Why determinism in physics has no implications for free will

Michael Esfeld
University of Lausanne, Department of Philosophy
Michael-Andreas.Esfeld@unil.ch

(draft 8 October 2017)
(paper for the conference "Causality, free will, divine action", Vienna, 12 to 15 Sept. 2017)

Abstract

This paper argues for the following three theses: (1) There is a clear reason to prefer physical theories with deterministic dynamical equations: such theories are both maximally simple and maximally rich in information, since given an initial configuration of matter and the dynamical equations, the whole (past and future) evolution of the configuration of matter is fixed. (2) There is a clear way how to introduce probabilities in a deterministic physical theory, namely as answer to the question of what evolution of a specific system we can reasonably expect under ignorance of its exact initial conditions. This procedure works in the same manner for both classical and quantum physics. (3) There is no cogent reason to subscribe to an ontological commitment to the parameters that enter the (deterministic) dynamical equations of physics. These parameters are defined in terms of their function for the evolution of the configuration of matter, which is defined in terms of relative particle positions and their change. Granting an ontological status to them does not lead to a gain in explanation, but only to artificial problems. Against this background, I argue that there is no conflict between determinism in physics and free will (on whatever conception of free will), and, in general, point out the limits of science when it comes to the central metaphysical issues.

Keywords: determinism, free will, physical laws, functional reduction, classical mechanics, quantum mechanics

1. Determinism and probabilities in physics

Atomism is the paradigm that prevails in science. It is the idea that matter is composed of tiny, indivisible particles. In fact, atomism is as old as philosophy, going back to the Presocratics Leucippus and Democritus. The latter is reported as maintaining that

> ... substances infinite in number and indestructible, and moreover without action or affection, travel scattered about in the void. When they encounter each other, collide, or become entangled, collections of them appear as water or fire, plant or man. (fragment Diels-Kranz 68 A57, quoted from Graham 2010, p. 537).

In a similar vein, Newton writes at the end of the *Opticks*:

> ... it seems probable to me, that God in the Beginning form'd Matter in solid, massy, hard, impenetrable, moveable Particles ... the Changes of corporeal Things are to be placed only in the various Separations and new Associations and motions of these permanent Particles. (quoted from Newton 1952, question 31, p. 400)

To turn to contemporary physics, Feynman says at the beginning of the famous *Feynman lectures*:

> If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generations of creatures, what statement would contain the most information in the fewest words? I believe it is the *atomic hypothesis* (or the atomic *fact*, or whatever you wish to call it) that *all things are made of atoms – little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another*. In that one sentence, you will see, there is an enormous amount of information about the world, if just a little imagination and thinking are applied. (Feynman et al. 1963, ch. 1-2)

What makes atomism attractive is evident from these quotations: on the one hand, it is a proposal for a fundamental ontology of nature that is most parsimonious and most general. On the other hand, it offers a clear and simple explanation of the realm of the objects that are accessible to us in perception. Any such object is composed of a finite number of discrete, pointlike particles. All the differences between these objects – at a time as well as in time – are accounted for in terms of the spatial configuration of these particles and its change. This view is implemented in classical mechanics. It conquered the whole of physics via classical statistical mechanics (e.g. heat as molecular motion), chemistry via the periodic table of elements, biology via molecular biology (e.g. molecular composition of the DNA), and finally neuroscience – neurons are composed of atoms, and neuroscience is applied physics (applied classical mechanics and electrodynamics, or, maybe, quantum mechanics in case quantum effects are proven to be operational in the brain).

What is relevant for the account of the perceptible macroscopic objects are only the relative positions of the point particles – that is to say, how far apart they are from each other, i.e. their distances – and the change of these distances. Let's call the particles matter points. They can be considered as substances because they persist. However, they are not substances in the Aristotelian sense of objects that have an inner form (eidos) – in other words, that are characterized by some intrinsic properties. There is nothing more to the matter points than the way in which they are spatially arranged and the change in their arrangement. But that (in contrast to supposed intrinsic properties) is sufficient for their individuation: each matter point can be distinguished by – and hence individuated by – the distances it bears to the other matter points in a given configuration. Employing the distance relation to individuate the matter points and admitting only distances among the matter points in contrast to an absolute space in the ontology has the great advantage of not being committed to a bare substratum view of matter. Matter, consisting in matter points, is what is individuated by its standing in distance relations to each other (by contrast to minds, angles, or abstract objects, which, if they exist, do not stand in spatial relations).

We can thus sum up the gist of atomism in these two axioms (for a detailed argument, see Esfeld and Deckert 2017, ch. 2.1, as well as Esfeld 2017 for a concise metaphysical argument):

(1) *There are distance relations that individuate simple objects, namely matter points*.
(2) *The matter points are permanent, with the distances between them changing*.

Let's call the ontology of nature defined by these two axioms the *primitive ontology*: matter points individuated by distances and their change are the ultimate referent of our physical theories, the bedrock of nature according to science so to speak.

However, the idea of matter being constituted by atoms in the sense of matter points is not sufficient to fulfill the promise of atomism, namely to explain everything in nature on the basis of the atomic hypothesis. That explanation is not carried out by the hypothesis of the atomic constitution of matter as such, but by showing how the change in the atomic composition of objects accounts for their perceptible change. In other words, the burden for fulfilling the promise of atomism is on laws of motion for the matter points. But the conceptual means provided by the primitive ontology – i.e. the concepts of matter points, distances and their change admitted as primitive – are not sufficient to formulate a law of motion. Using only these conceptual means, one could not do much better than just listing the change that actually occurs, but not formulate a simple law that captures that change. The reason is that there is nothing about the distance relations in any given configuration of matter that provides information about the evolution of these relations.

To extract such information from the configuration of matter, we have to embed that configuration in a geometry and a dynamics: we have to conceive the configuration of matter as embedded in a space with a metric (such as three-dimensional Euclidean space) and we have to attribute parameters to the configuration of matter that are introduced in terms of their functional role for the change in the distance relations among the matter points. These can be parameters that are attributed to the matter points individually (such as mass, momentum, charge), to their configuration (such as total energy, or an entangled wave function), or constants of nature (such as the gravitational constant). They can always remain the same (such as mass and charge) or vary as the distance relations among the matter points change (such as momentum, fields, a wave function). In any case, conceiving the configuration of matter as being embedded in a geometrical space and as being endowed with parameters that are set up in terms of their function for the change in the distance relations defining that configuration then enables the formulation of a physical law. The law is such that by means of specifying an (initial) value of these parameters as input, it yields the evolution of the configuration of matter as output. Let us call these parameters and the geometry the *dynamical structure* of a physical theory.

The claim then is that the primitive ontology remains constant – from Democritos to today's physics –, whereas the dynamical structure changes as we make more progress in formulating a theory that describes the evolution of the configuration of matter in a way that is ever more informative, while remaining as simple and as general as possible (for details, see Esfeld and Deckert 2017, ch. 2.2). In other words, there is something in a physical theory that serves as the – ultimate – referent of the theory, what there simply is in nature according to the theory. That something can be specified independently of the theory change in the history of science, atoms in the guise of matter points characterized by their relative positions and the change of these positions being that something. Furthermore, there is something in a physical theory that is introduced in terms of the role that it plays (i.e. its function) for the evolution of what there simply is according to the theory. Thus, in classical mechanics, point particles characterized by their relative positions are what there simply is according to the theory – they have no further function in the theory apart from filling the place of the candidate for what simply exists in nature –, whereas the parameter of mass, for instance, is introduced in terms of what it does for the motion of the particles.

It would therefore be a misconception to think of the parameters that enter into the dynamical structure of a physical theory as providing for an intrinsic essence of the matter points. As, for instance, Mach (1919, p. 241) points out when commenting on Newton's *Principia*, "The true definition of mass can be deduced only from the dynamical relations of bodies”. That is to say, both inertial and gravitational mass are introduced through their dynamical role, namely as dynamical parameters that couple the motions of the particles to one another. In general, even if attributed to the particles taken individually, mass, charge, etc. express a dynamical relation between the particles instead of indicating an intrinsic essence of the basic objects. As Hall (2009, § 5.2) puts it,

> the primary aim of physics – its first order business, as it were – is to account for *motions*, or more generally for change of spatial configurations of things over time. Put another way, there is one Fundamental Why-Question for physics: Why are things located where they are, when they are? In trying to answer this question, physics can of course introduce *new* physical magnitudes – and when it does, new why-questions will come with them.

This, again, alludes to the crucial distinction between primitive ontology and dynamical structure: the fundamental issue is the location of things and its change, and the account of this fundamental issue requires the introduction of further parameters that allow us to formulate laws about how the change of location of things occurs.

The benchmark for these laws is to simplify the representation of the change that takes place in the configuration of matter – by contrast to merely dressing a list of that change – without losing the information about the change that actually occurs. The task hence is to specify a dynamical structure such that, for any configuration of matter given as initial condition, the law fixes how the universe would evolve if that configuration were the actual one. The dynamical structure thus goes beyond the actual configuration of matter: it fixes for any possible configuration of matter what the evolution of the universe would be like if that configuration were actual. It thereby supports counterfactual propositions.

Against this background, it is evident why there is a commitment to determinism built into the dynamical structure of a successful physical theory: dynamical parameters figuring in laws that fix all the change, given an initial configuration of matter, are the simplest and most informative way to capture change. In other words, in the ideal case, the law is such that given an initial configuration of matter as input, the law yields a description of all the – past and future – change of the configuration as output. It may turn out that, as a matter of fact, such a law cannot be achieved. But if there are dynamical parameters that designate only possibilities for how the configuration of matter may evolve, given an initial configuration, there always remains the question open whether one can do better, that is, find dynamical parameters that fix that change. To put it differently, once one has obtained such parameters, one knows that the work of building a physical theory is done: one has achieved a description of the change that is both simple and maximally informative in requiring only one configuration of matter points as input in order to yield the whole past and future change as output. The question that remains then only is whether that description is empirically correct and whether it can be further simplified without losing informational content. By way of consequence, as far as ontology is concerned, there is no reason to bring in probabilities.

In any case, a fundamental physical theory is such that it defines a dynamical structure for the configuration of matter of the whole universe. That is to say, a primitive ontology of atomism goes in any case together with a dynamical structure of holism. It is therefore a sign of confusion to oppose atomism to holism without further specification (and if the matter points are individuated by the distance relations among them, they are structurally – and hence holistically – individuated). For example, in Newtonian gravitation, the acceleration of any matter point at any time depends, strictly speaking, on the positions and masses of *all* the other matter points in the universe at that time. Even if action at a distance in Newtonian gravitation is replaced with local action in classical field theories, as soon as there are globally conserved quantities (such as total energy), dynamical holism obtains, since the motion of any one object in the universe then is represented as being correlated with, to be precise, the motion of any other object in the universe such that the quantity in question is globally conserved. In quantum physics, again, strictly speaking, due to entanglement, there is only one wave function for the configuration of matter as a whole (i.e. the universal wave function), and a point in the configuration space on which that wave function is defined represents a possible configuration of the matter in the universe as a whole.

On the one hand, the dynamical structure of a fundamental physical theory is defined for the universe as a whole. On the other hand, any such dynamical structure is *per se* useless for calculations. We cannot know initial conditions for the configuration of matter as a whole. Furthermore, the evolution of a given configuration of matter points that we can manipulate may be extremely sensitive to perturbations on its initial conditions. Hence, a slight error about the initial conditions may lead to a great error in predicting the evolution of the system. Already this fact makes clear that there is no conceptual link between deterministic laws and our ability to predict with certainty the evolution of a given system. Everything depends on the extent to which we can specify the initial conditions of a system and on how sensitive the evolution of the system is to slight variations of its initial conditions.

By way of consequence, setting out a primitive ontology and a dynamical structure is not sufficient to build up a physical theory. The dynamical structure has to be construed in such a way that it allows us to answer the following question: What evolution of a given system can we typically expect – that is, in the vast majority of situations – under ignorance of its exact initial conditions? For instance, when flipping a coin, it is impossible to predict the individual outcomes and thus to predict the exact sequence of heads and tails, although this sequence is completely determined by the laws of classical mechanics and the initial conditions. Nevertheless, it is possible to derive the proposition that in by far the most cases, the number of heads will be almost equal to the number of tails provided that the number of coin flips is large enough. There are situations in which we can predict individual outcomes, such as when throwing a stone on Earth, but these are the exception rather than the rule. The dynamical structure of a physical theory therefore has to be linked with a probability measure by means of which we can derive propositions about which evolution of particular systems we can expect to obtain in most cases under ignorance of the exact initial conditions. There hence is a clear reason why even a deterministic physical theory requires probabilities and a detailed procedure how to introduce them on the basis of – fundamental and universal – laws (for details, see Esfeld and Deckert, ch. 3.4).

As regards classical mechanics, notably Boltzmann has established how to derive such probabilistic statements from the deterministic laws (see e.g. Lazarovici and Reichert 2015), and classical statistical mechanics then paved the way for developing atomism into precise scientific theories also in chemistry, biology and beyond. As regards quantum mechanics, it is by no means evident that the situation with respect to probabilities is different from the one in classical physics. What is a fact is that situations like the classical coin toss are generic in quantum mechanics, that is, situations that are highly sensitive to slight variations of the initial conditions, and we cannot know these initial conditions with arbitrary precision. That fact is brought out by Heisenberg's uncertainty relations. Consequently, we can only make predictions about the statistical distributions of measurement outcomes by using Born’s rule, but in general not predictions about individual measurement outcomes.

However, this fact does not imply that probabilities have another status in quantum mechanics than in classical mechanics. The question is what the law of motion for the evolution of the individual quantum systems is that underlies Born’s rule for the calculation of measurement outcome statistics. Only if one includes what is introduced in the textbook presentations of quantum mechanics as the postulate of the collapse of the wave function upon measurement into the law does one obtain an indeterministic law in quantum mechanics. Doing so requires amending the Schrödinger equation with parameters that include the collapse of the wave function under certain circumstances. As things stand, these parameters have to be introduced by hand (see Ghirardi, Rimini and Weber 1986), and they lead to predictions that deviate from the textbook predictions in certain specific situations. In any case, it is an open issue whether such an indeterministic law is a fundamental or rather a phenomenological one – taking gravitation into account, for example, may turn this law into a deterministic one (see Penrose 2004, ch. 30). The only example of a candidate for an indeterministic law in a fundamental physical theory hence confirms the general statement made above, namely that in the case of an indeterministic law, it always remains an open issue whether that law can be turned into a deterministic one by including further parameters that restrict the many possible evolutions of a given system that the probabilistic law allows to one evolution, thus both simplifying the law and increasing its informational content.

Apart from the version of quantum mechanics that includes the postulate of the collapse of the wave function in the physical law, there are two other versions that both are deterministic. In brief, the version going back to Everett (1957) admits only the Schrödinger equation and, in consequence, no unique measurement outcomes. It is therefore known as many worlds quantum mechanics, because, in brief, every possible outcome of a measurement becomes real in a branch of the universe (see Wallace 2012 for details). The version going back to Bohm (1952) adds to the (deterministic) Schrödinger equation a further (deterministic) law, known as the guiding equation, that describes, in brief, how the particles move in physical space as guided by the wave function. In the elaboration of this theory known as Bohmian mechanics, it is shown how Born’s rule can be deduced from these laws by means of a probability measure that is linked with these laws in a way that matches the way in which the probability calculus of classical statistical mechanics is deduced from the deterministic laws of classical mechanics (see Dürr et al. 2013, ch. 2). The existence of Bohmian mechanics hence refutes any attempt to infer from Born’s rule – or the Heisenberg uncertainty relations, or the randomness of individual measurement outcomes – the conclusion that probabilities have a more fundamental status in quantum mechanics than in classical mechanics. The question is what the law is that underlies Born’s rule. The standard for assessing the proposals for that law is independent of the issue of determinism vs. indeterminism. The standard is what is the best solution to the quantum measurement problem (as illustrated, for instance, in Schrödinger’s cat paradox). There are cogent arguments in favour of the Bohmian solution to this problem (see e.g. Esfeld 2014). The consequence then is that probabilities in quantum physics have the same status as probabilities in classical physics.

To sum this section up:

(1) There is a clear reason to seek for deterministic laws in the formulation of a physical theory, since these maximize both simplicity and informational content.

(2) There is a clear procedure available how to get from fundamental deterministic laws to predictions about statistical distributions of measurement outcomes both in classical and in quantum physics.

(3) Apparently random behaviour of investigated systems (including rules stating that randomness, such as the Heisenberg uncertainty relations) never justifies the conclusion to indeterminism. The issue is what the laws underlying this behaviour are. It is true that the determinism in classical mechanics would lose persuasiveness if there were not the clear cut paradigm examples of deterministic predictions in classical gravity (such as throwing a stone on Earth), and it is a fact that there are no such clear cut cases in quantum mechanics. But this is merely a heuristic matter. There is no conceptual link from deterministic laws to deterministic predictions, and, hence, no link from probabilistic predictions to probabilistic laws either.

2. *Explanations in physics*

The *raison d'être* for laws in physics is that they explain the observed phenomena by subsuming them under a law – in whatever way one then spells out in philosophy of science how bringing phenomena under a law explains them (covering law, causal explanation, unification, just to name the most prominent accounts). This role of the laws raises the issue of their ontological status. In any case, as regards our knowledge, we cannot but make conjectures about what the laws are based on the data that become available to us. The standard for these conjectures is the extent to which they optimize both simplicity and informational content in accounting for the data. According to the stance known as Humeanism in today's metaphysics, this is all there is to the laws: they are nothing more than means of representation that seek to optimize simplicity and informational content. Super-Humeanism goes beyond standard Humeanism (see e.g. Lewis 1986, introduction) by putting the geometry and the dynamical parameters – that is, the dynamical structure – also on the side of the laws: the ontology is only the primitive ontology, such as matter points individuated by distance relations and the change in these relations. That change manifests certain patterns. Geometry, dynamical parameters and the laws linked with a probability measure are the package that enables us to achieve a representation of these patterns that is both as simple about the patterns and as informative about the change as possible (see Esfeld and Deckert 2017, ch. 2.3, for details).

(Super-)Humeanism is distinct from instrumentalism. It is a scientific realism: the claim is that what there is as far as the ontology of the natural world is concerned is exhausted by the primitive ontology. Dynamical parameters have a nomological role by figuring in the laws of nature. From that nomological role then derives their role in the predictions, as the laws are linked with a procedure to derive probabilities from them as sketched out in the previous section. The claim of Humeanism then is that the laws do not require additional ontological commitments. The claim of Super-Humeanism is that geometry, dynamical parameters and laws form a package that has only a representational purpose and that does hence not call for ontological commitments that reach beyond the primitive ontology. In short, the issue is what the ontology of the natural world is in a scientific realist framework.

Of course, physics explains the motions of bodies by using a geometry and dynamical parameters that figure in laws. However, the argument for an ontological commitment to the geometry and the dynamical parameters cannot simply be that they figure in our best physical theories. Reading the ontology off from the mathematical structure of physical theories would be begging the question of an argument for ontological commitments that go beyond what is minimally sufficient to account for the phenomena in a scientific realist vein, namely the commitment to a primitive ontology as given by the two axioms of distance relations individuating matter points and the change in these relations. In a metaphysics based on science, the argument can only be that by subscribing to ontological commitments that go beyond that minimum, one achieves a gain in explanation.

(Super-)Humeanism can easily account for the scientific practice of explanations and its conceptualisation in terms of covering laws, causation or unification (see e.g. Loewer 2012). The geometry and the dynamical structure of a physical theory can explain the phenomena by bringing out the patterns or regularities in the motion of particles; bringing out these patterns or regularities obviously requires no ontological commitment beyond particles that move. For (Super-)Humeanism, first comes the particle motion, which as a contingent matter of fact exhibits certain patterns or regularities, then come the laws, including the geometry. Hence, the laws, the parameters figuring in them and the geometry are not some sort of an agent that forces the particles to move in a certain way. The laws do not constrain the particle motion. It is the particle motion that fixes the laws. Hence, if one asks why there are the patterns in the particle motion that there are in fact, (Super-)Humeanism cannot answer that question. The claim of (Super-)Humeanism is that there is no scientific answer to that question. Our scientific understanding of the world comes to an end once the salient patterns in the change of the elements of the primitive ontology are reached, such as e.g. attractive particle motion.

The argument for this claim is the one illustrated in Molière's piece *Le malade imaginaire*: one does not explain why people fall asleep after the consumption of opium by subscribing to an ontological commitment to a dormitive virtue of opium, because the dormitive virtue is *defined* in terms of its functional role to make people fall asleep after the consumption of opium. By the same token, one does not obtain a gain in explaining attractive particle motion by subscribing to an ontological commitment to gravitational mass as a property of the particles, because mass is *defined* in terms of its functional role of making objects attract one another as described by the law of gravitation. Of course, mass, charge and the like are fundamental and universal physical parameters, by contrast to the dormitive virtue of opium. But the point is that they are defined in terms of the functional role that they exert for the particle motion. Why do objects move as they do? Because they have properties whose function it is to make them move as they do. An ontological commitment to such properties does not yield a gain in explanation. The same holds for forces, fields, wave functions, an ontic structure of entanglement in quantum physics, laws conceived as primitive, etc. It also applies to geometry: it is no gain in explanation to trace the characteristic features of the distance relation back to the geometry of an absolute space, because that geometry is defined such that it allows for the conception of distances in that space.

It is true that by tracing the distance relations back to an absolute space, or the change in the distance relations back to properties of the particles that are dispositions for that very change, the characteristic features of the distance relations as well as those of the patterns of the change in them come out as necessary instead of contingent. However, shifting the status of something from contingent to necessary does not amount to a gain in explanation. Quite to the contrary, one only faces drawbacks that come with the commitment to a surplus structure in the ontology in the guise of an absolute space, fundamental dispositional properties of the particles, ontic dynamical structures of entanglement, etc.: differences with respect to absolute space that do not make a difference in the configuration of matter, questions such as how an object can influence the motion of other objects across space in virtue of properties that are intrinsic to it, how a wave function defined on configuration space can pilot the motion of matter in physical space, etc. (see Esfeld and Deckert 2017, ch. 2.3).

To sum this section up:

(1) The business of physics is to achieve on the basis of the available evidence a theory that is as simple and as informative as possible in accounting for that evidence and in predicting new evidence, with such a theory being characterized by the three features outlined in the previous section.

(2) Given the primitive ontology in terms of the notions of distances individuating matter points and the change of these distances, one can then define any further notion that one needs in one's theory of the natural world in terms of its functional role in the represenation of that change, without thereby subscribing to an additional ontological commitment. One thereby remains a scientific realist and is fully entitled to the use of these further notions in the scientific explanations that one's theory yields.

(3) Subscribing to an ontological commitment that goes beyond what is minimally sufficient to account for the evidence (i.e. the primitive ontology) is not implied by the physics: one cannot read off the ontology from the mathematical structure of a physical theory. The issue can only be whether granting that structure an ontological status over and above the primitive ontology yields an explanatory gain. However, far from doing so, this leads only to drawbacks stemming from a commitment to surplus structure.

3. *The limits of physics*

Minimizing the ontological commitments of physics as outlined in the two preceding sections, while fully respecting scientific realism, not only prevents artificial problems from arising in the philosophy of nature, but also has repercussions for metaphysics in general. For instance, against the background set out here, it is evident that there is no conflict between physical determinism and free will. As argued in the first section, the most simple and most informative representation of what there is in nature preferably is one in terms of a deterministic law of motion. The predictions derived from such a law can turn out to be correct, thus suggesting that the law has captured a salient pattern in nature. Furthermore, it may even be so that if an intelligence knew the whole particle motion throughout the history of the universe, that intelligence would come up with a deterministic law representing that motion – and yet, there is no clash with free will (in whatever way one may conceive free will). The reason is that the motion comes first, including the motion of our bodies induced by our intentions, then come the laws. Hence, the laws do not predetermine our actions, they only represent what happens in nature (see Beebee and Mele 2002).

Only if one loads the laws of physics with some sort of necessitation – e.g. by conceiving them as modal primitives, tracing them back to fundamental dispositions, powers or modal ontic structures instantiated by the physical objects – can a conflict with free will ensue (at least on an incompatibilist conception of free will); there then is something in the world that is independent of our decisions and that makes our decisions necessary. Obviously, this conclusion is independent of determinism: it also concerns probabilistic laws, insofar as these are conceived as referring to entities in the world that make probabilities for certain of our actions necessary and that are independent of us (cf. Loewer 1996). However, as far as the ontology of physics is concerned, there is no need to subscribe to any such commitment, and doing so leads only to drawbacks, as argued in the previous section.

Hence, this paper is directed against a certain sort of a scientific worldview, namely one that implies a misconception of the enlightenment that comes with science: it is not that science teaches us that if there are deterministic laws in physics – or, for the sake of the argument, deterministic laws in genetics or evolutionary biology –, our decisions are necessitated by factors that are outside of our control. Besides, if that were so, what would follow for the decisions that a person has to take? Obviously nothing, since deducing norms from facts would in any case be a naturalistic fallacy. Of course, also actions are open to scientific explanations; but these are explanations in retrospective, never justifications. For instance, there certainly are explanations of social practices (at the present, or in the past) that violate basic human rights in terms of evolutionary biology; but such explanations can never justify these practices – they remain morally wrong, if violations of basic human rights are morally wrong, scientific explanations notwithstanding. In brief, science cannot take away from us the freedom to make decisions and the responsibility that goes with that freedom.

In general, this paper is about limits of science when it comes to the central metaphysical questions. In contrast to other attempts in that sense that argue for a limitation of the range of physical laws within the physical domain itself (see e.g. von Wachter 2015 according to whom physical laws, even when they are deterministic, indicate only tendencies for what happens in nature), the argument of this paper takes universal physical laws, also when they are deterministic, at face value as encompassing all the motions of bodies in the universe in a simple and general equation (or at least as striving for that ideal, as illustrated in the Newtonian law of gravitation). The argument then is that attributing a modal status to these laws is not justified by the physics, even if scientific realism is taken for granted. From that then follow certain limits of science, in particular that there is no clash between the scientific representation of the motions of bodies in terms of universal and deterministic laws and some such motions being the manifestation of human free will.

Nevertheless, one may wonder why, if there are parameters such as human free will that influence some motions of bodies, these parameters do not appear in the laws of physics. The reason is this one: when it comes to giving concrete explanations, one never explains a human action by invoking only the parameters that figure in physical laws. In general, one does not explain concrete chemical, biological, psychological, sociological phenomena by employing only the parameters that figure in physical theories. One will never do so, and be it only for limited capacities of calculation. When it comes to the principled issues of the fundamental physical laws being universal and deterministic, introducing variables such as fitness, or free will that apply only to some systems in nature would greatly compromise the simplicity of these laws without resulting in a significant gain in information. That is the reason why one would never include such variables in the universal and fundamental laws of physics.

Once one has identified a primitive ontology of the natural world and thus settled for the concepts admitted as primitive that characterize that ontology, one can define every further concept that enters into one's theory of the world in terms of the function for the primitive ontology. This applies not only to the parameters that appear in physical theories, but to any concept, including the ones describing the mind (see e.g. Lewis 1972). It is easy to provide a scheme for the functional definition also of mental concepts in terms of, in the last resort, changes of the physical configuration of the body and its environment. Such functional definitions are undisputed in the natural sciences: it would be odd, for instance, to postulate a heat stuff to account for thermodynamical phenomena, since these can be defined functionally in terms of changes in molecular motion. By the same token, it would be odd to postulate an *élan vital* to account for organisms and their reproduction. Again, since the advent of molecular biology, the evolution of organisms and their reproduction can be accounted for in terms of molecular biology. There is no explanatory gap here.

However, when it comes to consciousness as well as rationality and the normativity and free will that are linked to rationality, one may maintain that there is an explanatory gap in the sense that functional definitions in terms of, in the last resort, changes in the configuration of matter do not capture what is characteristic of mental phenomena (see Levine 1983). Once one has understood the science, it is obvious how a functional definition of, for instance, water in terms of the effects on the interaction of H_2O molecules captures and explains the phenomenal properties of water and how a functional definition of organisms captures and explains their reproduction, including the link from genotypes to phenotypes. However, it is not obvious – at least not obvious in the sense of these paradigmatic examples – what the qualitative character of conscious experience, or the normativity that comes with rationality have to do with molecular motion in the brain.

The argument of this paper implies the following: in case the mental cannot be functionally defined on the basis of a primitive ontology of matter in motion, then an ontological commitment to the mental is called for over and above the ontological commitment to a primitive physical ontology. Moreover, such an ontological commitment then is as fundamental as the commitment to a primitive physical ontology, although the mental may only become manifest in certain systems in the universe and only at a certain period of time in the evolution of the cosmos. In general, whatever does not come in as being entailed by the primitive ontology is itself a further fundamental ingredient of the ontology (cf. e.g. Jackson 1994, or Chalmers 2012, although the argument of this paper is not committed to *a priori* entailment). This makes (again) evident the price that comes with any position whose ontological commitments go beyond a primitive physical ontology.

In the case of the additional parameters figuring in scientific theories, there is no reason to pay that price, as argued in the previous section. But the case of the mental is different, and be it only for the reason that one cannot derive normative statements from statements about physical facts. Irreducible normativity in that sense arguably concerns not only actions and morality, but already semantics and conceptual content (at least in the tradition of Sellars 1956; see e.g. Brandom 1994 and Esfeld 2001, chs. 2-3). Positions that seek to avoid paying that price for instance by putting their stakes on emergence do not cut the ontological ice: if what emerges can be functionally defined on the basis of the ontology that is admitted as primitive, then there is no emergence in the sense of something that calls for new ontological commitments. If what emerges cannot be thus defined, then one is committed to more in the ontology than the ontology originally admitted as primitive. Consequently, there then are further primitives that hence have the same ontological status as the original primitives.

The issue of the mental thereby is linked with the issue of the cosmos as a whole. Solving a differential equation that expresses a physical law requires fixing an initial state of the system under consideration that is inserted as initial condition into the equation in question. When the law is universal, that would have to be an initial state of the configuration of matter of the whole universe. Any state can be chosen as initial state as far as the law is concerned. If the law is deterministic, the law then yields the whole past and future evolution of the system as output. Axiom 2 in section 1 can be read as suggesting that change in the configuration of matter is eternal.

Nevertheless, there may be a distinguished initial state of the universe, namely a state of extremely low entropy, in order to explain the actual evolution of the universe (this is known as the past hypothesis; see Albert 2000, ch. 4). That explanation then accounts for everything in the physical world, given the laws, including the reproduction of certain chains of molecules and the formation of brains that are the physical basis for mental states. If change in the configuration of matter is indeed infinite, then any possible configuration of matter will come up if one waits long enough so to speak, including a configuration of low entropy with the ensuing evolution of the universe that we know. However, the question whether that change is indeed infinite or whether it has an absolute beginning, which admits reflections about a cause beyond the physical that accounts for its (distinguished) initial state, is beyond the scope of science.

This is the core metaphysical debate, about the cosmos and about our place in it. Science can be understood on the basis of a primitive ontology that, even if the dynamics for that primitive ontology is deterministic, has no implications for what is right or wrong about these core metaphysical issues. Elaborating on the primitive ontology of science makes, however, clear the price that one has to pay for any further ontological commitments that then would have to come in as further primitives. The credibility of any such commitments hinges upon working them out into an overall metaphysical position that matches the paradigm of science in its clarity and precision as well as the concrete explanations that it provides.

References

Albert, David (2000): *Time and chance*. Cambridge (Massachusetts): Harvard University Press.

Beebee, Helen and Mele, Al (2002): “Humean compatibilism”. *Mind* 111, pp. 201-223.

Bohm, David (1952): “A suggested interpretation of the quantum theory in terms of ‘hidden’ variables. I and II”. *Physical Review* 85, pp. 166-193.

Brandom, Robert B. (1994): *Making it explicit. Reasoning, representing, and discursive commitment*. Cambridge (Massachusetts): Harvard University Press.

Chalmers, David (2012): *Constructing the world*. Oxford: Oxford University Press.

Dürr, Detlef, Goldstein, Sheldon and Zanghì, Nino (2013): *Quantum physics without quantum philosophy*. Berlin: Springer.

Esfeld, Michael (2001): *Holism in philosophy of mind and philosophy of physics*. Dordrecht: Kluwer.

Esfeld, Michael (2014): “The primitive ontology of quantum physics: guidelines for an assessment of the proposals”. *Studies in History and Philosophy of Modern Physics* 47, pp. 99-106.

Esfeld, Michael (2017): “A proposal for a minimalist ontology”. Forthcoming in *Synthese,* DOI: 10.1007/s11229-017-1426-8.

Esfeld, Michael and Deckert, Dirk-André (2017): *A minimalist ontology of the natural world*. New York: Routledge.

Everett, Hugh (1957): “‘Relative state’ formulation of quantum mechanics”. *Reviews of Modern Physics* 29, pp. 454-462.

Feynman, Richard P., Leighton, Robert B. and Sands, Matthew (1963): *The Feynman lectures on physics. Volume 1*. Reading (Massachusetts): Addison-Wesley.

Ghirardi, Gian Carlo, Rimini, Alberto and Weber, Tullio (1986): “Unified dynamics for microscopic and macroscopic systems”. *Physical Review D* 34, pp. 470-491.

Graham, Daniel W. (2010): *The texts of early Greek philosophy. The complete fragments and selected testimonies of the major Presocratics. Edited and translated by Daniel W. Graham.* Cambridge: Cambridge University Press.

Hall, Ned (2009): “Humean reductionism about laws of nature”. Unpublished manuscript, http://philpapers.org/rec/HALHRA

Jackson, Frank (1994): “Armchair metaphysics”. In: M. Michael and J. O’Leary Hawthorne (eds.): *Philosophy in mind. The place of philosophy in the study of mind.* Dordrecht: Kluwer. Pp. 23-42.

Lazarovici, Dustin and Reichert, Paula (2015): “Typicality, irreversibility and the status of macroscopic laws”. *Erkenntnis* 80, pp. 689-716.

Levine, Joseph (1983): “Materialism and qualia: the explanatory gap”. *Pacific Philosophical Quarterly* 64, pp. 354-361.

Lewis, David (1972): “Psychophysical and theoretical identifications”. *Australasian Journal of Philosophy* 50, pp. 249-258.

Lewis, David (1986): *Philosophical papers. Volume 2.* Oxford: Oxford University Press.

Loewer, Barry (1996): “Freedom from physics: quantum mechanics and free will”. *Philosophical Topics* 24, pp. 91-112.

Loewer, Barry (2012): “Two accounts of laws and time”. *Philosophical Studies* 160, pp. 115-137.

Mach, Ernst (1919): *The science of mechanics: a critical and historical account of its development. Fourth edition. Translation by Thomas J. McCormack.* Chicago: Open Court.

Newton, Isaac (1952): *Opticks or a treatise of the reflections, refractions, inflections and colours of light. Edited by I. B. Cohen.* New York: Dover.

Penrose, Roger (2004): *The road to reality: a complete guide to the laws of the universe.* London: Jonathan Cape.

Sellars, Wilfrid (1956): “Empiricism and the philosophy of mind”. In: H. Feigl and M. Scriven (eds.): *The foundations of science and the concepts of psychology and psychoanalysis.* Minneapolis: University of Minnesota Press. Pp. 253-329.

von Wachter, Daniel (2015): “Miracles are not violations of the laws of nature because the laws do not entail regularities”. *European Journal for Philosophy of Religion* 7, pp. 37-60.

Wallace, David (2012): *The emergent multiverse. Quantum theory according to the Everett interpretation.* Oxford: Oxford University Press.