, space can have causal efficacy. But it has been argued that even when a container conception is retained, the non-Euclidean geometry of general relativity makes space into a causal agent which affects the things contained.

When space is regarded as *causal* it easily becomes regarded as *anisotropic*, too; i.e. the causal efficacy is different in different directions. This is the case in general relativity. If we bring in the prime stuff view, the space-time of general relativity is not even homogeneous. Different parts are substantially different; some are space-as-matter, some are space-as-gravitational field. Space becomes *heterogeneous*. In relation to some problems within QM, proposals have even been made to regard space (and time) as *discontinuous*.

2.7 Newtonian time has all the characteristics of Newtonian space described above, except, perhaps, one. It may be open to

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Formerly, it was taken for granted that if time has a directedness this is a direction toward the future. Today, in modern quantum field theory, there are interpretations which entertain the idea that the so-called anti-particles are particles that move backwards in time. What kind of conception of time such processes imply is not easy to say.

In Newtonian mechanics space as well as time is homogeneous, but they were regarded as *heterogeneous with respect to each other*. And they were so regarded quite independently of the problem of whether space is isotropic and time anisotropic. Before special relativity this heterogeneity was only challenged by ontologies holding that space and time are similar in so far as both are mere appearances (often illusory) of an underlying reality. Now, however, it is a physically significant problem to what extent space and time are homogeneous or heterogeneous.

The Causal Connection. 3.1 Since Hume, the outstanding ontological problem with regard to causality has been *the problem whether causality contains necessity or is mere ordered contingency* (correlation). Before modern times this was no problem at all. It was taken for granted that most natural processes are causal and that the cause in some sense necessarily produces an effect. With Galileo, Newton, and the rise of classical physics, mathematics irreversibly entered natural science, a change which had repercussions also for the understanding of causality.

Some familiar mathematically expressed regularities, like Galileo's law of falling bodies, are such that it is hard to give them a causal interpretation; the time of fall does not cause the distance fallen with which it is functionally related. The mathematical relationship represents a *non-causal law*. Mathematics made it possible to do important physics without necessarily being concerned with causes, though, as a matter of fact, all the main figures of classical physics were preoccupied with both causal and non-causal laws.

The split between causal and non-causal laws, however, seems to have had long-term effects. The more physics became mathematically clothed, the less important the concept of causality seemed. Since causality and necessity were thought to be intertwined, it also meant that the question of necessity *in re* was lost from sight. In this way it became rather easy for physicists to subscribe to the positivist idea that all real necessities are *de dicto*, i.e. are effects of language. For natural science, this thesis entails that causality leaves the stage and only correlation remains.

3.2 For a very long time there were two main opposing concepts with which the concept of causality was contrasted: *contingency* and *spontaneity*. Newtonian mechanics came mostly to be interpreted as being inconsistent with both the latter concepts. The world began to look deterministic. In the 19th century, however, a new and third opposing concept appeared, that of *statistical laws*. The second law of thermodynamics was reinterpreted (by Ludwig Boltzmann, 1844–1906) as probabilistic in character; the tendency for entropy to increase was regarded as a greater probability of disorder. Deterministic causation was rivalled by indeterministic causation, and there arose the *problem of determinism and indeterminism*.

With quantum mechanics indeterminism

becomes a major topic for discussion. True, the fundamental laws (the equations describing the temporal development of the state functions) are deterministic in the old-fashioned sense, but these equations do not describe any ordinary measurable quantities. QM is mostly interpreted as merely specifying *probable* values of the measurable magnitudes, and so as being indeterministic.

3.3 In the shift from scholasticism and Aristotelian physics to classical physics, final causation (teleology) was gradually banished from natural science. Causality was reduced to efficient or external causality. Carriers of internal causality or *causa sui*, were no longer regarded as having explanatory force. However, the question remains as to whether all kinds of *causa sui* have to imply final causation. It has, for example, been argued that the Newtonian concept of inertia implicitly presupposes an Aristotelian concept of self-change. According to the first Newtonian law of motion, a body not affected by forces continues *of itself* to move – to change its place – in a straight line with constant velocity. The common interpretation has been to regard uniform motion not as a change but as a *state*. Acceleration, on the other hand, has been regarded as a change, a change explained by external forces. In this way, no place was left for self-change in Newtonian mechanics.

Internal causality has, however, staged a minor come-back. According to the so-called propensity interpretation of quantum mechanics, some sub-atomic arrangements have – in and of themselves – propensities or tendencies to develop in a certain way. Such tendencies are in one sense Aristotelian, but in another not. We have here *probabilistic potency*, an idea quite foreign to both the ancients and the medievals.

3.4 Leaving contingency, indeterministic causation, and internal causation aside, there remains a major problem with efficient causality: *the problem of contiguity*. It is a problem with regard to both space and time. Are cause and effect necessarily spatially contiguous? And are they necessarily temporally contiguous? In both cases two sorts of negative answer are possible. One can oppose contiguity by claiming either that cause and effect can be spatially overlapping or that there is action at a spatial distance. And one may claim either that cause and effect can be simultaneous or that there is action at a temporal distance.

Of these options, only the opposition between action by contact and action at a distance have received any considerable attention within the natural sciences. Newton's law of gravitation, taken at face value, refers to gravitational forces which momentarily connect bodies as far apart as the Earth and the Sun. This law seems to presuppose action at a distance. Newton himself thought a lot about possible causes of the gravitational force. Dissatisfied with the Cartesian idea of push-mechanisms, he looked in other directions, but he found no observable evidence for any specific hypothesis. This is the background for his remark, "I feign no hypotheses".

Like gravitation, magnetic and electrostatic phenomena seemed on the surface to involve action at a distance. But even here the founding fathers (e.g. William Gilbert, 1540–1603, and Charles Augustin de Coulomb, 1736–1806) disliked 'occult qualities'. They speculated or they remained agnostic about the 'true causes' of the phenomena dealt with. The development of the electromagnetic field theories in the 19th century strengthened disbelief in the idea of action at a distance, and it was seemingly given a death-blow by the theories of relativity.

According to the theories of relativity, it is impossible to transport energy faster than light. And, since it is normally assumed that a cause needs energy in order to bring forth its effect, momentary action at a distance becomes an impossibility. Relativity theory is inconsistent with Newtonian mechanics. That fact, however, was only a problem in the period between special relativity and the appearance of general relativity. The latter theory is a gravitational theory without any action at a distance. Problems arose when slowly it was recognized that even quantum mechanics presupposes a kind of action at a distance and is, therefore, in a sense inconsistent with relativity theory.

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contact versus action at a distance is framed in terms of *locality* and *non-locality*. A local property is a property of a thing which cannot change due to any kind of action at a distance. In relativity theory all properties are local. A non-local property is a property which can change at a specific instant due to something happening at that very instant at another place. It has been proved (J. S. Bell) that if QM is about determinate properties which, of course, may be affected by measurements, but which none the less can exist independently of measurements, then these properties have to be non-local. If we want to retain locality within QM we have to say that the world is indeterminate (cf. the determinate-indeterminate problem above). It should be stressed, though, that the non-local properties of QM are non-measurable ('hidden') properties. Therefore, the non-locality of QM does not imply that it is possible to transport 'ordinary' energy faster than light.

Problems of the stuff of nature and of the causal connection are here, as in many other cases, closely connected.

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Nature, Ontology of

Nature-ontology centres upon the issue of what *basic existential* elements make up nature or the natural world, their types and character. Beginning with the Ionion cosmologists, the question 'What is nature?' itself has characteristically been converted into the ontologically oriented question 'What are things actually made of?', or even 'What is the original unchanging substance which underlines all the changes of the natural world?' That set the main historical agenda for answering the key questions concerning what kinds of natural items there are. For in this regard it is often claimed that there are two main traditions in Western philosophy: a dominant *substance* tradition, established by Aristotle, and perhaps obtaining its acme in the varying substance philosophies of the rationalists, René Descartes, Leibniz, and Spinoza, before it was overtaken by further developments in science; and a highly recessive *process* or relational tradition, which has become more conspicuous in recent times, through the work of Henri Bergson and A. N. Whitehead, and through new turns in science.

One important cross-classification of substance philosophies concerns the issue of basic elements: whether these are wholes of some sort, perhaps immaterial wholes as under German idealism, or smallest parts, typically material, as under atomisms (thus too various intermediate and compromise positions between extreme holism and extreme partism). Another major cross-classification of both traditions concerns the extent of the intensionality of components discerned: whether they are purely extensional, like inert particulate matter, or whether some or all exhibit life, sentience, mind, spirit, or other intensional features in an irreducible way (e.g. whether, as on ancient natural science, nature is saturated with or permeated by mind, or not). There is no longer any pressing need to try to answer these and connected questions, for instance as to the intensional hierarchy of substance (now largely an interesting historical exercise). For the idea of substance has largely dropped out of contemporary philosophy (in